WATER QUALITY ASSESSMENT OF THE BAGMATI RIVER AND ITS TRIBUTARIES, KATHMANDU VALLEY, NEPAL

DISSERTATION

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Submitted by

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Abstract

- The present study "Water quality assessment of the Bagmati river and its tributaries, Kathmandu valley, Nepal" consists of three monitoring aspects such as bacterial, benthic macroinvertebrate and chemical parameters. The result for each monitoring aspect is referred to the saprobic water quality classes. The study comprises a total of 79 and 74 sample sites from post-monsoon and pre-monsoon season respectively from head water to the lower reach of the river.

- The saprobic (biological) water quality class in the Bagmati river changes from saprobic water quality class (SWQC) I (non polluted) to IV (extremely polluted) within about 30 km length from its origin to the valley region.

- The change of SWQC is strongly influenced by anthropogenic activities, season and receiving tributaries in the study area. Upper headwater region where all the SWQC I lie, has less bacterial number, high diversity of biota and low organic nutrient content and once the river passes down from the head water region to the valley basin region water quality has been found deteriorated gradually. Once it reaches to the mid valley region water quality changes to III-IV to IV with high bacterial count, low diversity of taxa and high organic nutrient content and it again recovers in lower reach.

- The comparison of colony forming unit (cfu/ml) of heterotrophic bacteria at 22°C with reference to the existing European scheme of bacteriological water quality class, 75 % sample sites of each saprobic water quality class of the study region lie within the range and remaining 25 % lies above the range.

- The study has enlarged the existed Nepal biotic score (NEPBIOS) for estimating the biological water quality class. The enlarged NEPBIOS would give better precision in biological water quality assessment in Nepal.

- With reference to bacterial and chemical parameters the saprobic water quality class I, I-II and II can be used as raw water for potable abstraction with simple, moderate and intensive treatments respectively. Saprobic water quality class II-III to IV are not recommended to use any kind of domestic purposes.

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NEPĀL
PHYSIOGRAPHIC
Scale 1 : 2,000,000
C H I N A
I N D I A
Physiographic Division
High Himalaya
High Mountain
Middle Mountain
Siwalik
Terai
BOUNDARIES
International, Regional, Zonal, District
HEADQUARTERS
Capital, Regional, Zonal, District
ROADS
PRONUNCIATION GUIDE
MUSTĀNG
DOLPĀ
HUMLĀ
KATHMANDU
Third Edition

1 INTRODUCTION

This introductory chapter begins with the issues in river water quality assessment, followed by rationale of the study, objectives, hypotheses and limitations.

1.1 Background

Freshwater is an invaluable as well as a finite natural resource to man's varied activities. Streams and rivers like other water bodies are specialised habitats of plants and animals; their ecosystems are particularly sensitive to change induced basically by man's activities in the water balance, in water chemistry and in habitats. The quality of freshwater is an ever increasing important issue. Over time, water requirements have emerged for drinking and personal hygiene, religious activities, fisheries, agriculture (irrigation and livestock supply), industrial production, hydropower generation, and recreational activities such as bathing and fishing. In parallel with these uses water has been considered, since ancient times, the most suitable medium to clean, disperse, transport and dispose of wastes (domestic and industrial wastes, irrigation returns etc.).

Water quality is used to refer to the suitability of water to sustain living organisms and other uses such as drinking, bathing, washing, irrigation, industry and so on. They require certain level of physical, chemical, or biological characteristics of water and hence water quality can be defined by a range of variables which limit water use. It is recognised that natural ecosystems have a legitimate place in the consideration of options for water quality management. They are sensitive indicators of changes or deterioration in overall quality, providing a useful addition to physical, chemical and other information.

The composition of surface water is dependent on natural factors (geological, topographical, meteorological, hydrological and biological) in the drainage basin and varies with seasonal differences in run-off volumes, weather conditions and water level. Human intervention also has significant effect on water quality. Some of these effects are the result of hydrological changes, such as the building of dams, drainage of wetlands and diversion of flow. More obvious are the polluting activities, such as discharge of domestic, industrial, urban, and other wastewater into the water-course, the spreading of chemicals on agricultural land, and uncontrolled land use for urbanisation or deforestation in the drainage basin. Water pollution and wasteful use of freshwater threaten all types of development activities and on top of them, the lives of living communities associated with water. Therefore, understanding the role of rivers and streams as sites for floral and faunal diversity is essential in conservation decisions. It is essential to characterise the riverine ecology in terms of biological community and abiotic features, and assess their environmental significance for the people.

The extent of the human activities that influence the environment has increased dramatically during the past few decades, affecting freshwater significantly. The scale of socio-economic activities, urbanisation, industrial operations and agricultural production has a widespread impact on water resources. As a result, very complex inter-relationships between socio-economic factors and natural hydrological and ecological conditions have developed. Gross organic pollution leads to disturbance of the oxygen balance which is often accompanied by severe pathogenic contamination resulted from enrichment with nutrients of various origins, particularly domestic sewage, agricultural run-off and agro-industrial effluents. With application of increasing amount of agrochemical, agriculture land use is causing widespread deterioration of the surface water ecosystem. The main problems associated with agriculture are salinization, nitrate and pesticide contamination, and erosion leading to high concentrations of suspended solids in rivers and streams and the siltation of impoundment. Enteric pathogenic bacteria is transmitted by water or waste water to human beings and living organisms, which causes water borne diseases.

Undoubtedly, water of good quality is crucial to sustainable socio-economic development. Assessment of river water quality has always been a matter of discussion at the scientific as well as at the conservation policy level. However precise information on this subject particularly in developing countries is scarce. Information on bacteriological, biological and chemical of river water is essential to determine its quality condition. These three components are complementary. However, in general biological assessments are suggested to be used often as an early warnings system and should be the precursor of extensive bacteriological and chemical analyses, identifying the causes of the biological stress (DePauw and Roels 1988). Hence, a need for comprehensive assessments of trends in water quality. This would be an essential step not only to address the consequences of present and future threats of contamination but to raise awareness of the urgent need and provide a basis for action at all level as well.

1.2 Rationale of the Study

Water is the largest natural resource of Nepal. The major sources of water are glaciers, snow-melt from the Himalayas, rainfall and ground water. Of these, river water is the most significant in terms of potential development. The rivers alone cover about 54 percent of the total water coverage area in the country (McEachern 1994). There are over 6,000 rivers in Nepal with an estimated total length of some 45,000 kilometres (CBS 1995). These rivers flow through the extensive mountain region and then through the narrow plain terrain and thus have turbulent and rapid flow which have considerable self cleansing abilities through mechanical and oxidation processes.

In Nepal, most of the large rivers are considered for hydroelectric generation and irrigation, while small rivers or streams for drinking water and small irrigation schemes. The importance of rivers implies not only the development of hydroelectricity, irrigation, drinking water, but also the social-cultural values specially related to the religious activities of the people. The latter aspect is particularly important with regard to the quality of river water as people are closely linked with it. The following three issues are pertinent to be addressed in the context of the river water quality in Nepal:

- What is the 'state of quality' of river water?
- What are the uses of river water? and
- What are the government efforts towards conservation of river water?

One of the fundamental issues in nature conservation in Nepal is the quality of river water upon which an overwhelming proportion of the population is dependent for drinking, bathing and washing, besides river water as being major source of irrigation, fishery and hydro-development. Recently, the river course particularly in major urban areas has become the site for urban drainage and waste dumping. Water quality assessment programs in Nepal have concerned generally with public health issues and therefore, safe drinking water has been the primary emphasis of these programs while the conservation of river water quality has received little attention in terms of its development. Two environmental projects, such as the Bagmati watershed project and the Bishnumati watershed project concern with the environmental conservation including river source and their aquatic organism, however.

Nepal is one of the least industrialised countries in the world. However, the national conservation strategy in Nepal has under pollution control programme begun to identify industrial pollution for immediate attention (IUCN 1991). As industrial effluents are discharged untreated into the rivers, this step is assumed to be essential. Though Nepal's mere 10 percent of the total population live in urban areas (CBS 1995), large cities like Kathmandu, Lalitpur, among others are expanding rapidly since last few decades due to rapid population growth and influx of migrants (Stanley 1993). Evidence is that some of the urban rivers in Nepal are becoming increasingly contaminated by domestic sewerage and chemicals from industrial effluents. To the extent that these rivers are being used as drinking and washing water resources, chemical contamination of public water supplies could become a problem in the not too distant future.

Reliable pollution studies are very recent to Nepal and limited in the areas they cover. However, since the last few decades, the number of studies has been increasing due to growing public concern about pollution and its impact on human health and the environment. Studies show that pollution is increasing both in terms of area contaminated and in the levels of pollution, posing a serious threat to human health and the environment.

Sanitary state of river water is undoubtedly important matter. But the quality of urban river water is deteriorating which is not only because of poor management or lack of resources, but because of lack of awareness towards sustaining it. One major factor of the urban river water pollution in particular in Nepal is the rapid population growth in urban areas. This has caused not only in degradation, displacement, or diminishing of aquatic organisms, but in poor health condition of general people and in the overall environment quality as well. Though pollution of drinking water is the most serious public health issue in Nepal, the close connection between water and health is given little emphasis in government policy on water supply (UNICEF 1987). Faecal and organic pollution is considered most serious problem in Nepal.

The study of ABD (1985) showed that more than 50 percent of the hospital patients in Nepal were suffering from gastrointestinal disorders normally caused by water borne pathogens, and about one third of child deaths under four years of age in rural Nepal are due to such waterborne diseases as cholera, typhoid, dysentery, and gastro-enteritis.

Pollution regulation and management is non-existent in Nepal. Two fundamental weaknesses exist in the river water quality assessment. One is the lack of regular monitoring of river water quality, and the other is the inadequacy of physical facilities including laboratory and man-power. Therefore, there is limited baseline information on the condition of river water quality. Sewage treatment and industrial pollution control measures are clearly needed to prevent further degradation and to restore the river to the upstream water quality. Though there have been made some attempts to study the organic and industrial pollution in the river, more quantitative work on the river water pollution are needed before remedial action priorities can be set.

The Bagmati river is an important source of drinking water for the people of the valley and also one of the important holy rivers of Nepal. Because of rapid population growth, there is a growing pressure both on the supply of drinking water (derived mostly from the rivers) and the land for housing. Uncontrolled growth of urban population has encroached even the flood plains and banks of the river. The river is also a major place for urban solid waste disposal as well as for domestic sewerage disposal and industrial effluents. This unpleasant phenomenon of urban growth has caused basically in deteriorating the river water quality leading to water borne diseases using such poor water. However the response to anthropogenic impacts in river water quality is highly variable in the valley. The degree of inter-acting among the people (number), surrounding land use (pattern), and river water (use) varies from place to place in the valley.

Studies indicate that the water quality of the Bagmati river and its major tributaries have a high degree of pollution from untreated sewage and industrial effluents in the valley cities. There have been made some efforts to reverse this trend but are inadequate. Awareness of a problem is the first step in formulating a solution. However, limited management structure, technical capacity, and regulatory and institutional frameworks hinder the study of, and responses to, pollution problems.

Assessment of river water quality is important to determine the condition of water, to provide the basis for detecting trends and to provide the information enabling the establishment of cause-effect relationship. Such study will be of great help to provide information for the government systematic planning at both national and local levels, for the incorporation of practical standards and guidelines based on studies, and for the monitoring of river water which is essential to minimising the degradation of the country's resource base through pollution.

1.3 Objectives of the Study

The general objective of this study is to investigate the state of overall water quality of the Bagmati river system based on saprobic water quality classes.

The specific objectives are as follows:

(i) to assess the bacteriological water quality of the river;

(ii) to evaluate the biological water quality of the river;

(iii) to assess the physico-chemical condition of the rivers;

(iv) to find out bacterial quality and chemical quality based on saprobic water quality classes (SWQC).

(v) to provide pragmatic suggestions for policy prescriptions so as to conserve the river water quality.

In this study saprobic water quality classification is defined as an assessment methodology used to measure the degree of organic pollution in rivers based on the assemblage of organisms present. The basis for saprobic water quality assessment is saprobic water quality classes defined by Moog (1991), ÖNORM 6232 (1995), Nepal biotic score (NEPBIOS) method (Sharma 1996) based on the philosophy of biological monitoring working party. With the increasing pollution level four main and three transitional saprobic water quality classes have been adopted such as SWQC I non to very slightly polluted (oligosaprobic), SWQC I-II slightly polluted (oligosaprobic to beta-mesosaprobic), SWQC II moderately polluted (beta-mesosaprobic), SWQC II-III critically polluted (beta-mesosaprobic to alpha -mesosaprobic), SWQC III heavily polluted (alpha-mesosaprobic), SWQC III-IV very heavily polluted (alpha -mesosaprobic to polysaprobic) and SWQC IV extremely polluted (polysaprobic).

1.4 Hypotheses of the Study

(i) Faecal indicator bacteria determines the hygienic condition of river water;

(ii) The diversity and abundance of macrozoobenthos indicate the biological water quality of the river water;

(iii) Different chemical parameters indicate their roles in determining river water quality.

1.5 Limitations of the Study

This study has following limitations. Nevertheless, the information gathered from the present sample sites is adequate to derive generalisation about the water quality condition of the study area.

(i) Besides bacteriological, macrozoobenthos and few selected chemical parameters such as Chloride, Nitrogen - Ammonium, Total Phosphate and BOD_5 are considered for the study.

(ii) Information on characteristics of the stream water quality has not been gathered during rainy season;

(iii) Some of the sites of some of the tributaries of the Bagmati river system at head water region have not been covered due to practical difficulties.

2 LITERATURE REVIEW

This chapter is divided into two sections. The first section deals with theories and concepts regarding river water quality assessment and the second section describes the research studies so far undertaken on river water quality in Nepal in general and the rivers of Kathmandu Valley in particular.

2.1 Theories and Concepts

2.1.1 Water Quality

Water quality reflects the composition of water as affected by natural causes and man's cultural activities, expressed in terms of measurable quantities and related to intended water use. Water quality is perceived differently by different people, for example, a public health official is concerned with the bacterial and viral safety of water used for drinking and bathing while aquatic scientists are concerned with the health of aquatic habitats, including fish, plankton, and other plants and organisms. The terms pollution, contamination, nuisance, and water degradation are often used synonymously to describe faulty conditions of surface and ground water.

Water pollution is a change in the bacteriological, biological and physico-chemical quality of the surface or ground water resource caused by man's activities that is injurious to existing, intended, or potential used of the resource. Water quality can be determined and measured by comparing physical, chemical, biological, microbiological, and radiological quantities and parameters to a set of standards and criteria (Bartram and Ballence 1996; Canter 1985). The source of causes of pollution can be of two types: (i) point sources and (ii) non-point source. Point source of pollution can be defined as pollutants that enter the transport routes at discrete and identifiable locations. Major point sources include sewage municipal and industrial wastewater and effluents from solid waste disposal sites. Non-point sources refer to those substances which are introduced into receiving waters as result of urban or rural run-off. These intermittent sources of pollutants are usually associated with land or land use.

Water pollution is not a new phenomenon. Researchers have dealt with the effects of pollution upon aquatic life and human health since over 150 years (Davis and Simon 1995). In the mid-1800s, researchers made a first attempt to use aquatic organism as indicator of environmental pollution (Hassall 1850; Cohn 1853 Cited in Ingram 1966). These researchers found the relationship between human illness and poor sanitary and drinking water conditions. Those early efforts have been the basis for the bacteriological tests still nowadays for protecting human illness due to contaminated drinking and recreational waters. Direct measurements of plants, invertebrates, fish and microbial life are still used as indicators for sanitation, potable water supplies, protection of fisheries, and recreation (McKenzie et al. 1992).

2.1.2 Concepts in River Ecosystems

River ecology concerns with energy transformation, nutrient turnover, and the storage and processing of organic substrates. Elwood *et al.* (cited in Henderson-Sellers and Robinson 1984) argued that lotic or running water ecosystems are longitudinally interdependent and that energy processing depends on the retention and cycling of nutrients by biological communities in upstream areas.

Rivers are closely linked to their watersheds. Almost all the biotic energy that drives stream communities is dependent upon allochthonous or dead organic matter of terrestrial origin such as leaves, twigs, grasses, fruits and fallen insects derived from outside the channel (Horne and Goldman 1994). Where sunlight can penetrate, attached algae, macrophytes, and mosses produce autochthonous organic matter. The structure of river ecosystems requires an understanding of the controls of lotic habitats as well as the cycling of energy in the form of carbon compounds. Many aquatic plants, invertebrates and fish have adapted to fill a specific niche. Within most rivers, the pattern of flow variation is the dominant factor controlling species distribution (Henderson-Sellers and Robinson 1984).

(a) River continuum concept

The *river continuum concept* originated with Vannote et al. (1980) describes the structure and function of communities along a lotic or river system in relationship to the abiotic environment, such as the depth and width of channel, substrate composition, loading, transport, utilisation and storage. The concept provides a generalised conceptual framework for characterisation of pristine running water ecosystems. The approach, based on stream order, type of particulate organic matter, and type of benthic invertebrates present, proposes a grouping of lotic communities into headwater streams, middle-water streams and large rivers. This concept states that the structure and function of the benthic invertebrate community from headwaters to river mouth is strongly regulated by the gradient of allochthonous and autochthonous organic matter. The relative importance of most of the major functional invertebrate groups, shredders, grazers, collectors, and predators, gradually changes down-stream with the food supply. The headwater region (upper reach of the river) is usually heterotrophic due to the inhibition of light by reparian vegetation contributing organic input into stream as terrestrial detritus. Shredders are the dominant organism of this region. In contrast to it, in the mid-water region the importance of riparian vegetation and detritus input decreases. As a consequence, river gets more light which increases the temperature of the water. As increase in light and temperature and decrease in terrestrial input encourage a shift from heterotrophy to autotrophy relying on algal and rooted plant production. The dominant organism in this region are the grazers. The higher reverine conditions develop as the stream order increases and river again gradually back to heterotrophy showing collectors as the dominant animals.

The general predictions of the river continuum concept for biological populations have been confirmed (Hawkins and Sedell 1981). The study of Ryder and Scott's study (1988) as well as Miller's study (1985) found no positive relationship between canopy closure and number of shredders in the upstream region. Culp and Davies (1982) have proposed modifications on the concept in order to give due consideration to variable riparian influences, to tributary inputs from different biomes which large rivers must traverse, and to irregular variations of channel morphology. In the study of Minshall *et al.* (1985) they argue that the river continuum concept is required to be evaluated at world-wide scale. However, whatever the propositions, the fundamental characteristics of the river are dependent upon the downstream transfer of all sorts of matter (sediment, nutrients, and organic debris), i.e. the flow of water along the slope caused by gravity. The continuum is not completely fixed in time or space but shows seasonal variations. The anthropogenic impact is the most important factor to bring about change in the state of river continuum concept. Following two concepts deal with the change conditions of river ecosystems.

(b) Patch dynamics concept

Based on the landscape ecology, the concept of patch dynamics of Pringle *et al.* (1988) and Townsend (1989) presents a framework for the investigation of pattern and process in lotic ecosystems. The concept concerns with the way how specific patch characteristics can determine biotic and abiotic processes over various scales. The authors define patch characteristics in terms of size, size distribution within the landscape, juxtaposition, diversity, duration and mechanisms affecting patch formation.

The authors argue that a patch-dynamics perspective coupled with a strong experimental approach can enhance the utility and predictive power of unifying concepts in lotic ecology, such as the river continuum hypothesis and nutrient spiralling, through its focus on organism and process-specific building blocks of lotic systems.

(c) Mosaic Dynamic concept

A river shows a series of ecological gradient, such as water flow, organic matter, fish populations, and many other factors which change somewhat gradually from headwaters to mouth as a *river continuum* (Peterjohn 1984.and Frissell, et al. 1986.) The gradients also extend across the corridor from upland to river channel. In most areas the matrix, the floodplain, and the river itself are highly patchy, with relatively distinct boundaries (Gregory et al. Cited in Forman1995) Thus, a *river mosaic*, superimposed on the underlying gradients, is normally pronounced (Forman1995).

(d) Serial discontinuity concept

Ward and Stanford (1995) have developed the serial discontinuity concept (SDC) as a theoretical construct. The model views impoundment as major disruption of longitudinal gradient along river course. According to the SDC, dams result in upstream-downstream shift (expressed as discontinuity distance) in biotic and abiotic patterns and processes. The direction and extent of the displacement depend on the variable of interest and are a function of dam position along the river continuum. The perspective presented in the revised version of the SDC attempts to encompass the dynamics of alluvial river flood plain of a hypothetical temperate zone river system into the model using a three reach characterisation, such as constrained headwater reach, braided reach, and meandering reach. The model assumes that the lateral interactions between the channel and the flood plain are critical to a holistic understanding of natural river ecosystems and the alterations induced by regulation. The fringing flood plains with their diverse aquatic and wetland communities are considered an integral part of the river system. The three-reach model is used to predict the spatial patterns of selected variables along the river continuum and the downstream changes engendered by dams positioned in each reach. The main intention of this model building is to serve as a framework for specific systems and regulation scenarios to provide a broad perspective of the ecology of regulated rivers.

(e) Connectivity concept

Standford and Ward (1993) focused on the connectivity between river and ground water ecosystem, and considering them as linked components of a hydrological continuum. The characteristics of the hyporheic zone tend to vary widely in space and time as well as from system to system. The hyporheic interstices are functionally a part of both the fluvial and ground water ecosystem. The permeability of the ecotone depends on the hydraulic conductivity of the sediment layers which, because of their heterogeneity, form many flowpath connections between the stream and the catchment, from the small scale of a single microhabitat to the large scale of an entire alluvial aquifer (Brunke and Gonser 1997). The river-ground water interface can act as a source or sink for dissolved organic matter, depending on the volume and direction of flow, dissolved organic carbon size distribution and by spates involving bedload movement that may import or release matter, depending on the season. The hyporheic corridor concept emphasises connectivity and interactions between others which focus on surficial processes in the lateral and longitudinal dimensions (Standford and Ward 1993). The ecological integrity of groundwater and fluvial systems is often threatened by human activities: by reducing connectivity; by altering exchange processes and by toxic or organic contamination (Brunke and Gonser 1997)..

(f) The Flood Pulse Concept in River-Floodplain System

According to the flood pulse concept (Jung et al. 1989), flood pulse plays significant role for the existence of productivity and interaction of the major biota in the river-flood plain which is also designated as aquatic-terrestrial transitional zone (ATTZ) systems. The geomorphological and hydrological conditions prevailing to the place produce flood pulses, which range from unpredictable to predictable and from short to long duration. The short and unpredictable pulses occur in low order streams and heavily human interfered or modified floodplains. The low order streams have an irregular flood pattern with numerous peaks because they are strongly influenced by local precipitation. Aquatic and terrestrial productivity of river-floodplain system depend mainly on the nutrient status of the water and sediments, on the climate and on the flood pulse. Primary production associated with the ATTZ is much higher than that of permanent water bodies in unmodified systems and can often exceed that of permanent terrestrial habitats. Transport of organic carbon from upstream catchment areas into the floodplain (spiralling) is of little importance to the productivity of the floodplains. The main function of the river channel in relation to plants and animals in the river floodplain system is that of a migration route and dispersal system to access resources and refuges (Bayley.1991). Human intervention greatly decreases the natural spatiotemporal heterogeneity and disrupts major interactive pathways, which results in the reduction of in the structural and functional integrity of riverine -wetland ecosystems (Ward 1989).

The authors conclude with the view that the flood pulse is a batch process and is distinct from concepts that emphasise the continuous processes in flowing water environments such as the river continuum concepts. Floodplains are distinct because they do not depend on upstream processing inefficiencies of organic matter, although their nutrient pool is influenced by periodic lateral exchange of water and sediments with the main channel.

2.1.3 Biological River Water Quality

(i) Biological monitoring

Freshwater biological monitoring based on the responses of living organisms is a measure to determine whether the environment is favourable to living material. This classical or traditional measure has generally concerned with identifying structural changes in the species present and their abundance resulting from the introduction of an alternation of the physical habitat (Norris and Georges 1993). Biomonitoring still is in the early phase. According to Cairns and Pratt (1993), community-based studies of microinvertebrates form the basis of most biological studies of water quality chiefly for three reasons: first, macroinvertebrate communities are easy to collect and identify; second, they are fish food and so are explainable to the general public; and lastly, their analysis allows inferences to be drawn about the food base (algae, leaves), habitat quality, and relative health of the community.

(ii) Saprobien system

The saprobien[1] system is used to deal with the degree of pollution in running water. Lauterborn (1901 cited in Cairns and Pratt 1993) defined the term saprbic and saprobic zone in running waters as the 'zone of processes of decomposition'. In 1902, the German biologists Kolkwitz and Marsson developed a saprobien system based on indicator organisms to classify streams. This idea of saprobity as a measure of the degree of contamination by organic matter and the resulting decrease in dissolved oxygen, provided the concept of biological indicators of environmental condition. They identified three saprobic zones of progressive decomposition of slow-moving waters affected by sewage, such as polysaprobic, mesosaprobic and oligosaprobic. In addition, a fourth zone, i.e. katharobic was also identified with very low nutrient content. Based on the type and abundance of certain taxa associated with the individual zones of contamination, they developed the first extensive lists of indicator organisms. Since its inception, the saprobien system remained modified largely by several scientists in Europe (Kolkwitz, Liebmann, Sjerdingstad, Sladecek, Bick, Foissner cited in Cairns and Pratt 1993).

Despite the saprobien system and the general concept of indicator organisms have been widely used, there is a great deal of criticism. Doudoroff and Warren (1957) criticised the saprobien system and the indicator organisms in three aspects: first, they reflected only pollution from sewage waters; second, the relationships among organisms and pollution tolerances not well studied, and third, the indicator organisms used were generally not reflective of economic value. Tittizer and Kothe (1979) argued that although the saprobic system of Kolkwitz and Marsson showed the way for biological water analysis but did not provide strict and detailed instructions for common practice.

Roback (1974) strongly argued that the concept of indicator organisms has little validity in assessing pollution of water, even though the concept is quick and easy way of making judgements. The characteristic feature of insect species is that they in the average eutrophic body of water can tolerate a broad range of water chemistry and physical conditions to render them useless. In addition to water chemistry, Roback put forward four conditions to determine the presence or absence of a species, such as (1) presence or absence of species pool available for colonising the area under study, (2) season, (3) river flow conditions, and (4) chance. One of the fundamental issues raised by Roback in the indicator species concept is the problem of dealing with absent species. In supporting this view of Roback, the theory of dynamic community structure of Schoener (1983) predicts that species groups change continually and sometimes predictably. Basically, short-lived organisms may have a greater probability to be excluded.

It is well established regularity that certain species can be used to indicate certain types of environmental conditions. As some of the environmental requirements are known for many species, their presence indicates something about the nature of the environment in which they are found. Thus, the concept of the presence of species to indicate certain conditions is a practical approach and easily verifiable. It requires therefore a thorough investigation of most of

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[1] The word saprobic is derived from the Greek word *saprobiotic* meaning decay (Davis and Simon 1995).

the significant species under investigation. However, the absence of a species is considered more risky (Cairns and Pratt 1993).

Saprobity has been based on score system for monitoring ecosystem. Scores are assigned to biotic groups based on generally accepted organism sensitivities to pollution and habitat disturbance. Scores increase according to their presence and abundance. However, this score system does not consider differences in tolerance within taxa which is as broad as families (Guhl 1987). Many biologists believe that most aquatic species have extremely broad tolerances. However, organisms integrate effects of altered environmental quality over a period of time. If degraded conditions are present for a period sufficient to produce population effects then community structure will change. The concept of broad tolerances is probably true in the short term but not in longer term. Schindler (1987), Schaeffer *et al.* (1988), Gray (1989), etc. argue that biological surveillance of communities with special emphasis on characterising taxonomic richness and composition is perhaps the most sensitive tool for quickly and accurately detecting changes in aquatic ecosystems.

Recent methods to solving environmental impact problems developed by Hughes and Larsen (1987), and Omernik (1987) are based on two concepts. One includes communities within delimited regions which are likely to be more similar to each other than to communities from other regions. The other is the homogeneous region within which the natural structure and variability of communities can be determined (Karr *et al.* 1986). Unlike others, these new developments acknowledge that different regions have different biota.

However, the saprobien system can be considered as a tool for measuring water resource quality in terms of presence or absence of a wide range of indicator biota. Several indices have been developed in this system to identify saprobic classes more precisely. Consideration of relative abundance and distribution of communities or specific assemblages (e.g. benthos) is an important contribution in this system. The direct development of numeric biotic (or saprobic) indices is considered perhaps the most remarkable scientific contribution of the saprobien system.

(iii) Numerical index

The first numerical index, concerning the numerical abundance of particular organism to assess the degree of pollution was attempted in the work of Wright and Tidd (1930). Richardson (1928), however, argued that in the numeric index, consideration of the relative abundance and overall occurrences of the organisms found to be much more significant than the mere their numerical abundance. Richardson concluded that seasonal and habitat changes were responsible for much of the variability of species abundance at a given site, supporting the use of relative abundance as the better index measure. Thereafter several attempts have been made to numerically characterise the biological data in a meaningful and understandable manner. Under this index, two types of indices are described below.

(a) Diversity index

Diversity index as a measure of stream community response to pollution has been widely used since the 1960s. Conceptually, the diversity index comprises three components of community structure such as richness, evenness and abundance. The index assumes that an undisturbed environment is characterised by a wide range of species or diversity, even distribution of individuals among the species, and moderate to high counts of individuals (Mason *et al.* 1985). This numerical index takes into account of the relationship between number of species and their abundance, and probably is best used to assess toxic pollution (Hawkes 1977). Several diversity indices such as Simpson index, Margalef index, the Shannon-Wiener index, etc. have been developed. Of these, the Shannon-Wiener index can be considered as one of the most popular diversity indices for water resource quality assessment (Davis 1995). Despite the popularity of this index, it has been severely criticised in the Western countries on the following grounds (Washington 1984; Metcalfe 1989; Fausch *et al.* 1990): (1) its inability to reflect ecological significance, (2) total reliance upon structural (abundance) measures that vary greatly depending upon the time of year sampled, the collecting tools used, and the level of taxonomic resolution, and (3) the loss of community composition information by using a single index value. Despite these limitations, the index is currently used to characterise a variety of aquatic assemblages in different aquatic resource types throughout the world.

(b) Saprobic index

The biotic index developed by Pantle and Buck (1955) has been based directly upon the saprobien system. The index has concerned with the artificial four zones of stream pollution and assigned each zone a number from 1 to 4, indicating 1 for oligosaprobic, 2 for beta-mesosaprobic, 3 for alpha-mesosaprobic, and 4 for poly-saprobic. Each organism associated with the various zones based upon Liebamann's (1962) revised list of indicator organisms is assigned the respective indicator values *(s)* multiplied by a relative abundance weight *(h)* of either 1 (species only found by chance), 3 (species occurring frequently), or 5 (species occurring in abundance). These weight values are then averaged to derive the saprobic rating, *S*, as follows:

$$S = \frac{\sum s \times h}{\sum h}$$

According to them, the saprobic ratings of 1 to 1.5 indicate very light impurity, 1.5 to 2.5 moderate impurity, 2.5 to 3.5 heavy impurity, and 3.5 to 4.0 very heavy impurity.

The saprobic index has been modified in many ways since it was first proposed by Pantle and Buck. For general use of indicator organism, Zelinka and Marvan (1961) have added a saprobic valency and indicator weight to the original index of Pantle and Buck. The saprobic valency has expressed the relative frequency of the species in different degrees of saprobity on a scale that totalled 10. They have assigned an indicative weight arbitrarily from 1 (poor indicator) to 5 (very good indicator). The authors assumed that the best indicators were those species that had been assigned with a saprobic valency of 8, 9, or 10 within any given zone. According to them, the best indicators were representative of a single saprobic zone. The lowest indicator weights were given to species found throughout many or most of the saprobic zone.

To make saprobic water quality assessment more precise, saprobic list of indicator organisms has been revised in detail in Austria in Fauna Aquatica Austria (Moog 1995 ed.). The catalogue also provides additional information regarding functional feeding group and expected longitudinal zonal distribution of the taxa.

According to Moog (1995), in Austria saprobic water quality assessment follows the saprobic system and which has been thoroughly revised and standardised. Hence, the river quality assessment here is made under ÖNORM M 6232 (1995) which gives clear guidelines for the assessment. The author adds that the current method of river water quality assessment integrate river habitat conditions with a number of biota, including bacteria, algae, water plants protozoans and benthic invertebrates. The precision of quality assessment depends on the sample efforts, the number of indicator groups and the taxonomic level of the taxa identified.

There have been developed the selected macroinvertebrate indices. For instance, the Trent biotic index (TBI) for the biological system of stream classification varies 0 to 10, with 10 representing clean water, based on the relative abundance of representative benthos groups. This index has greatly influenced the development of many other indices including the Chandler biotic index (CBI), Belgian biotic index (BBI), Extended biotic index (EBI), and Indice Biologique (Metcalfe 1989). Hilsenhoff (1977) recognised the direct relationship between the early saprobic indices and biotic indices. The Hilsenhoff biotic index (HBI) includes a wide array of aquatic insect taxa for water quality assessment. This index is calculated by multiplying the number of individuals of each species by its assigned tolerance value, summing these products, and dividing by the total number of individuals. Total tolerance values are assigned on a scale of 0 to 10 with 0 being the least tolerant and 10 being the most tolerant. The formula of this index is:

$$\text{Biotic Index} = \frac{\sum ni \times ai}{N}$$

Where ni = number of individuals of each taxon,
ai = tolerance value assigned to that taxon
N = total number of individuals in the sample.

Most biologists argue that pollution assessment is basically a biological problem. Biological zonation is usually obtained on the basis of organic pollution and dissolved oxygen concentration. However, there is not a full agreement among the scientists with the assignment of saprobic valences, i.e. a ranking of the indicator value of a species for levels of pollution and the application of various biotic indices. Nevertheless, the saprobien system is very much popular among the European scientists and the concept of saprobity has had a profound influence on the development of laws and regulations for managing surface waters in European countries. While in North America the system is little use as the scientists there still belief in the importance of chemical measures of water quality (Cairns and Pratt 1993).

During the period 1975 - 1980 a Biological Monitoring Working Party (BMWP) was set up which produced the BMWP biotic index used by the National Water Council (1981). It is in many ways a development of the TBI (Trent biotic index) as it centres on macro-invertebrates and a score on the scale 1-10 is allocated to each type of animal present, according to its tolerance or intolerance of pollution. Scores are added together and the higher the total score the cleaner the river on the scale 1-10
Corning and Küchenhoff (1994) transformed after modification BMWP score and BMWP/ASPT (Average score per taxon) to seven saprobic water quality classesbased on Anglian water authority which is shown in table 2.1.

Table 2.1: Transformation of scores of BMWP and BMWP/ASPT to saprobic water quality classes

Based on Anglian Water Authority, 1986 (after modification)	Based on Corning and Küchenhoff (1994) after modification		Equivalent Saprobic Water quality classes
BMWP	BMWP	ASPT	
>151	>151	8.00-10.00	I
101 - 150	>151	7.00 - 7.9	I-II
51 -100	101 -150	5.50 - 6.90	II
26 - 50	51 - 100	4.00 - 5.49	II-III
7-25	26 - 50	2.50 - 3.90	III
1-6	0 -25	1.01 - 2.49	III-IV
-	-	1	IV

Source: Sharma (1996)

Koller- Kreimel et al.(1997) Compared BMWP/ASPT (family level score) to Saprobic water quality class (Species level score) with altogether 806 sample sites. According to BMWP/ASPT method best water quality classes i.e. class I and I-II were under estimated while poor water quality i.e. water quality class IV and III-IV were over estimated. The correlation coefficient between the two methods were also found out very low. This study shows that family level water quality classification has less precision than species level water quality classification. The study has given one example of genus Rhithrogena with four groups and each group has many species and each species had its own saprobic score.

2.1.4 Concepts in Bacteriological Water Quality

(I) Introduction

Bacteria plays an important role in aquatic ecosystem. They are ideal indicators because of their fast response to changing environmental conditions. Heterotrophic bacterial community plays a decisive role in degrading organic matter in river ecosystem. However, bacteria has a role not only in decomposition of organic matter in aquatic system but in food chain as well (Sherr et al. 1984). The latter concept is of recent origin (Azam et al. 1983).

The refuse and effluents coming from different sources, especially domestic sewage to the river water resources cause the mass development of bacteria. The pathogenic bacteria are also transported into waters through sewage and can cause dangerous epidemics. Pollutants of various kinds that get into water from many sources, get oxidative and degradative processes with the help of heterotrophic micro-organisms and as a result, biological oxygen demand (BOD_5) increases causing deficit in oxygen (O_2). Continuous oxygen deficiency leads to the elimination of bottom fauna and the change in microflora. Ultimately, sulphate is reduced to hydrogen-sulphate (H_2S) by bacteria *Daesulfovibrio* species. In such situation, most living organisms die after a relatively short time due to the toxic effect of H_2S while sheathed bacteria *Sphaerotilus natans* form a thick lawn at the bottom of strongly organic polluted site which is visible to the naked eye.

The bacterial community is mainly determined from allochthonous sources rather than autochthonous sources. However, only a small part of the whole heterotrophic bacterial community can be grown on nutrient agar plates (Kasimir and Kavaka 1988).

(ii) Bacteriological water quality

There are two methods such as bacterial culture and direct count of bacteria which are employed to determine the quality of water.

(a) Culture of bacteria

The bacterial parameters include heterotrophic bacteria counts and faecal indicator bacterial counts which have been used for the assessment of water quality in surface water for many decades. In the faecal indicator bacteria, coliform, *E.coli* and faecal streptococcus are commonly used. To test water quality especially for faecal contamination, different methods such as most probable number, membrane filter technique, present absent test, and quanty tray technique are used. Of these, however, the first two methods have been used more widely for long time. In case of the heterotrophic bacterial count, pour plate technique and spread plate technique are used.

For many years, those methods described above have been remained the same to culture the bacteria. But the media used for culture have been replacing by new ones from time to time. Because the newer ones are more efficient and specific. As they are less time consuming and more convenient and easier, there is a growing demand among the researchers working in this field. The previous methods were time consuming and inconvenient for which several handling steps were required. For example, in the studies of Feresu and Sickle (1989) and Rivilla and Gonzaliz (1989) they took 5-6 days to confirm *E.coli* from total coliform bacteria in the sample water on the traditional media such as MacConkey broth, brilliant green bile broth, violet red bile agar plates, among others.

Scientists have continued their efforts to find even more easier and effective media. As a result, recently, new media or modified media with Fluorogenic and Chromogenic substrate have been discovered (Manafi 1991). The media such as Fluorocult, LMX broth, EMX Manafi and Kneifel, Chromocult agar, Colilert, etc. are quite efficient and rapid. In general, flurogenic and chromogenic substrates have proved to be a powerful tool for utilising specific enzymatic activities of certain micro-organisms. By incorporation of the synthetic Fluorogenic or chromogenic substrates into primary selective media, enumeration and detection can be performed directly on the isolation plate. The introduction of many of these media has led more accuracy and faster to detect target organisms. Their use has often reduced the need for isolation of pure culture and confirmatory test (Manafi 1991).

(b) Direct enumeration of total bacteria

In this method, the number and biomass of bacteria is considered important to understand the ecological role of bacteria in aquatic environment. Epifluorocent direct count is the best method available for the enumeration of total bacteria in environmental sample. It yields more accurate estimate of total (including nonviable and viable but nonculturable) cell number in wide variety of situation. The commonly used fluorochromes in direct count methods are 3,6-bis [dimethylamino] acridinium chloride (Acridine orange, *i.e.* AO), fluorescein isothiocyanate and 4,6-diamidini-2-phe-nylindole (DAPI). Between 1940 and 1980 roughly 90 percent of all bacterial direct counts were performed by using staining with AO (Kepner and Pratt 1994). They reported that AO and fluorescein isothiocyanate were the two fluorochromes in most common use. Within the last decade however, DAPI has largely displaced all other non-Acridine based fluorochromes (including fluorescein isothiocuanate).

(iii) Bacteriological Water Quality Classification

The bacteriological parameter for river water quality assessment has been used in many studies (Hegedus *et al.* 1990; Petto *et al.* 1991; Tripathi 1988; Nieves 1989; Hegedus *et al.* 1990; Klove *et al.* 1993; Petersen *et al.* 1992). In Europe, the bacteriological water quality is found to be divided into seven classes (Bahr 1953; Liebmann 1959; Wachs 1969; Kohl 1973; Jung 1988; and Popp 1991 cited in Popp 1994). Of the seven classes, four classes are considered as the main and the remaining three as intermediate classes between main classes. Class I represents unpolluted or slightly polluted and class IV shows extremely polluted water. The basis of this classification is the quantitative range of heterotrophic plate counts (Table 2.2). Among them, however, Kohl's classification has been widely used for water quality assessment (Ganjin *et al.* 1990; Kavka 1994; Kavka *et al.* 1996). Besides heterotrophic plate count, faecal coliform counts are also used for water quality

Table 2.2: Heterotrophic bacterial number (cfu/ml) and water quality classes by different authors

SWQC	Bahr (1953)	Liebmann (1959)	Wachs (1969)	Kohl (1975)	Jung (1988)	Popp (1991)
I	10^1 - 10^2	<10^2	10^0-10^2	<$5x10^2$	<10^3	<$2x10^2$
I-II			10^2 - 10^3	$5x10^2$ - 10^3		$5x10^1$ - $1x10^3$
II	10^3 - 10^4	<10^5	10^3 - 10^4	10^3 - 10^4	10^3 - $2x10^4$	$2x10^2$ - $5x10^3$
II-III			10^4 - $5x10^4$	10^4 - $5x10^4$		$1x10^3$ - $3x10^4$
III	10^5- 10^6	meist<10^5	$5x10^4$ - 10^5	$5x10^4$ - 10^5	$2x10^4$ - $4x10^5$	$5x10^3$ - $2x10^5$
III-IV			10^5 - 10^6	10^5 - $7.5x10^5$		$3x10^4$ - $2x10^6$
IV	10^6 - 10^8	>10^6	10^6 - 10^8	$7.5x10^5$ - $5x10^8$	$4x10^5$	>$2x10^5$

Source: Popp (1994)

Table 2.3: Classification of river water quality classes with reference to faecal coliform (Escherichis coli) Kohl (1975)

WQC	cfu/100ml
I	>1-10
I-II	>10-10^2
II	>10^2- 10^3
II-III	>10^3 - 5×10^3
III	>5×10^3 - 10^4
III-IV	>10^4 - 10^5
IV	>10^5

Source: Kavka (1994)

Table 2.4: Classification of river water quality classes with reference to *Salmonella* positive sample percentage

Percentage of positive *Salmonella* sp.sample	Quality
0 -10	Fair
>10-25	Moderately polluted
>25 -50	Strongly polluted
>50 - 70	Very strongly polluted
>70 - 100	Excessively polluted

Source: Kavka (1994)

classifications (Kohl 1975). In Table 2.3, the range of faecal coliform counts for the same seven water quality classes is depicted. In addition to these quantitative classification, Kohl (1975) has also used qualitative classification of water quality in terms of percentage of salmonella positive samples to the total samples (Table 2.4). Direct bacterial count and the ratio between direct bacterial count and heterotrophic plate counts have been used to verify those water quality classes (Kohl 1975 cited in Kavka 1994; Ganjin *et al.* 1990).

The above classification system is not widespread in other countries. Outside Europe, researchers rather have focused on the change condition in the water quality monitoring among the sample stations and between seasons based on simple quantitative measures such as ratio, percentage and so on. Monitoring of river in terms of faecal indicator bacteria is used in many studies (Niemi and Niemi 1990; 1991; Lee and Chen 1991; Thayib *et al.* 1989; Rahim and Suthienkul 1989; Fidalgo *et al.* 1990). In the study of Massa *et al.* (1989) they found a close link between faecal coliform and the presence of *Salmonella sps.*

In the study of Heikkinen and Viruri (1990) they have dealt with bacterial density and nutrient condition of the river. Bacterial biomass is used to measure the amount of organic carbon dissolved in water, thus indicating nutrient status of the water. One of the faecal indicator bacteria is faecal streptococcus. Geldreich and Kenner (1969) found that faecal streptococcus densities are significantly higher than faecal coliform densities in all warm-blooded animal faeces except for that of humans. In human faeces, the faecal coliform to faecal streptococcus ratio is 4.4, whereas the ratio for all other warm-blooded animals is less than 0.7. Some conflicting information to this ratio between faecal coliform and faecal streptococcus (FC/FS) has been reported. According to Wheater *et al.* (1979), the FC/FS in faeces of waterfowls is similar to those of human faeces. Mara and Oragui (1981) found FC/FS greater than 4 in faecal samples of cattle, sheep, pigs, ducks and turkeys. This indicates that the applicability of the FC/FS to the determination of sources of pollution in urban runoff is questionable (Poucher et al.).

2.1.5 Concepts in Chemical River Water Quality

Chemical composition of water is of great significance for aquatic life. Each species has a reflective response to particular type and content of chemical parameter. The chemical significance of biological information for the assessment of river water quality is an important issue at both academic and practical levels. Generally, the degree of chemical pollution load is a clear indicator of the biological state of water. However, studies including a great variety of chemical parameters at wider scale are essential to show their effect on the biological condition. Chemical parameters of river water quality are indeed instantaneous in time. Therefore they provide only a momentary picture of the degree of pollution (DePauw and Roels 1988). Chemical monitoring is an essential part for biological assessment of water quality and offers information in identifying the causes of the biological stress.

Chemical parameters are of two types such as organic and inorganic. The organic content of water include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and a total oxygen demand (TOD). Inorganic chemical parameters include salinity, hardness, pH, acidity, alkalinity, iron, manganese, chlorides, sulphate, sulphides, heavy metals, nitrogen (ammonia, nitrite, nitrate) and phosphorus.

Of the chemical parameters, oxygen is very important to significantly determine different types of species in river water. It is known that the different sensitivities of organisms to water pollution are due primarily to the different oxygen demands of the various species. Dependence on oxygen may be so strong that certain species known as clean water organisms can live even in waters with a heavy organic load if sufficient oxygen is introduced into the receiving stream. Besides oxygen, other chemical composition of water such as NH_3, and H_2S content is also equally important. Steinmann and Surbeck (1918 cited in Ellis 1989) in their study found that many of the organisms known to be indicators of heavily polluted water occur in these pollution zones not only because they can live on traces of oxygen, but because in contrast to many other species, they are particularly resistant to putrescence substances. On the other hand, there are clean water indictors which cannot live there not only because they require a high oxygen content, but because they are so sensitive to putrescence substances that they die in a NH_3 rich medium even if the oxygen supply is sufficient.

Studies have been carried out to classify river water quality in terms of various chemical parameters. For example the studies made by Hamm (1969), Perchlaner (1985), Doetsch (1987) and Vollenweider (1980). The BOD content for each of seven water quality classes is differently proposed by various authors. Similarly, the amount of oxygen saturation has also been given for each of seven water quality classes.

Besides, chemical component, physical parameters are also important in the study of river ecosystem. Physical parameters consist of colour, odour, temperature, solids (residues), turbidity, oil, and grease. Subparameters for solids include suspended and dissolved solids as well as organic (volatile) and inorganic (fixed) fractions. Also included in physical characteristics of the river water are channel width and depth, velocity, discharge, substrate composition and so on.

(a). Chemical Index for Water Quality Classification

There exist number of chemical indices for water quality classification. The numbers and types of parameters considered vary from index to index. The weight assign to each parameter in each index also differs accordingly. Some of these indices are described here in brief. Schimitz (1971) has given ranges for the three chemical parameters such as BOD_5, NH_4 and NO_2 on the basis of the total sample sites. For each parameter the value of the percentage range of 50%, 25-75% and 5-95% of samples sites are given as shown in Table 2.5.

Table 2.5 Water quality classification based on Schimitz (1971)

WQC	Statistical range	Chemical parameter		
		BOD_5 (mg O_2 /l)	NH_4-N (mg/l)	NO_2 (mg N /l)
I	M = C_{50}	1.4	0.07	0.003
	C_{25} - C_{75}	1.2-1.7	0.03-0.11	0.001-0.008
	C_5 - C_{95}	0.8-3.0	<0.01-0.37	<0.001-0.031
II	M = C_{50}	2.6	0.16	0.020
	C_{25} - C_{75}	1.9-3	0.10-0.24	0.012-0.050
	C_5 - C_{95}	1.2-5.5	0.03-0.69	0.006-0.14
III	M = C_{50}	3.2	0.31	0.030
	C_{25} - C_{75}	2.3-4	0.25-0.48	0.021-0.065
	C_5 - C_{95}	2-8.5	0.09-2.4	0.016-0.29
IV	M = C_{50}	4.6	0.03	0.072
	C_{25} - C_{75}	4.0-5.3	0.61-1.3	0.055-0.13
	C_5 - C_{95}	2.5-9.5	0.18-5.2	0.028-0.50
V	M = C_{50}	10.0	4.3	0.15
	C_{25} - C_{75}	8.2-14	2.5-5.7	0.095-0.21
	C_5 - C_{95}	5.3-26	1.0-1.7	0.025-0.34

Source: Doetsch (1987)

LAWA (1980) has developed scores in reference to saprobic water quality class and saprobic index for the chemical parameters like BOD5, NH4-N, and oxygen which is shown in Table 2.6.

Table 2.6:Water quality classification based on LAWA (1980)

WQC	Saprbic quality	Saprobic index	Chemical parameter		
			BOD_5 (mg/l)	NH_4-N (mg/l)	O_2 (mg/l)
I	Oligosaprobic	1.0-<1.5	1	<0.1	>8
I-II	Oligosaprobic - β-mesosaprobic	1.5-<1.8	1-2	0.1	>8
II	β-mesosaprobic	1.8-<2.3	2-6	<0.3	>6
II-III	β-mesosaprobic - α-mesosaprobic	2.3-<2.7	5-10	<1	>4
III	α-mesosaprobic	2.7-<3.2	7-13	0.5 to more	>2
III-IV	α-mesosaprobic - polysaprobic	3.2-<3.5	10-20	More	<2
IV	Polysaprobic	3.5-<4.0	>15	More	<2

Source: Doetsch (1987)

Similarly, Brown et al. have developed water quality index considering 9 different parameters. Each parameter has been given weight based on his study as shown in Table 2.7

Table 2.7: Weight given to each parameter (Brown et al. 1970)

Parameter	weight assign to parameter (w)
Oxygen Saturation	0.17
Total number of Coliform	0.15
pH	0.12
BOD_5	0.10
NO_3	0.10
Total phosphate	0.10
Temperature	0.10
Turbidity	0.08
Total suspended matter	0.08

Source: Doetsch (1987)

Water quality Index is calculated from the following equation:

$$WQI = \sum_{i=1}^{9} wiqi$$

here

WQI = Water quality index

wi = Weight of i th parameter

i = Number of Parameter

q = Estimated value for each parameter from 0-100

The index of Prati et al. also consists of nine parameters such as pH, DO, BOD_5, COD, Permagnate test, Suspended solid, NH_3, NO_3, Cl and the equation is as follows:

$$TI = \frac{1}{9}\sum_{i=1}^{9} Xi$$

TI = Total index, Xi = Transformed value of each parameter

The example of one sample site with all the parameters and the equation for transformation used is shown in the Table 2.8.

Table 2.8: The example of one sample site with the transformation equation used for each parameter

Parameter	Value of parameter Yi	Transformation	Xi
pH	7,7	$X = (Y-7)^2$	0.49
DO %	89	$X = 0.08\ (Y-100)$	0.88
BOD5	3,4	$X = Y/1.5$	2.267
COD	30,1	$X = 0.1\ Y$	3.01
Kubel test	3,2	$X = 0.4\ Y$	3.01
SS	176	$X = 2^{2.1 \log (y-10)/10}$	0.298
NH_3	0,49	$2^{2.1 \log (10y)}$	2.73
NO_3	0,59	$2^{2.1 \log (Y/4)}$	0.298
Cl	11,1	$X = 1.57\ Y/50 + 0.57\ (Y/50)^2$	0.373

Source: Doetsch (1987)

TI = 1.9148 is calculated and this is categorised into WQC on the basis of the value given on

Table 2.9: Water quality class and Score

Quality	Score
Excellent	<1
Acceptable	<2
Slightly polluted	<4
Polluted	<8
Heavily polluted	>8

Source: Doetsch (1987)

Bach (1980) developed index which is different from other indices. In this index for each parameter the transformed value raised to power of the weight of the particular parameter assigned as shown in is calculated and thus obtain eight values for eight parameters are multiplied to get chemical index of that site.

$$CI = \prod_{i=1}^{n} qi^{wi}$$

Where CI = Chemical index,
qi = Transformed value of each parameter
wi = relative weight of n *th* parameter
qi^{wi} value for each parameter is given in the appendix Q

Table 2.10: Weight assign to each parameter (Bach 1980)

Parameter	Unit	Weight
Saturation of dissolved oxygen	%	0.20
BOD_5	mg/l	0.02
Water Temperature	°C	0.08
Ammonium NH_4	mg/l	0.15
Nitrate NO_3	mg/l	0.01
Ortho-Phosphate $O\text{-}PO_4^{3}$	mg/l	0.10
pH		0.10
Conductivity	µS/cm	0.07

Source: Herausgegeben von der Bayerischen Landesanstalt für wasserforschung(1986)

After index calculation for each sample the classification of the index has been done on the basis of table 2.11.

Table 2.11: Water quality classification based on chemical index (Bach 1980)

Water Quality Class	Chemical Index
I	>83
I-II	73-82
II	56-72
II-III	44-55
III	27-43
III-IV	17-26
IV	<17

Source: Herausgegeben von der Bayerischen Landesanstalt für wasserforschung(1986)

Besides these indices there are many other indices developed in different studies developed by different authors prevailing to their studies, some of them are Richert (1975), Horton (1965), Dinus (1972), Iawr (1978), Sontheimer et al. (1978), Hormonnay (1979) and Müller (1980).

2.2 River Water Quality Studies in Nepal

2.2.1 Overview of Nepalese River System

Water resource is the largest natural resource of Nepal. The major sources of water are glaciers, snow-melt from the Himalayas, rainfall and ground water. Of these, river water is the most significant in terms of potential development. The rivers alone cover about 54 percent of the total water coverage area in the country (McEachest 1994). There are over 6,000 rivers in Nepal with an estimated total length of some 45,000 kilometres (CBS 1995). These rivers flow through the high mountain and plain terrain and thus have turbulent and rapid flow which have considerable self cleansing abilities through mechanical and oxidation processes.

Rivers and streams are major sources of drinking water in Nepal. In addition, they are important for recreation, irrigation, hydropower generation and fisheries and hence important role in the economic development of the country. Yet they are also the main repository for the nation's untreated sewage, solid waste and industrial effluent, thus becoming river water and course more deteriorated in its quality threatening to ecosystem of the region.

The main basis of classification of river system of Nepal is the origin of rivers. As the origin of rivers is directly associated with the physiography regions of Nepal (Sharma 1977), three major types of river system corresponding to three broad physiographical regions can be made. They are such as (1) the Himalayan river system, (2) the Mahabharat river system, and (3) the Chure river system.

The *Himalayan river system* includes those rivers which have their origin in the Himalayan region in the north of the country with elevation over 2700 meters where the snow peak range with above 5,000 meters run from east to west. There are three principal rivers, namely the Kosi in the east, the Gandaki in the centre, and the Karnali in the west and each has made a longitudinal river basin in its own watershed region. These rivers originate in the trans-Himalayan region (beyond the main Himalayas) in the north and flow down through the mountains of Himalayas, Mahabharats and Chures, and the plain to the south to meet the Ganga river of India, thus making long profiles. These rivers have established antecedent drainage in the mountain regions and made deep gorges and valleys, perhaps some of the deepest gorges in the world. The water volume of these rivers relies on the snowfed water and glaciers and hence are permanent in nature. They are the largest and longest rivers of Nepal. As these rivers flow down to the successive lower elevation regions in the south, many tributaries join them and supply water to add in their volume.

The next lower order river system is the *Mahabharat rivers* which are primarily as tributaries to the main Himalayan rivers. These rivers are originated beyond the Mahabharat hill ranges which with height over 1000 meters run from east to west parallel to the northern Himalayan ranges. They are medium sized rivers in terms of length and volume of water. Since the main sources of water of these rivers are springs and rainfed, the volume of water level fluctuates very much with usually high in the rainy season. During this season, the excessive rainfall causes floods in these rivers. Landslides and soil erosions are often associated with these rivers. These rivers number in thousand in the country.

The *Chure river system* is the lowest order river. It includes the rivers that come out beyond the Chure hills, the first hill range with elevation from 300 to 1000 meters from the south bordering the east-west extended the *Tarai* plain and join as tributaries of the Mahabharat or the Himalayan rivers. Thus they have short length. The main source of water of these rivers is rainfed and therefore there is a great deal of fluctuation in the water level between rainy and dry seasons. Most of them are ephermal and so they get their beds without water in winter-dry season. In short rainy season, these rivers get excessive water volume and as a result floods occur in them and in the meantime, they carry enormous volume of boulders, stones, pebbles and sands with them and deposit extensively over the flat plain area in the south. These rivers also cause frequent landslides and soil erosions on the Chure hill slopes.

2.2.2 Studies on River Water Quality in Nepal

As Nepal lacks many other natural resources, the only available largest water resource is being used for different purposes, ranging from domestic use to national economic development. At present, the river water pollution is the most serious environmental quality issue in Nepal. There are three review studies on water bodies of Nepal which are particularly important as regard to state the water quality condition. Swar (1980) has attempted to provide information of the status of limnological studies in Nepal before 1980. The second study is IUCN (1991) which deals with water pollution studies before 1990. The third is related to the attempt made by Shrestha (1995), describing the status of limnological studies before 1994.

Studies on river water quality assessment in Nepal in terms of biological, bacteriological and chemical aspects are very much limited and information on fresh water ecology is scattered and fragmentary. A study carried out by Sharma (1996) concerns with the biological assessment of the river water quality of Nepal. Based on the gathered macro-zoobenthos from a total of 165 sample sites of the rivers across the country, the level of river water quality has been classified into seven groups using the saprobien system based on Moog (1991). He has developed Nepal Biotic Score (NEPBIOS) system on the basis of his study considering the philisophy of biological working party (BMWP). NEPBIOS is suitable for biological water quality assessment in Nepal. However, this system needs to be followed by similar studies to get regional validity because the distribution pattern of the sample sites with respect to the relative importance of each individual river is not fairly adequate. For example, only nine sample sites have been selected from the longest river Karnali which is one of the few rivers in the world to demonstrate biodiversity (Bauer *et al.* 1994), while a maximum of 49 sample sites selected from the Bagmati river which is not as big and important as is the Karnali river, and 11 sites from the local river Tinau whereas only five sample sites from one of the important rivers Mahakali.

Rundle *et al.* (1993) conducted physico-chemical and macroinvertebrates investigation in fifty-eight streams in three different parts of the Himalayan region such as Annapurna, Langtang and

Everest. In their study, forty-seven macroinvertebrates taxa were identified and their community structure found to be related to physico-chemistry, physiography and land use. In a study of Bauer *et al.* (1994), it is argued that in Nepal, the arrival of hydrodevelopment has become the death knell for aquatic life and species diversity. They found that there has occurred the effects of continuous habitat degradation in the downstream Karnali in the Tarai due to the construction of dam or impoundment in the upstream Karnali. The study of Shrestha, Shrestha and Pradhan (1979) has dealt with aquatic ecology and potential fishery development in the downstream section of the Bagmati river in the Tarai region. McEachern's study (1994) attempted to create baseline data of Nepal's wetland ecology so as to conserve the wetland environment. JOCV (1986) has carried out ecological studies of the rivers Marsyangdi and Budhigandaki for fishery development.

Besides, there are studies on the impact of industries on river ecosystem in some of the major urban areas of the country. Studies carried out by RONAST (1987), ISC (1984), and Pradhan *et al.* (1988) have examined the impact of paper mill effluents on the local biotic systems of Narayani and Orahi rivers as well as water quality of the rivers located in the central Tarai region of Nepal. The study of CEDA (1989) concerned with the industrial effluents of the industrial district in Pokhara and of the jute and the iron industries in Biratnagar. The EISP study (1987) focused on the effluents discharged by leather and tanning in Birganj, Bhairhawa and Kathmandu. These studies have been able to show the general changed condition of the river ecosystem due to the industrial effluents across the country.

Of the above studies, particularly the biological one gives a feeling that any attempt based on new method or index to be used in the national context should be simple, objectivity and transparent so that others can follow it and realise its importance for use in academic as well as practical field.

There are several studies on drinking water quality which, to some extent, indirectly relate to the river water quality as much of the drinking water has been based on river and stream sources. Of these studies, majority have been concentrated in Kathmandu valley (Sharma 1978, 1986; Adhikari *et al.* 1986; CEDA 1989; DISVI 1989, among others) and a very few studies in other parts of the country (CEDA 1989; DISVI 1990a, 1990b). These studies have investigated the chemical and bacteriological test of the drinking water supply system including taps, reservoirs, containers and other sources and found that bacteriologically, the quality of public drinking water was far from satisfactory, in most cases. The drinking water pollution in the valley is caused by the disposal of solid and liquid wastes on land or into surface waters. The most significant wastes are sewerage, industrial effluent and agricultural residues and chemicals. Sewerage originated primarily from domestic premises has been discharged untreated into streams and rivers directly via the public sewerage system and indirectly through runoff and open drains. Likewise, industrial effluents are also being poured untreated into rivers. Pesticides, fertilisers and livestock are the main agricultural sources or non-point sources of ground and surface water pollution.

Nepal's bulk of rural population does not have accessed to piped drinking water supply nor waste disposal facilities. Majority of rural population depend upon natural and unprotected water sources for drinking and other purposes. They continue to use the most convenient sources of water irrespective of quality (ADB 1985). Rural people in the hill areas use water from springs, rivers and ponds and in the Tarai plain from rivers, ponds, wells and shallow tubewells. Collected water is contaminated both outside and within the domestic environment through poor hygiene and sanitation practices. Though pollution of drinking water is the most serious public health issue in Nepal, the close connection between water and health is given little emphasis in government policy on water supply (UNICEF 1987).

Studies carried out on the water quality of different water bodies such as dugwell, tubewells, stone spouts of groundwater source (Sharma 1986; CEDA 1989; ENPHO/DISVI 1990) and spring (Adhikari *et al.* 1986). These studies found that the water was contaminated. Limnological studies on ponds (Hickel 1973a; McEastern 1993; Pradhan 1995) and lakes (Löffler 1969; Ferro 1978, 1978/79; Hickel 1973b; Nakanishi 1986; Jones *et al.* 1989; Rana 1990) are also available.

2.2.3 River Water Quality Assessment Studies in Kathmandu Valley

Available studies show that the quality of the Bagmati river in Kathmandu valley is receiving the most consistent attention. Several studies on water pollution of the Bagmati river have been carried out (Shrestha 1980; Upadhyaay and Roy 1982; Pradhanang *et al.* 1988; DISVI 1988; RONAST 1988; Karmarcharya 1990; Shrestha 1990; Moog and Sharma 1996; Hydrology Division/HMG 1996; and several development project works).

Of these, the most comprehensive and directly related to the present study is the one conducted by DISVI (1988). Based on the analysis of information of water samples and biological samples collected from a total of 10 sample sites along the Bagmati river and its three major tributaries, this study has classified the river water quality into five pollution zones such as the zone of unpolluted, slightly polluted, polluted, extremely polluted, and recovery. The extended biotic index (EBI), which is used to indicate the degree of pollution of surface water based on benthic invertebrates as indicators, has been used in the classification. The EBI value of water quality has been obtained on the known pollution tolerance of specific invertebrate species. Thus, the least polluted river water is classified under class I and the most polluted as class V. Chemical parameters such as COD, BOD_5, NH_3-N, PO_4-P, Cl^- and conductivity have also been examined to determine the river water quality as corresponding to each of the five quality levels obtained by the extended biotic index (EBI). The results of the study indicated that the diversity of macroinvertebrates was higher in the unpolluted zone of the upper reach of the Bagmati river than in the polluted zones in the lower reach or valley floor. In the polluted zone, only few taxa were found present. Bacteriological analysis showed that there was high faecal coliform contamination in the river water at most of the sample sites. Chemical parameters such as levels of detergents found to be increased downstream and then slightly decrease downstream of Chobhar or recovery zone. Seasonally, the river water quality varied remarkably, with higher pollution in the dry-summer, and lower and low in winter and rainy season respectively. The study concluded that the Bagmati river and its tributaries maintain good chemical and biological quality before they enter the core urban area. In the urban core, the untreated sewage and wastewater discharge into the rivers of both domestic and industrial were the main factors to destroy the aquatic ecosystem of the river, and thus the self purification capability of the Bagmati river found to be degenerating. Though the number of sample sites considered in the study seem to be fairly inadequate to generalise the water quality into the five zones, the results obtained from this study are helpful to compare them with the results of this study. Similar attempt has also been made to classify the Bagmati river into seven water quality levels based on saprobic system by Moog and Sharma (1996).

The Hydrology Division of His Majesty's Government of Nepal (1996) has since 1992 initiated an attempt to collect water quality samples of some of the main rivers in Kathmandu valley, as well as in other parts of the country with a view of monitoring river water quality. While regular sampling for the chemical analysis of the river water was initially confined only in the valley, since the last year the work has begun to cover some of the rivers in other parts of the country, and has a plan to cover all over the country. Such a regular collection and analysis of water samples has now been able to show basically the water quality scenario of the Bagmati river in the valley. The chemical data of this report can, however, be used in the present study for comparison.

The study on aquatic life, including phytoplanktons and zooplanktons in the Bagmati river system has been conducted by Stanley (1994). This project work has gathered information on benthic macro-invertebrates of the Bagmati river, showing 21 taxa belonging to 5 invertebrate groups, insect nymphs/larvae (13 taxa), snails (2 taxa) and bivalves (1 taxon). Of which, insect nymphs/larvae were the dominant invertebrate group in the Bagmati and its tributaries. Based on the dominant number of benthic macroinvertebrates, pollution level of the river has been determined. Four main regimes of benthic macro-invertebrate groups along the Bagmati river system have been delineated and shown in the map, such as: the *first zone* contained a diverse range of stoneflies, mayflies and bivalves in the upstream reaches of the Bishnumati and Nakhu khola, in the *second zone*, the dominant presence of blood worms and beetles in the upstream stretch of the Bagmati river and the Manohara river; in the *third zone*, the dominance of blood worms and oligochaetes occupying most parts of the Bagmati river, as well as in the Hanumante river, Dhobi khola and Tukucha khola; and the *fourth zone* represented by one insect larval taxon, the blood worm in the downstream of the Dhobi khola. On the basis of phytoplankton, zooplankton, periphyton and macrophytes, the Bagmati river has also been divided into five zones such as: (1) health or trout zone (upstream to Sundarijal), (2) moderately polluted zone (downstream of Sundarijal), (3) polluted (urban area), (4) recovery zone (near Daksinkali), and (5) clear zone (downstream of Pharping). This project study concluded that there occurred a gross pollution in the downstream section of the Bagmati river system in the urban area. Though this study comprised diverse components such as geophysical environment (topography, water resource, vegetation and land use), aquatic, socio-economic (population and economic activities) and so on to fulfil the project's objectives so as to improve the environmental quality of water resources and restore the river ecology (both natural and cultural) along the water courses of the Bagmati river system, it is useful as it concerned with the biological indicators of pollution of the river and particularly the policy recommendations towards improving it. Other studies on fish and aquatic life and pollution in the Bagmati river are associated with Shrestha *et al.* (1979), Shrestha (1980), Pradhanang *et al.* (1988) and SMEC (1989).

There are three other project studies on river water quality in Kathmandu valley. One is the study of ENPHO (1996) on the water quality assessment of eleven streams in the headwater region of the rivers, Bagmati and Bishnumati in the Shivpuri watershed area. The water of these streams, which is being tapped in the drinking water reservoirs, has been analysed in terms of physico-chemical, microbiological and biological parameters (benthic macroinvertebtate). The result is that, with a high diversity of macroinvertebrates, the upstream region of the streams has shown the best water quality in terms of both biological and chemical parameters. But bacteriologically, the water contained high number of total coliforms and in some cases, faecal coliforms have also been recorded. The other two studies are associated with the Bishnumati river in the same Shivpuri watershed area. One of them is associated with Bajracharya (1994). This study concerned with physico-chemical components of the river and concluded that chemically, the river water quality was not permissible for general use such as domestic, drinking and fish farming. It recommended that the bacteriological analysis of the water be carried out as there had occurred water borne diseases. Based on four sample sites along the Bishnumati river in the Shivpuri hill, the other study carried out by Vaidya (1990) showed the dominance of pollution intolerant fauna of macrozoobenthos in the upper part of the hill slope of the river.

The impact of industrial effluent on the Bagmati river water has also been conducted by Sharma and Rijal (1988), CEDA (1989), Khadka *et al.* (1981), Miyoshi (1987), among others. The information obtained from these studies can be used as reference for the type of chemical and bacteriological content of the effluents of such industries as tannery, carpet, distillery, cement and the industrial district as a whole. Other studies on the Bagmati river water quality belong to Upadhyaya and Roy (1982), Khadka (1983), CEDA (1989), Karmacharya (1990), and Shrestha (1990). These studies are relevant to the present study as much as they throw light on biological, bacteriological, and chemical aspects of the Bagmati river water quality.

There are few literature concerning with the record of benthic animals of Nepalese rivers. Attempts made in the collection and identification of animals particularly in the Bagmati river, Kathmandu valley include basically the work of Vaidya (1990), Stantely (1994), ENPHO (1996), and Sharma (1996). Of these, Vaidya and ENPHO have concentrated mainly on the upstream region of the Bagmati river system, whereas the study report of Stanley has covered several parts including foot-hills of the Shivpuri range and the valley basin of Kathmandu valley. Vaidya has identified animals at order level whereas in ENPHO's study 30 families of the benthic invertebrates have been identified. In case of Stanely's report, altogether 21 families were identified. In his attempt in collecting animals from different rivers of Nepal including the Bagmati in the valley basin and lower head water region of Kathmandu valley, Sharma found altogether 53 families. The present study has made an attempt to gather animals from different river profile regions of the Bagmati such as headwater, valley basin and low (Tarai) region and its all tributaries, and two different seasons. The identification of the collected animals has been made at the possible taxonomic level. In this sense, this study provides an exhaustive information about the benthic invertebrates of the Bagmati river system. The detailed information is listed in appendix R.

In addition to these, attempts have also been in listing the animals from other parts of Nepal and most of them are based on the collection and identification made by several foreign expedition teams basically from the rivers of the Himalayan region. A few of them are illustrated here. The Japanese expedition in Nepal's Himalayan region made in 1952- 53 collected many animals, of which several new genera and species were identified from the families belonged to the ephemeroptera order. Another Himalayan expedition in Nepal was made by the experts from the British Natural History Museum in 1954 and 1961-62. This team also collected different kinds of animals. From this collection Kimmins (1964) made a list of twenty-eight species of Trichoptera, of which, one genus and fourteen species were described as new and from the same collection From the specimens collected by the Canadian expedition team to Nepal in 1967, Happer published a series of papers on Nepalese Himalayan stonefly in 1974, 1975, 1976, and 1977. Zwick and Sivec (1980) have described more than 30 species from different families of Plecoptera such as Taeniopterygidae, Capniidae, Leucridae, Nemouridae, Peltoperlidae, Perlodidae and Perlidae from the collection of the Yugoslav Entomological Expedition to Nepal in 1980. Ueno (1955) identified some of the families of Ephemeroptera from the collection of the Yugoslav-Nepal Expedition in 1983 and the Himalayan expedition of J. Martens in 1983-84. Malisky (1993a) and (1993b), and Graf and Sharma (1996) have contributed to explore many new species and genera from different families of Trichoptera from Nepal. The checklist published of water beetles of Nepal by Jäch and Sharma (1996), and distribution of species composition of Leeches in the aquatic habitat of Nepal by Nesemann and Subodh (1996) are valuable contribution for water quality assessment in Nepal.

Besides, Darsie *et. al* (1994) has studied genus Aedes, Culex and Anophles from Culicidae family collected in some districts of southern Nepal. Alexander (1956) has described crane flies - Trichocerudae and Tipulidae - from the collection of research scheme on Nepal Himalaya. Yet, the existing studies show that there is limited authentic information about the biotic change occurring over time. Only comparison of the findings of different studies having similar theme can be made.

In deed, the above studies on the Bagmati river system are of diverse in nature, scope and coverage, and above all, individual study's objective specific. For example, some studies have dealt with water quality of the Bagmati river in terms of biological, while others concerned with chemical and physical, and some included all three components such as bacteriological, biological and chemical. Further, those studies attempted to cover all the Bagmati river system on the basis of only a few training or sample sites, or part of the system, or a few tributaries, but not covered all or most of the tributaries of the Bagmati river. Some focused on few particular sites along the

Bagmati river or Bishnumati only. There is a great deal of problems in matching the sample locations in those studies, though there are mentioned the locality names characterised by some prominent features.

The present study covers the Bagmati river system, including its long profile region from the source region upstream to downstream in the Tarai; its all tributaries and characteristics and the sampling sites with the description of prominent features. Moreover, this study encompasses all three components of river water quality assessment such as bacteriological, biological, and physico-chemical and seasonal characteristics. Hence, it is justified.

3 RESEARCH METHODOLOGY

3.1 Selection of the Study Area

Assume that rivers and streams that are flowing through a geographical region consisting of a mixture of diverse topographical features, climate, and social and cultural characteristics, do exhibit variant riverine characteristics resulting into different levels of water quality. Keeping in view these elements, the Kathmandu valley of Nepal as study region has been selected for investigation of the dynamics of riverine phenomena. The region has a wider valley basin surrounded by mountain range from where a number of rivers have originated to drain the valley. These different terrain features of the valley basin and mountain range present an ideal laboratory for comparative study of water quality of the rivers that reflected through the contrast geographical and socio-economic conditions.

3.2 Selection of Sample Sites

3.2.1 Factors of Selecting Sample Site Locations

Following three major factors have been considered in the selection of sample sites for water quality assessment.

(i) Topographical factor

The topographical factor includes highland and lowland. The highland is used to refer to the surrounding mountains of the valley while the lowland the valley basin itself. Also considered in the lowland is the flat plain of the *Tarai* region[2] which lies outside of the valley through which the Bagmati river flows. On assumption that these different terrain would influence on the river system and its water quality. The mountain is the only supply source of water of the river. On the mountain terrain, rivers are characterised by narrow bank, rapid flow, dense riparian vegetation and so on and because of sloppy terrain there would be less human interference to rivers. So their water quality would usually remain to be relatively in good condition where there is pronounced effect of natural phenomena. On the other hand, in the low lying areas of the valley basin and the Tarai plain, rivers would flow over wide course with relatively slow speed due to their relative flatness. These areas appear to be the most suitable for human settlement and hence a great deal of human interference to the rivers.

(ii) Drainage system

Next important factor considered here is the river profile region which has been classified as headwater, valley segment, and lower reach. These different river profiles would be a great significance to examine the water quality of the rivers.

(iii) Spatial factor

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[2] The *Tarai* region of Nepal lying on its southern part bordering to India is a flat plain. Its elevation on average is below 300 m amsl. All rivers of Nepal originating from its mountain ranges flow through the *Tarai* plain and mix with the Indian Ganga river.

The spatial factor includes settlement pattern, population distribution and human activities. The amount of intensity of human activities is often related to the magnitude of population density or distribution of settlement pattern which in turn influence the quality of river water. Generally, the greater the density of population or compact and large size settlement, the larger would be the intensity of human activities to influence the river water. However, the influence to the river directly depends on the size and the discharge of the river.

3.2.2 Size of Sample Sites

Considering above three parameters, a total of seventy-nine sample sites along the Bagmati river and its tributaries were chosen for this study. They represent different geographical regions including headwater, valley basin and lower reach of the Bagmati river system. Each of these river profiles is described under separate heading 'river profile region' of this chapter. In addition to this spatial approach, the sample sites were also considered for seasonal data collection. In this temporal approach, the whole year has been broken down into three broad seasons, such as *pre-rainy season* (February-May), and *rainy season* (June-September) and *post-rainy season* (October-January). But however for the field data collection, only the first two seasons were considered. The reason is that during rainy season, it was practically not possible to gather benthic invertebrate samples from most of the rivers due to their strong current and flooding.

3.3 Methods of Data Collection

The methods of data collection in the field included two main steps. The first step referred to the determination of sample sites along the rivers and to get their characteristics, and the second step related to the collection of information from the sample sites. Information for the first component was obtained through using the structured field protocol form which is based on Moog (1991), ÖNORM M 6232 (1995) and Gordon (1992) and those for the second related to all three water quality parameters such as bacterial, macrozoobenthos, and chemical are considered for the study.

3.3.1 Field Protocol Survey

Prior to the field data collection, a reconnaissance survey of the study area was fulfilled and then the location of each of the sample sites was made on the Kathmandu valley map with the scale of 1:50,000 (Schneider 1989) and 49 sample sites were considered from the sites of Moog (1996) for comparison. Each site was given number. As one of the main concerns of the study was to determine the river water quality based on the environmental components of the sample sites and the river morphology assuming that these factors influence the quality of river water, a record of these factors for each of the sites *in situ* was made on the structured field protocol survey form (Appendix A). This survey form consisted of seven major sections such as general information, substrate composition, physical components, land use and type of influence, river's physical parameters, aquatic vegetation, and remarks. Following procedural steps were performed to fill in the Protocol form.

- Section 1: This section acquired information on such general attributes as site number, river's name, locality's name, date and time, altitude, weather condition, air temperature, river types, water level of the river, uses of water and effluents. Once the location of sample site was completed on the map, its number and the locality name were noted down. Other information such as altitude (from the reference map), air temperature (from thermometer), weather condition, type of river, water level and uses were recorded. Local people were also asked about the uses of river water in some cases.

- Section 2: In this section, the substrate composition of river water included boulder, cobble, pebble, gravel, sand and silt. They have been defined in terms of approximate size based on ÖNORM M 6232 (1995) and their coverage in the substrata at the sample site along the river (at least 20 meters length) was estimated in terms of percentage. The size of boulder has been defined with over 40 cm, and of cobble with 20 to 40 cm. Pebble has been broken down into two groups, large size with 20-6.3 cm and small size with 6.3-2 cm. Gravel has been defined as the size ranging from 2 to 0.2 cm, sand with 0.2-0.063 cm. and silt with below 0.063 cm.

- Section 3: This component of the protocol included the following physical attributes of the river: width of river channel (maximum and minimum), depth (maximum and minimum), bank types (natural or man-made), type of vegetation on both sides of the bank, bank structure (both sides: hard or erodable), channel types: V-shaped, Rectangular, Trapezoidal, terraced (Gordan 1992), flow types, velocity and plant shading coverage. The width and depth of the streams at the sample points measured through using a long plastic rope having scale marked on it. The rivers' velocity at each sample site was measured through using a rule of thumb method. Under this method, two points at distant of 5 meters along the rivers were fixed and a leaf was dropped at the first point and time was recorded synchronising with the dropping of the leaf and its crossing at the end point. This was done three times and the mean velocity was calculated as meter per second (m/s). Flow types have been described as turbulent or rapid (≥1 m/s), medium (>0.2 m/s), and low (<0.2 m/s) on the basis of velocity (Gordon 1992). Others remaining components have been observed and recorded.

- Section 4: Components related to landscape ecology included land use and types of influence along the river course in this fourth section. The major land uses of the surrounding of the river sample site were noted down. The types of influence were identified as natural such as flood, siltation, erosion etc. and human impacts such as embankment, speed breaker, sand quarrying, pebble collection and so on. These information were observed and noted down.

- Section 5: The river's physical parameters included in this section were odour, colour, temperature, transparency, conductivity, pH value and total hardness were noted down. The reductive feature and physical appearance of water were noted according to table 3.1 and 3.2 respectively. Odour was obtained through smelling of the sample river water and surroundings and colour was determined through looking into water surface. In order to obtain the level of transparency, a wooden rod with measuring scale was dipped slowly into the water surface in the middle, deeper part of the river and the transparency level was determined at the point of the stick from where the base disappeared. Secchi disk is recommended to measure transparency. Transparency was defined as high, medium and low in terms of magnitude of light penetration into the water surface. High transparency meant to almost or fully penetration of light into the water surface or the base of the stream is clearly seen, medium indicated to more than 20 cm and low meant to below 20 cm. Temperature and conductivity *in situ* were obtained through using conductivity meter by dipping its electrode about 20 cm below the water surface in an undisturbed condition in the middle part of the river. pH and total hardness were measured in the laboratory. Reductive feature was recorded by observing stream bed stones and fine sediments. Black patches around and underside of stones identified as reductive feature while in case of fine sediments, its level of depth was obtained with the help of plastic core. The plastic core was dipped into the fine sediments and its upper mouth was closed with plastic cap and took it out from the water surface. The level of reductive feature was seen, if any. and classified according to the Table 3.1.

Table 3.1: Reduction feature and water quality class

Water quality class →	I	I-II	II	II-III	III	III-IV	IV
Reduction							
Lenic (<0.25 m/s)							
Anoxic condition with a patch of oxidation layer				....			
Anoxic condition without a patch of oxidation layer						....	
% of reduction (lower part black of stone)			<25	<75	≈ 100	100	100
Lower and upper side of stone black					+	+	+
Lotic(0.25-0.75m/s)							
Anoxic condition with a patch of oxidation layer						....	
Anoxic condition without a patch of oxidation layer							
% of reduction (lower part black)				<50	50-100	100	100
% of reduction (lower and upper side black)					+		+
Lotic (>0.75m/s)					....		....
% of reduction (lower part black)				<25	25-50	50-100	≈ 100
% of reduction (lower and upper side black)							+

Source: ÖNORM M 6232 (1995)

Table 3.2: Physical appearance of water and water quality class

Water quality class →	I	I-II	II	II-III	III	III-IV	IV
Turbidity				+/-	+/-	+	+
Colour			+/-	+/-	+/-	+	+
Foam			(+)	(+)	(+)	(+)	(+)
Organic matter floating		(+)	(+)	+	+	+	+
Smell (water and its surrounding)			(+)	+	+	+	+
Noticeable impurity		(+)	(+)	(+)	(+)	(+)	(+)

Source: ÖNORM M 6232 (1995)

- **Section 6** related to aquatic vegetation, including the relative magnitude of coverage of different types of vegetation (macrophyte, moss, filamentous algae, algae and fungus) and detritus (wood, leaf, coarse particulate organic material or CPOM, and fine particulate organic material or FPOM). Information on them was obtained in terms of percentage cover approximately.

- In **Section 7** information was sought on animal species, saprobic water quality classes, and other descriptions, if any. One of the main objectives of this study was to determine saprobic river water quality classes in terms of gathered animal species from each of the sample sites. Upon completion of recording information as described above, a wide variety of animal species from all possible places in the river was attempted to gather. A detailed explanation about this is made in separate section under 'method of collection of benthic invertebrate'. After the sampling of macro-zoobenthos, their types and abundance related to each of the sample sites were noted down as described below. In addition to these, sketch map of each sample site was drawn, and photographs and slides were taken to show the locational features of the sample sites.

3.3.2 Abundance of animals

Abundance of animals is one of the indicators of river water quality in the field. Generally, if particular type of taxa is found in the sample site having particular environmental condition, it is said to be a good indicator. Conversely, if a taxa is available in sample sites having different environmental conditions, it is said to be poor indicator. In other words, some species are very sensitive to particular environmental condition while others not.

Table 3.3 Description of abundance of animals

Rank value	% composition in the sample	Description
1	1	Very rare
2	1-2	Rare
3	2-5	Common
4	5-15	Abundance
5	more than 15	Highly abundance

Source: Sharma (1996)

The abundance of fauna at a certain site with the section of river was estimated in the 1 to 5 scale as proposed by SCHWERDTFEGER (1975 cited in Sharma 1996). Table 3.3 reflects the rank value as well as their description. Rank 1 is given to very rarely occurred fauna and 5 for highly abundance. The ranks in between 1 and 5 are determined on the basis of their percentage composition in the site.

On the basis of field observation taking into account of above said parameters of the field protocol, the sample sites were classified into seven saprobic water quality classes on the basis of Moog (1991) as shown in Appendix A3. These field quality classes in this study has been considered as Saprobic water quality classes (SWQC) which is further verified with the collected benthic animals. This SWQC is the basis for further samplings and laboratory analysis.

3.3.3 Biological and Chemical Samplings

The second important part of the field survey was to carry out samplings for the bacteriological, macrozoobenthose and chemical analysis. Each of these components was fulfilled through using the following procedural steps:

(i) Bacteriological data

- Prier to water sample collection, the best sampling point for each sample site was chosen on the basis of river channel morphology i.e. narrow width where best mixing is observed. The place of sample along the cross-section of the sample point was determined after analysing cross-section samples of the river. On the basis of cross-section sample, three replicates samples were necessary to take for each site for analysis. They are one from the middle and one each from the two banks about 1 meter away from the bank i.e. from the flowing water from both bank.

- Sterile glass bottles with the capacity of 500 ml were used for water sample collection. The bottle was fitted with screw cap. The cap and neck of the bottle was protected from contamination by thin aluminium foil. Silicon rubber liner that could withstand repeated sterilisation at 160°C was used inside screw cap. During sample collection, the cover and the cap of the sterile sample bottle were removed aseptically and faced the mouth of the bottle upstream. The neck of the bottle was plunged downwards ≈20 cm below the water surface, and then tilted the neck slightly upwards to let it fill completely. Where there were no current, the bottle was pushed forward horizontally until it was filled. Each of the water sample bottles was labelled with the date, time and site number of sampling.

- The sample bottles were protected by foam and kept in cooling box containing ice packs and transported it to the laboratory within 8 hours of collection and processed immediately afterwards.

- At the laboratory, the water samples were divided into two parts. In the first part, water sample was preserved in 10 ml vile and fixed in 5% formaldehyde for bacteriological direct count. The other water sample was used for bacterial culture.

- Care was taken to prevent accidental contamination of the water during its collection and transportation to the water testing laboratory.

The main intention of water samples collection was to classify the Bagmati river system in quality classes and compare them between seasons and by river profile locations. Therefore, the water samples were collected from all seventy-nine sample sites during post-monsoon season and these also included four spring sources or *Kunds*. While in pre-monsoon only 74 sample sites were covered in which two sample sites along the Bagmati river in the Tarai region were excluded. However, the Tarai sample sites were covered just to see the trend of change in water quality. Out of the total sample sites, 35 sample sites representing 5 from each of the seven field water quality classes have been used to get bacterial biomass.

In addition to these, other types of sample collection such as cross-section, dial and daily were also carried out to examine the river pulse. The daily sample collection was fulfilled for 7 consecutive days. All these were considered for only one site except diel which was performed at two sites.

(ii) Benthic invertebrate data

The sampling of the benthic invertebrate data was obtained from each sample site *in situ* extending about 50 meters along the river. Following steps were used while collecting animals:

- All existing micro-habitats were considered and qualitative sampling was performed;

- A handy standard net sampler made up of synthetic textile with a mesh size of 100 μm connected to a round frame of 19 cm diameter was used to collect animals. In addition to this, metallic sieves of different pore size ranging from 1 mm to 2 mm were also used for collecting the fauna inhabiting in sandy or muddy substratum. The sampling was performed carefully so that no macroinvertebrate from the probable habitats such as cobble, rock outcrops, large woody debris, or other hard surfaces was left escaped;

- The collected animals were poured onto white trays with some water and identified each of them at possible levels on the basis of their external feature. In the meantime, abundance of each type of the animals was noted down at 1-5 range. Using a forceps, removed all animals from the trays and preserved them in a glass vial with 70% ethanol and then a piece of cotton plug was placed tightly onto it and capped. This was done to protect the shape of the animals. Each container was labelled with the date and site number of sampling. The label written on a piece of paper with pencil placed into each container.

- In the laboratory, the preserved animals were sorted first at family level by using a binocular dissecting microscope and placed each family into a separate container with labelling.

- A list on hierarchical order of animals such as order, family, genus and species belonged to each site was prepared. An indet was used to indicate the animals of which a further level could not be identified.

C. Chemical data

All 79 sample sites were also considered for chemical data and the water samples from both seasons, i.e. pre-monsoon and post-monsoon were collected. Following procedural steps were taken for chemical data collection.

- The same bacteriological sample sites having characterised by comparatively narrow width and good mixing of running water were determined for the chemical data, too;

- Before collecting water samples, the polythene sample bottles were rinsed twice with the river water;

- Standing in the stream against its water current three replicate water samples, from the same place where the bacteriological samples were taken, were filled in the bottle below 10 cm from the water surface and labelled it with the date and number of sampling. The sampled bottles were protected by foam and kept in a cool box with ice packs;

- The analysis of the parameters such as pH, chloride, Ammonia-Nitrogen, total phosphate, Nitrate -Nitrogen and total hardness were made in the laboratory;

- Temperature and conductivity of the sites were measured by using conductivity meter;

- Water samples in two BOD bottles of 300 ml for each replicate samples were collected. One of them was fixed with 1 ml manganese sulphate ($MnSO_4$) solution and 2 ml alkali-iodite-azide reagent for dissolved oxygen (DO). The other water sample bottle without addition of any chemicals for biochemical oxygen demand (BOD_5) was placed in the cool box with ice packs.

All these samplers were labelled with the date and number of sampling and brought them to the laboratory; and

- The sample water for BOD_5 was incubated in 20°C for 5 days and after that this sample was fixed with the same chemicals used for DO analysis;.

3.4 Methods of Data Analysis

Three monitoring aspects such as bacterial, benthic macroinvertebrate and chemical have been considered for the study. The main basis of water quality assessment is saprobic water quality classes. With the increasing pollution level four main and three transitional water quality classes have been defined such as SWQC I non to very slightly polluted (oligosaprobic), SWQC I-II slightly polluted (oligosaprobic to beta-mesosaprobic), SWQC II moderately polluted (beta-mesosaprobic), SWQC II-III critically polluted (beta-mesosaprobic to alpha -mesosaprobic), SWQC III heavily polluted (alpha-mesosaprobic), SWQC III-IV very heavily polluted (alpha -mesosaprobic to polysaprobic) and SWQC IV extremely polluted (polysaprobic).

3.*4.1* Bacteriological data analysis

(i) Methods of enumeration of bacteria

Two different methods such as culture and direct count have been used to enumerate bacteria from the sample water.

(a) By culture method

Prior to the culture of water sample, a pre-test of all available different methods, including pour plate technique, membrane filter technique and Quanty-tray technique was performed in the laboratory in order to choose one of them for the study. While doing so, pour plate technique for heterotrophic bacteria and membrane filter technique for faecal indicator bacteria were found more appropriate. Similarly, for the isolation of coliform bacteria specially E.coli bacteria from water, different media such as Tryptone soya agar, ENDO, EMX, Chromocult, and Fluorocult were used and of which, only one medium which would be adequately appropriate, cheaper and reliable for the analysis of above mentioned components, was to select. As a consequence, the Chromocult media was found the best, for it need not to have many biochemical tests for the confirmation of bacteria.

Three types of water pollution indicator bacteria, namely heterotrophic bacteria, *Escherichia coli*, and faecal streptococcus were considered to determine the bacteriological water quality. The water samples were used to culture heterotrophic bacteria and faecal indicator bacteria such as *E.coli* and enterococcus. For the first type bacteria, Tryptone soya agar (CM 131 Oxoid) media and pour plate technique was used where as for the second and third type bacteria, membrane filter technique was used. Further, two different media such as Chromocult agar (Merck 1.10426) for *E.coli*, and Slanetz and Bartley (Merck 1.05262) for enterococcus were considered. While culturing these bacteria, appropriate incubation temperature and time were given, such as 22°C for 48 hours for the heterotrophic count, 37°C for 24 hours for *E.coli*, and 44°C for 48 hours for enterococcus.

The analysis of the samples, the estimation of the appropriate dilution was one of the crucial steps in the processing of the water samples. The dilution was selected so that the total number of colonies on the plate would grow between 30 and 300. As shown in Table 3.4, the estimation of dilution was made based on the bacterial count defined by Kohl (1975), as well as on the saprobic water quality classes (SWQC) for Austrian river (Moog 1991). In order to be more secure, three consecutive dilution, each with two replicate plates were prepared. All the instructions and precautions given in the APHA (1995) were considered strictly during the processing of the samples.

Table 3.4: Dilution estimation for bacteriological analysis

SWQC*	Range of HPC cfu/ml**	Range of EC cfu/100 ml**	Dilution estimation		
			HPC count	*E. coli* (EC)	Enterococcus
I	<500	>1-10	1, 1, 10^{-1}	10, 50, 100	10, 50, 100
I-II	500 -1000	>10 - 10^2	1, 10^{-1}, 10^{-2}	1, 10, 50	1, 10, 50
II	1000 -10000	>10^2-10^3	10^{-1}, 10^{-2}, 10^{-3}	10^{-1}, 1, 10	10^{-1}, 1, 10
II-III	10000 -50000	>10^3-5×10^3	10^{-2}, 10^{-3}, 10^{-4}	10^{-2}, 10^{-1}, 1	10^{-2}, 10^{-1}, 1
III	50000-10^5	>5×10^3-10^4	10^{-3}, 10^{-4}, 10^{-5}	10^{-3}, 10^{-2}, 10^{-1}	10^{-3}, 10^{-2}, 10^{-1}
III-IV	10^5 -7.5×10^5	>10^4-10^5	10^{-4}, 10^{-5}, 10^{-6}	10^{-4}, 10^{-3}, 10^{-2}	10^{-4}, 10^{-3}, 10^{-2}
IV	>7.5×10^5	>10^5	10^{-5}, 10^{-6}, 10^{-7}	10^{-5}, 10^{-4}, 10^{-3}	10^{-5}, 10^{-4}, 10^{-3}

* Moog (1995), **Kohl (1975), APHA (1995)

(b) By direct count

An appropriate volume of water sample was estimated in order to get about 400 bacteria per filter and fixed it in 100µ DAPY for 10 minutes. The samples were then filtered through cellulose millipore filter with pore size 0.25µ. The cellulose millipore filter paper was fixed on the slide, a drop of paraffin was poured on this filter paper and covered it with cover slip. The slide was examined looking through immunofluorescence microscope, and counted the number of bacteria per 100 grids for a minimum of 15 times. The mean number of bacteria per 100 grids was obtained. This mean value was used to estimate the total number of bacteria per ml by using the following equation:

$$N[Bak/ml] = \frac{Na \times Fg \times Df}{Fa \times V_{fil}}$$

$$N[Bak/ml] = 31014 \times \frac{Na \times 1.05}{V_{fil}}$$

Na = Counted Bacteria

Fg = Area of Filter $(188.69\times10^6 \mu m^2)$

Df = Dilution factor(100 ml sample + 5 ml Formal = $\frac{105}{100} = 1.05$

Fa = Counted Area of the Filter $(6084 \mu m^2)$ *and* V_{fil} *= Filtrated volume(ml).*

(ii) Precision of method

It is calculated on the basis of the method given on APHA (1996). According to the method
Precision criterion = $3.27 \times \overline{R}$
$\overline{R}$ = mean of the range (R) of the logarithm transformed duplicate counts .

For this case duplicate analysis of 15 samples from different water quality class were analysed. Each enumerated values of the duplicate samples is transformed to logarithmic value and the range difference of each sample (R) is computed and mean range value ($\overline{R}$) is calculated and then precision criteria is found out.

Regular check on precision of duplicate count was made transforming logarithmic value and calculating their range. If the range is greater than $3.27 \times \overline{R}$ it shows excessive analyst variability and in this case the result is discarded. If the calculated range is less than $3.27 \times \overline{R}$, shows less variability and the count is accepted.

(iii) Types of Media tried to find the best one for E.coli isolation from surface water in field work (Nepal).

(a) ENDO media

On this medium containing lactose, coliform group comprises all the colonies that produce a dark red colonies with a metallic sheen within 24 hours. Some members of this group may produce dark red or nucleated colonies without a metallic sheen. When verified, these are classified as a 'typical coliform colonies'. The pink, blue, white, or colourless colonies are considered 'non-coliforms'. The purified cultures of coliform bacteria produce negative cytochrome test and positive β-galactosidase test reaction. The genera Enterobacter, Klebsiella, Citrobactor, and Escherichia usually are the examples of this group. Of these, only *Escherichia* coli indicates confirm faecal contamination which is identified by subculturing of coliform colonies.

One type of coliform is thermotolerant or faecal coliform. The term 'faecal coliform' has been used in the water microbiology to denote coliform organisms which grow at 44° or 44.5°C and ferment lactose to produce acid and gas. Sometimes, some organisms with these characteristics may not be of faecal origin. However, the presence of thermotolerant coliforms nearly always indicates faecal contamination. Usually, more than 95 per cent of thermotolerant coliforms isolated from water are the gut organism *Escherichia coli*, the presence of which is definitive proof of faecal contamination (Bartram and Ballance 1996).

(b) Fluorogenic and Chromogenic

Unlike above said traditional media, the fluorogenic and chromogenic media has proved to be a powerful alternative for rapid and sensitive detection of bacteria. The substrate test utilises hydrolyzable substrates for the simultaneous detection of enzymes of total coliform bacteria and Escherichis coli. According to this technique, total coliform is defined as all bacteria possessing the enzyme β-D-galactosidase which cleaves the chromogenic substrate resulting in release of the chromogen.

Under this technique, *E.coli* is defined as bacteria giving a positive total coliform response and 97% of *E.coli* strain produce the enzyme β-glucuronidase which cleaves a flurogenic and chromogenic substrate resulting in the release of the fluorogen and chromogen (Manafe 1991)

One fundamental concern of this study was to determine one of five media such as ENDO, Fluorocult, EMX, and Chromocult for membrane filter technique and one for Quantitray technique as more effective to be used for identification of *E.coli*. In order to do so, a comparative analysis of those four media has been carried out.

(iv) Mode of action of media

The characteristics of each of these media are described below.

(a) ENDO

In ENDO medium, sodium sulphide and fuchsin inhibit the growth of gram-positive bacteria. *E.coli* and coliform bacteria metabolise lactose with the production of aldehyde and acid. The aldehyde liberates fuchsin from the fuchsin-sulphite compound, the fuchsin then colours the colonies red. So, the red colonies with fuchsin are considered as coliform bacteria.

(b) Flurocult EDC Agar

In this medium, the bile salt inhibits the growth of accompanying flora. The fluorogenic substrate (MUG) is cleaved into 4-MU by *E. coli* and which florescence blue under long wave UV light.

(c) EMX Agar (LMX broth modified according to Manafe 1991)

The chromogenic (X-GAL) and fluorogenic(MUG) substrates cleaved by coliform and *E.coli.* respectively are seen simultaneously on the same plate in which the blue colonies indicate both coliform and *E.coli* but the latter gives a blue fluorescence under long UV-wavelength.

(d) Chromocult coliform agar

The content of Tergitol 7 largely inhibits the growth of gram-positive bacteria without a negative effect on the growth of coliform bacteria. The characteristic enzyme for coliform, β-D-galactosidase cleaves the Salmon-GAL substrate and causes a red colouring of the coliform colonies. The β-D-glucuronidase, a characteristic for *E.coli*, has been identified using the substrate X-glucuronide. Its cleavage product colours the positive colonies blue. Because *E.coli* cleaves both Salmon-GAL and X-glucucuronide, the colonies take on a dark-blue to violet colour, and therefore can be easily distinguished from the other coliforms which are coloured red.

(e) Colilert

A simultaneous detection of two specific enzymes activities such as beta -D- galactosidase and beta- D- glucuronidase of coliform and *E.coli* was seen using substrate combination of MUG and ONPG.

After 24 h incubation all the plates were taken out from the incubator and counted the number of colonies with reference to the three types of media used such as ENDO, Fluorocult and Chromocult. Each colony was enumerated as colony forming unit (cfu). On ENDO media there appeared different types of colony such as red, pink, red with pin headed and red with metallic sheen. Of these, only red colonies with metallic sheen were considered as coliform. For other colonies, further identification was performed. But other types of colonies like white, yellow, green were not considered as coliform bacteria. Further identification of *E.coli* from the coliform bacteria was made from randomly chosen coliform colonies. While doing so, what happened is that sometimes only red colonies among the typical colonies showed positive *E.coli* while colonies with fuchsheen sheen negative *E.coli*. So it was very difficult to estimate the number of *E.coli* on the plate and likewise it was not possible to confirm all the coliform colonies of the plate. In case of the fluorocult media, as it consists of fluorogenic substrate, the colonies which produce fluorescence are *E.coli* and therefore the further confirmation to the colonies need not necessary (Manafi 1991). But for some colonies it was very difficult to confirm whether they were fluoresce or not. The cross-checking of the counting for the same plate for fluorescence colony was sometime found to be different. These unconfirmed colonies were further confirmed. On the Chromocult media, the colour of the colony was very clear and there was no confusion between coliform and *E.coli*. Further confirmation of *E.coli* was over 95%. In case of expectation of high accompanying flora, especially *Pseudomonas sp.* and *Aeromonas sp.* let the medium cool to 45-50°C and added 10 mg Cefsulodin in 2 ml of demineralised water to 1 litre of the medium and then the mixture was homogenised by gently shaking and poured it onto plates. The plates got yellowish and stored them in a refrigerator and protected from light. To prevent plates from drying, they were sealed in plastic-pouches or bags.

For the confirmation of *E. coli*, sub-culture of randomly chosen coliform colonies from each of the plates was done on Fluorocult EDV media. Any coliform that produced the enzyme β-glucuronidase and hydrolysed the MUG substrate to produce a blue fluorescence around the periphery of the colony was considered as *E.coli* and it is further confirmed by Indole test. Presumptive *E.coli* are randomly chosen for pure culture and identified with API 20E system (Biomericux SA; Montalieu,Vercieu France).

Thus, the enumeration of bacteria by membrane filter technique on Chromocult media was found the best over other media because of the following reasons:

- Confirmation level was very high, about 97 percent;
- Colour was distinct among *E.coli*, coliform and other bacteria;
- Cost was more or less the same compared with other media;
- Media preparation was easier over other media, and
- Though the Quantitray MPN technique on Colilert media was more easier and time saving over the Chromocult media. But in terms of effectiveness they were more or less the same. However the former was very expensive to be used particularly in the Nepalese case.

(vii) Salmonella test

The *salmonella* test analysis has been made in terms of qualitative description. By virtue of convenient and provide rapid in vitro detection of presumptive *salmonella* sp., the Tectra unique™ *salmonella* test kit was used for *salmonella* test. The confirmation of *salmonella* was done by using the API test. The test kit also consists of unique dipstick to perform both the immunoenrichment and detection steps. A 25 ml water sample was used for the test. The other detailed steps were followed as mentioned in the test-kit.

3.4.2 Benthic invertebrates data analysis

In the laboratory analysis, the following steps were used to analyse the sampled animals:

- Sorting of the animals up to family level;

- The animals were further identified at possible levels of genus or species with the help of existing keys from different authors for different groups (Macan 1977;, Elliott 1977; Wallance et al.; Tillyard 1917; Sewel ed. 1936; Kihara ed. 1955; Jäch and Ji eds. 1995) and also special unpublished keys prepared by the specialists from Austria for different groups of taxa; and final confirmation for species level were made by the concerned specialists.

- Indices such as tolerance score for a taxon and biotic index for a site have been developed and used to classify identified animals. These indices are described and used in the contextual context wherever feasible.

-

3.4.3 Chemical data analysis

In the chemical analysis, parameters such as DO, pH, Conductivity, Hardness, Nitrogen-, Ammonia, PO4 - P, Biochemical Oxygen Demand (BOD) and Chloride were considered. Based of the APHA (1995), different appropriate and widely used methods were used in the analysis of these different chemical parameters, for example, the Wrinkler method was used for DO while the Calorimetric, Phenate and Hypochloride method for NH4-N; the 5-days incubation followed by the Wrinkler method for BOD_5; the Silver nitrade method for Chloride; and the Ascorbic acid method for the total-Phosphate. The method of analysis of each parameter is described below in brief based on APHA (1995).

PH Value

The measurement of pH is one of the most important and frequently used tests in water chemistry. pH is used in alkalinity and carbon dioxide measurements and many other acid-base equilibra. At a given temperature the intensity of the acidic or basic character of a solution is indicated by pH or hydrogen ion activity. PH is defined by Sorenson is - log $[H^+]$; it is the intensity factor of acidity. It is measured in this study by pH meter consisting of potentiometer, a glass electrode, a reference electrode, and a temperature-compensating device. A circuit is completed through the potentiometer when the electrodes are immersed in the test solution.

Total hardness

EDTA titrimetric method is used to know the amount of total hardness.

Ethylenediaminetetraacetic acid (EDTA) and its sodium salts form a chelated soluble complex when added to a solution of certain metal cations. If a small amount of a dye such as Eriochrome Black T or Calmagite is added to an aqueous solution containing calcium and magnesium ions at a pH of 10 ± 0.1 the solution becomes wine red. If EDTA is added as a titrant, the calcium and magnesium will be complexed, and when all of the magnesium and calcium become complexed the solution turns from wine red to blue, marking the red end point of the titration. Magnesium ion must be present to yield a satisfactory end point. To insure this, a small amount of complexometrically neutral magnesium salt of EDTA is added to the buffer; this automatically introduces sufficient maganesium and obviates the need for a blank correction.

Dilute 25 ml sample to about a 50 ml with distilled water in a porcelain casserole or other suitable vessel. Add 1 to 2 ml buffer solution. Usually 1 ml will be sufficient to give a pH of 10 to 10.1 . The absence of a sharp end-point colour change in the titration usually means that an inhibitor must be added at this point or that the indicator has deteriorated.

Added 1 to 2 drops indicator and standard EDTA titrant slowly, with continuous stirring, until the last reddish tinge disappeared. The last few drops at 3- to 5-s intervals added indicator. At the end point the solution normally turned blue.

$$\text{Hardness (EDTA) as mg } CaCO_3 \text{ /l} = \frac{A \times B \times 1000}{ml.sample}$$

Where:

A = ml titration for sample
B = mg $CaCO_3$ equivalent to 1 ml EDTA titrant

Dissolved Oxygen (DO)

For the estimation of Dissolved Oxygen (DO) the sample water which was already fixed with the chemicals in the field (as mentioned earlier) was analysed in the laboratory. When the precipitate in the bottle was seen settled sufficiently to leave clear supernatant above manganese hydroxide floc, then added 1 ml conc. H_2SO_4 .The bottle was re-closed and mixed by inverting several times until dissolution was complete. Then titrated with 0.025M $Na_2S_2O_3$ to know amount of dissolved oxygen (mg/l).

For titration of 200ml sample, 1 ml of 0.025M $Na_2S_2O_3$ = 1 mg DO/l

BOD_5

In this case DO was measured initially and after incubation of sample for 5 days . The BOD was computed from the difference between initial and final DO. With reference to APHA (1992) dilution was made from the range of 25-100% for polluted river water.
BOD_5 is calculated as follows:

$$BOD_5,\ mg/l\ O_2 = \frac{D_1 - D_2}{P}$$

Where:
D_1 = DO of diluted sample immediately after preparation, mg/l.
D_2 = DO of diluted sample after 5 d incubation at 20°C, mg/l.
P = decimal volumetric fraction of sample used.

NH4-N

In manual calorimetric technique Phenate method was used to compute NH4-N . This method has a sensitivity of 10μg NH4-N /l. Preliminary distillation is required if the alkalinity exceeds 500mg $CaCO_3$/l, if sample showed turbidity, or if it had been preserved with acid.
Most reliable results are obtained on fresh samples. If prompt analysis is impossible , preserve samples with 0.8 ml conc. H_2SO_4/l sample and store at 4°C. The pH of the acid-preserved samples should be between 1.5 and 2. If acid preserve was used , neutralised the samples with NaOH or KOH immediately before making the determination.

Total phosphates

Phosphorus occurs in natural waters and in wastewater almost as phosphates. These are classified as orthophosphates, condensed phosphates (pyro-, meta-, and other polyphosphates), particles or detritus, or in the bodies of aquatic organisms. Ascorbic acid method was used for the estimation of phosphate in the present study.
Principle:

Ammonium molybdate and potassium antimonyl tartrate react in acid medium with orthophosphate to form a heteropoly acid - phosphomolybdic acid- that is reduced to intensely coloured molybdenum blue by ascorbic acid. Approximately 10 µg P/l is detected.
Pipeted 50ml sample into a clean dry test tube or 125 ml Erlenmeyer flask. Added 0.05 ml (1 drop) phenolphthalein indicator. If a red colour developed, 5N H_2SO_4 was added to the solution dropwise to just discharge the colour. Added 8 ml combined reagent and mixed thoroughly. After at least 10 min but no more than 30 min, measured absorbnance of each sample at 880 nm, using reagent blank as the reference solution.

Prepared calibration curve and used distilled water blank with the combination curve. Plotted absorbance vs. Phosphate concentration to give a straight line passing through the origin. Phosphate here is measured as PO4 - P mg/l.

$$\text{PO4 - P mg/l} = \frac{mg.\,P(approx.58ml final vol.)\times 1000}{ml.\,sample}$$

Chloride

Argentometric method is used to estimated chloride ion. In a neutral or slightly alkaline solution, potassium chromate can indicate the end point of the silver nitrate titration of chloride. Silver chloride is precipitated quantitatively before red silver chromate is formed.

A 100-ml sample or a suitable portion diluted to 100ml was used . If the sample is highly coloured, add 3ml $Al(OH)_3$ suspension, mix, let settle, and filter. Titrated the sample at the range of pH 7 to 10. Added 1 ml K_2CrO_4 indicator solution. Titrated with standard $AgNO_3$ titrant to a pinkish yellow end point.

$$\text{mg } Cl^-/l = \frac{(A-B)\times N\times 35450}{ml.\,sample}$$

Where:
A = ml titration for sample,
B = ml titration for blank
N = normality of $AgNO_3$
mg NaCl/l = (mgCl^- /l) × 1.65

3.4.4 Comparative analysis of the parameters and basic statistic tool used

The comparative analysis of each of the monitoring aspect samples collected was analysed with respect to the saprobic water quality class of the site. The distribution of sensitive benthic invertebrates was also analysed with respect to the change in chemical parameter in the sample sites.

Four basic analysis tools including laboratory, statistical, mapping and observational based on field protocol have been used to furnish the results in the textual context. In statistics analysis, correlation analysis has been used to show the strength of relationship between paired variables.

4 THE STUDY AREA: KATHMANDU VALLEY

This chapter highlights different settings, comprising physical, land use, economic and social of the study area - Kathmandu valley .

4.1 The Settings

4.1.1 Physical Setting

(i) Location and topography

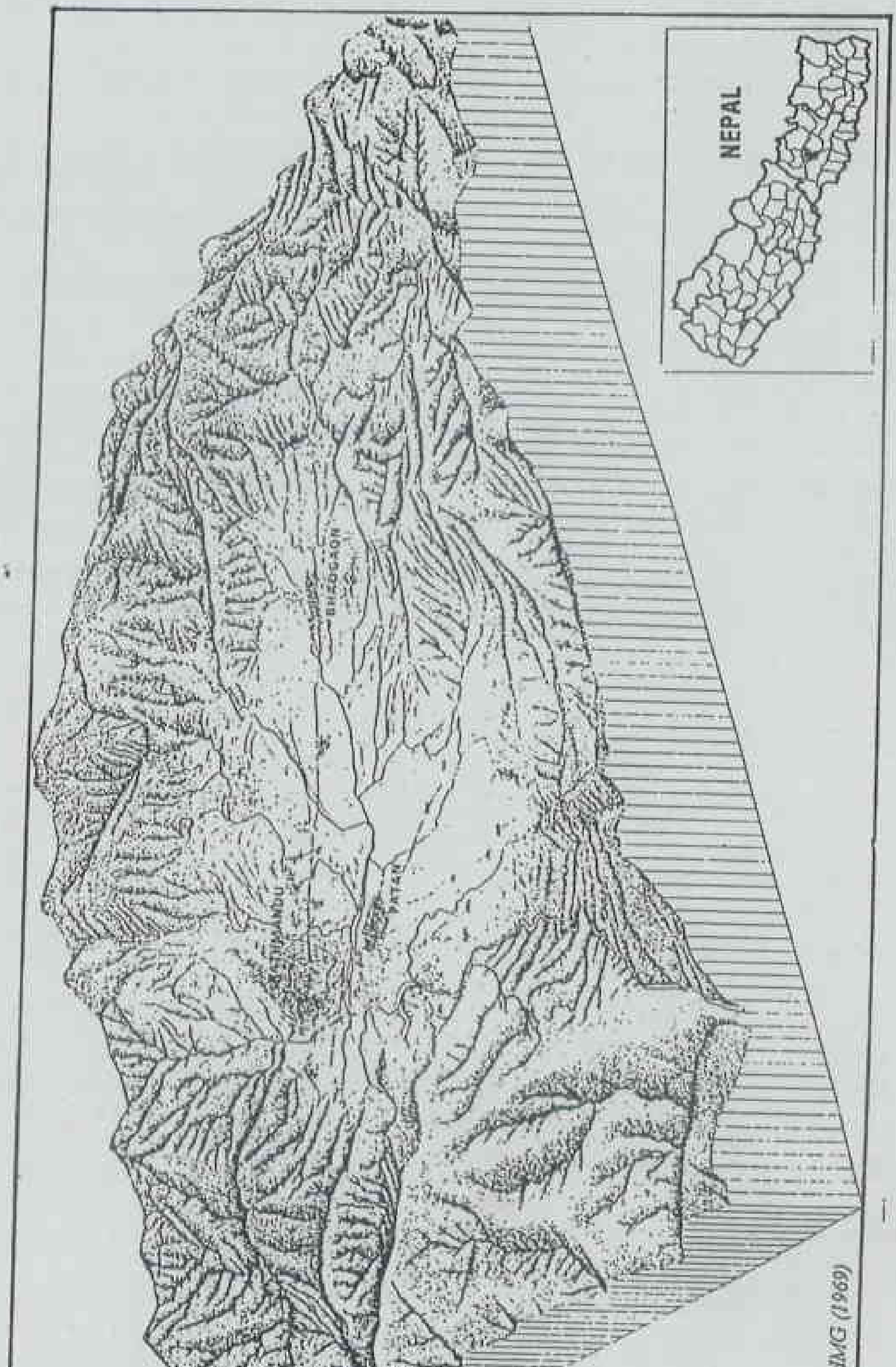
Kathmandu valley lies in the central hill region of Nepal (Figure 4-1). The valley with bowl shape is 19 by 30 kilometres. The valley region comprises three districts, viz. Bhaktapur, Kathmandu and Lalitpur. The valley's prominent boundary features are Shivpuri *lekh* (2,689 m) in the north, Phulchoki ridge in the south, Sanga *bhanjyang* (pass) in the east, and Bad *bhanjyang* in the west. The perimeter of the valley is defined by the ridgeline which forms the limits of its watershed.

Kathmandu valley is of tectonic origin (Hagen 1971). The floor of the valley lies at an average elevation of 1,250 m from the mean sea level from which mountains rise rather steeply on all sides above 1,800 m, the highest being the Phulchoki ridge with elevation of 2,831 m in the east. The valley floor is made up of fluvio-lacustrine sediments with vertebrate fossils of quaternary age (ESCAP/ HMG 1993). Two other distinctive associated physical features of the valley basin are *dol* and *tar*. The former is an alluvial flood plain, formed by recent alluvia freshly deposited by the rivers while the latter is an elevated terrace or table land and is relatively old. The surrounding mountains also known as *'Mahabharat'* range are composed of a thick sequence of meta-sedimentary and metamorphic rocks such as phyilites, quartzites, siltstones, schists and marble. These sediments are formed between Precambrian and Tertiary age (HMG/ICIMOD/ CDG/UNEP 1994). The hills are generally heavily dissected. The lower and gentler slopes have been used for terrace cultivation and forests are found only on the higher elevations.

(ii) Drainage system

Kathmandu valley is drained by the Bagmati river and its tributaries such as Balkhu, Bishnumati, Dhobi khola, Manohara, and Nakhu. Because of the relatively flat topography of the valley basin with soft, deep sedimentary deposits, these rivers have meandering courses and in some areas, wide flood plains. The general slope of the valley area is towards the central part and thence to the south-west. The central slope has an average gradient of above 1 in 236, and therefore all the tributaries flow centripetally toward the centre of the valley to meet with the Bagmati river which then emerges into an antecedent transaction valley cutting deeply in the south-west to flow out the valley. The Chobhar gorge through which the Bagmati leaves the valley has the lowest elevation of about 1,230 meters above the mean sea level. It then flows towards east for some distances following the range of '*Churia*' hills and then directs to the south over the Tarai plain of Nepal. Other tributaries flowing down from the southern hills of the valley meet the Bagmati river. These rivers are Durlung, Devata and Khanikhola.

Figure 4-1: Location of study area: Kathmandu valley (isometric view), Nepal



Source: HMG (1969)

The water level of all rivers is very much relied on the monsoon rain. The common feature of the rivers is that during monsoon season they often get flooded and deposit enormous amount of sands and fine particles over their banks. In the dry season, their water level is unusually small despite they are perennial.

Besides rivers, there are other water sources such as ground water and springs in the valley. Regarding ground water resources, there are few tube wells as well as few privately dug wells which supply small scale drinking water. Spring sources have been used primarily for domestic purpose. This particular aspect is very significant to explain the location of many village settlements near the source of spring over the hill slopes.

(iii) Climate

The Kathmandu valley region lies in the temperate climate zone. However, there is great variation in temperature condition between the valley basin and the surrounding hill ridge. The temperature recorded at three stations located at different altitudes, viz. Kathmandu (1,336 m), Godavari (1,400 m) and Nagarkot (2,163 m) show that the mean monthly maximum temperature for all stations occurs in June but with variable degrees, for example 29.2°C for Kathmandu, 26.6°C for Godavari and 23.8°C for Nagarkot. The mean monthly minimum temperature with 3.4°C at the Kathmandu station occurs in January while that at the Godavari station with 5.4°C occurs in February and at the Nagarkot station with 2.2°C in December (Figure 4-2). On the whole, the mean air temperature in the region rises during the pre-monsoon, reaches maximum in June-July, declines during the post-monsoon period, and further declines to a minimum value in the month of January.

The three stations also reveal striking feature of diurnal temperature variation. The diurnal temperature range at all stations in the summer is small because nights are usually warm. While in winter as nights are usually cold, the diurnal range of temperature is greater. The range of both diurnal and annual temperature variation is pronounced greater for Kathmandu than for other two stations. This is mainly due to elevation factor. For instance, Nagarkot, situated at the highest altitude among the three stations has an annual range below 8°C, whereas Kathmandu has an annual range nearly twice as high (14.3°C) as that of Nagarkot. This temperature condition signifies that the climate prevalent over the valley basin may be regarded as an extreme type. By contrast, Nagarkot and Godavari locating at higher altitude enjoy a fairly equitable climate because of neither of very hot summer nor cold winter.

The valley receives an average rainfall of 3220 mm annually. As in other parts of the country, the south-east monsoon is the main rain bearing wind which delivers about three-fourths of the total rainfall during the wet summer season, i.e. June through September (Figure 4-3). While the winter months remain mostly dry, occasional precipitation occurs in the form of winter rains caused by westerly cyclones. Geographically, rainfall in the valley is not evenly distributed. The highest precipitation is on the southern slopes of Shivpuri lekh (5,800 mm). The amount declines considerably from the surrounding ridge to the valley bottom with the highest at Nagarkot, higher at Godavari and lowest at Kathmandu.

Figure 4-2: Temperature and precipitation condition, Kathmandu valley

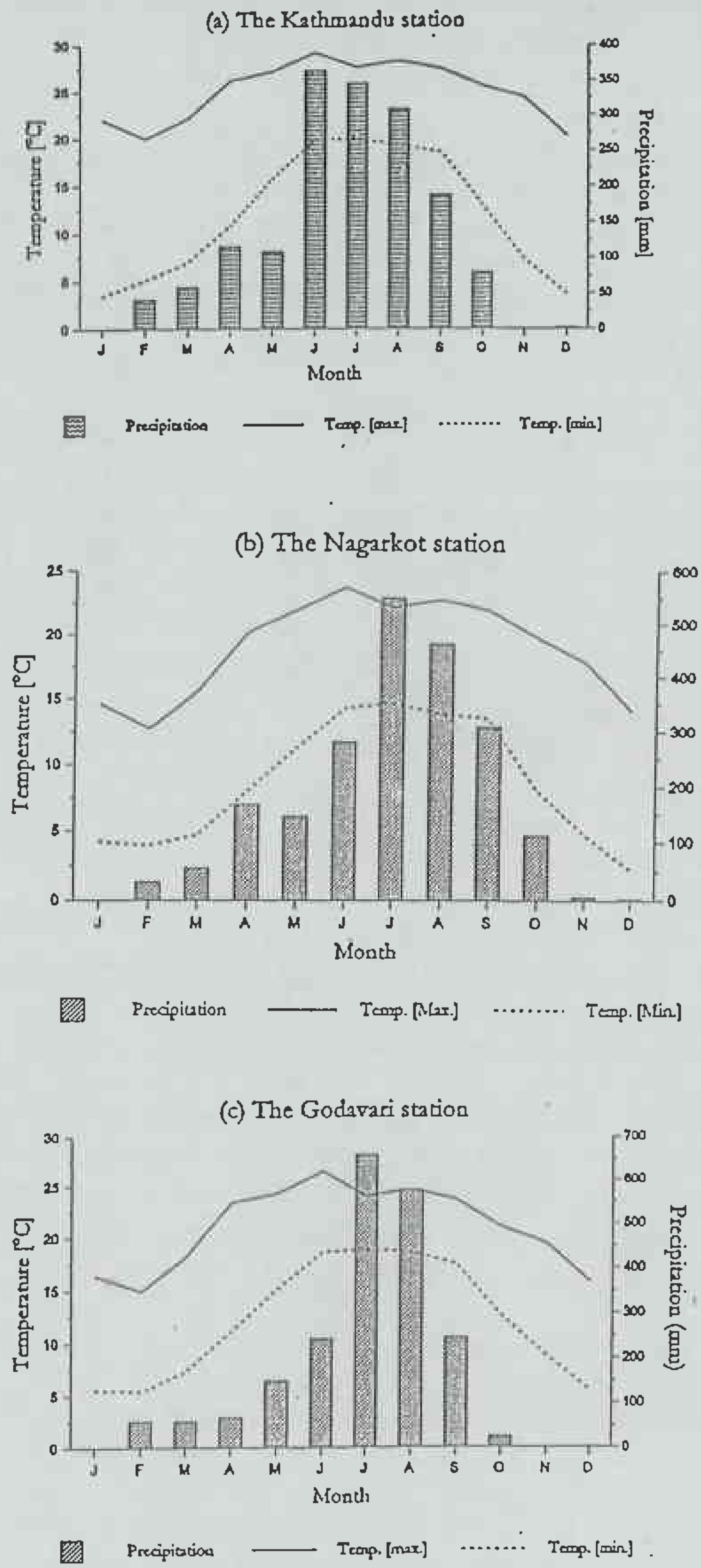
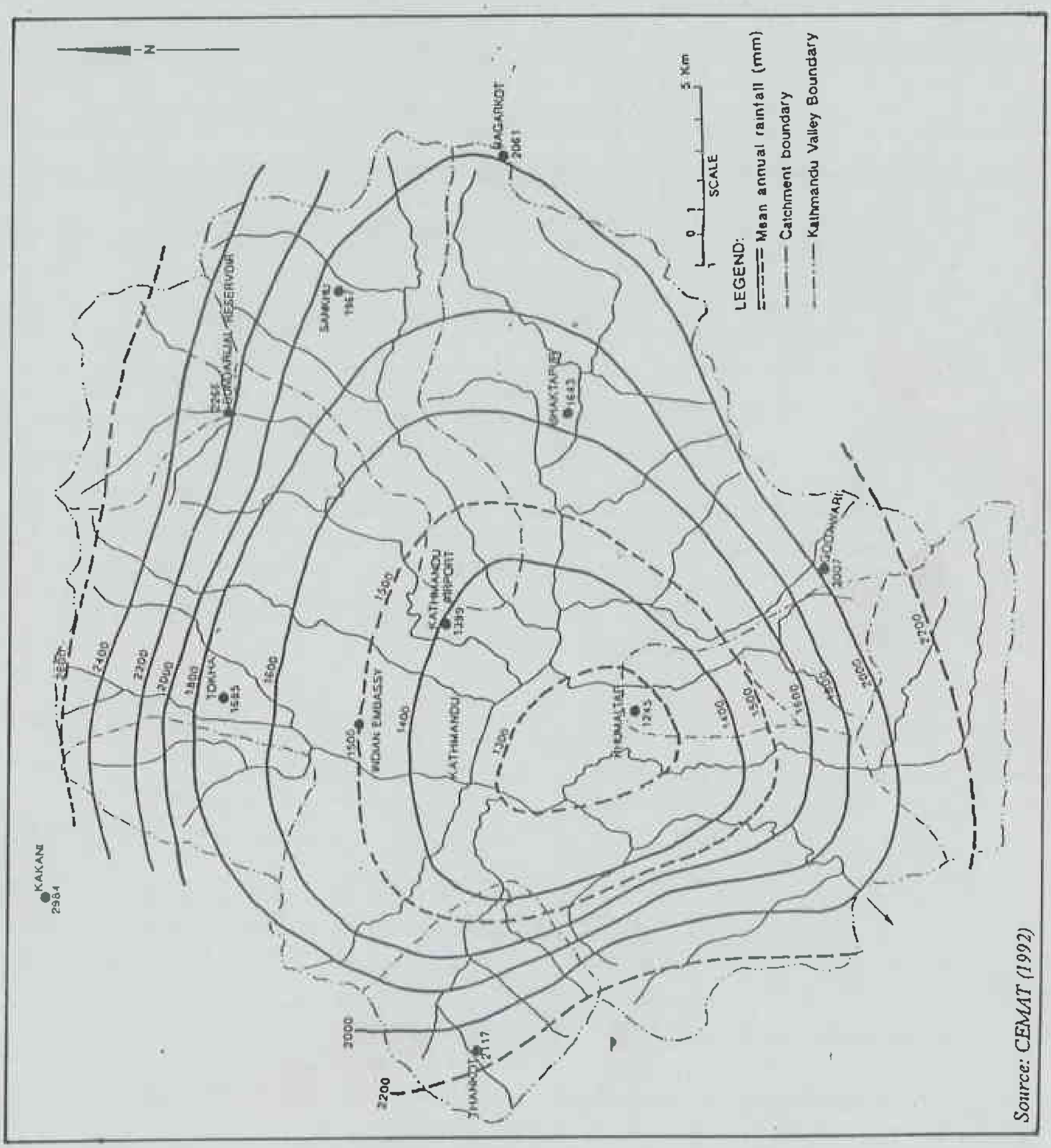


Figure 4-3: Rainfall distribution pattern, Kathmandu valley.



Source: CEMAT (1992)

4.1.2 Land Use

The land use analysis of the Kathmandu valley region is intended to provide for an understanding of status of the ecological conditions both natural and man-made.

Table 4.1: Major land use categories Kathmandu Valley

Categories	Area (km²)	Percent
Agriculture	421.8	64.3
Forest	203.2	31.0
Settlement area	26.4	4.0
Sand, gravel & boulder	4.6	0.7
Total	656	100

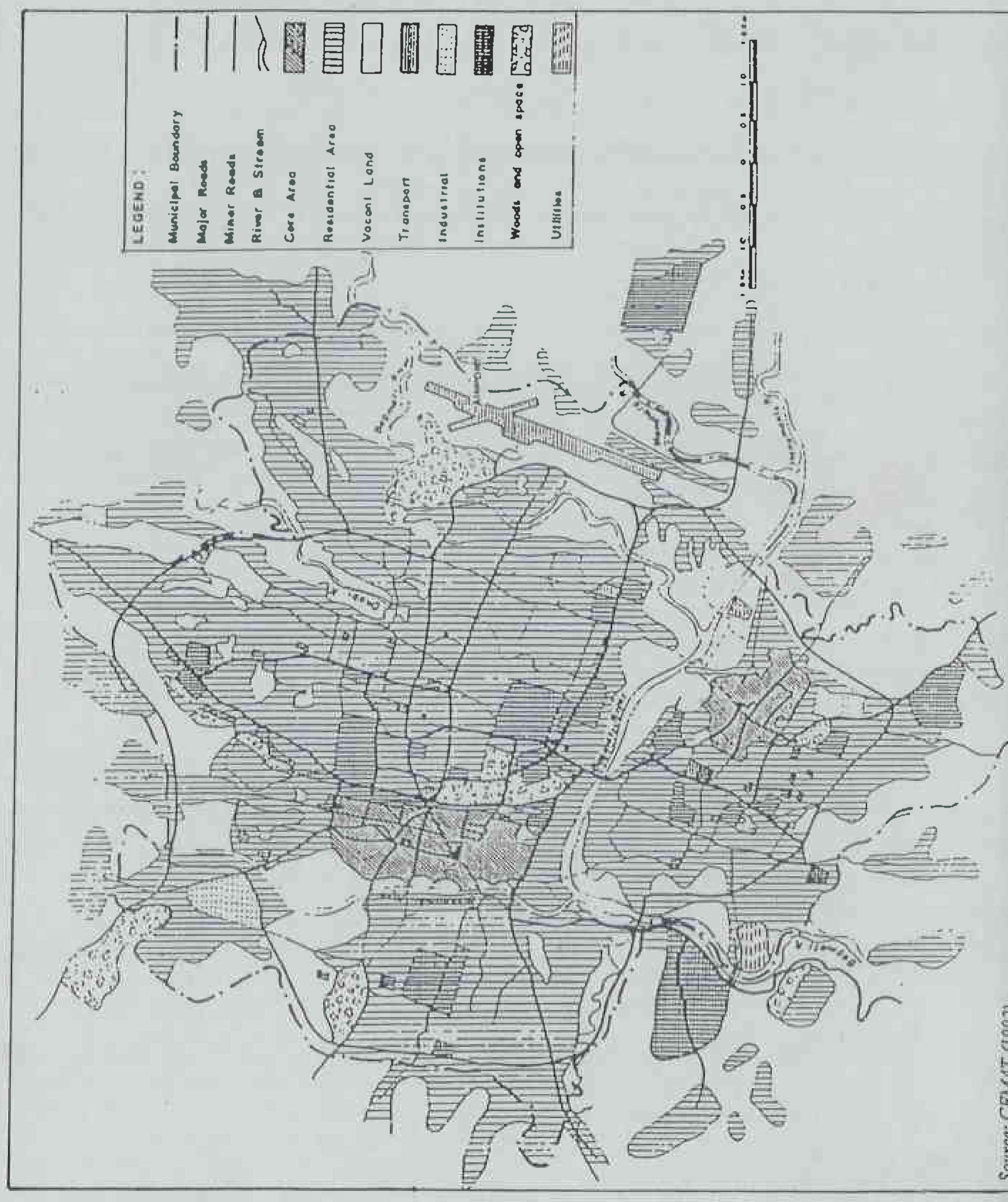
Source: Stanley International Ltd. (1994).

Of the four major land use categories (Table 4.1), the agricultural land covers the largest area, making up sixty-four percent of the Kathmandu valley's total area. This agricultural land can be divided into two types: valley cultivation and hill slope cultivation. The former consists of a series of river terraces of different ages with different soil textures such as *dol* and *tar* of the valley basin and is of great importance for agricultural production because of their best soil quality. These lands are used basically for paddy, the main staple crop of the people.

Next important land use is the forest coverage which makes up slightly below one-third of the valley total area (Figure 4-4). Broadly, the forest is of mixed type consisting of deciduous semi-hardwood, shrub and conifer. On the higher ridges above 2,100 m are grown oaks (*Queracus leucotrichophora, Q. lanata, Q. lamellosa and Q. glauca*), magnolia, alders, poplars, and conifer species, such as chirpine, hemlock and bluepines. On the lower slopes are the vegetation types dominated by broad leaf trees, such as *Schima wallichii* (Chilaune) and *Castonopsis indica* (Katus). Other common associates of this vegetation are *Dendrocalamus* (Bans) of numerous species, *Alnus nepalensis* (Utis), etc.

Much of the lower ridge forests has already been cleared for terrace cultivation. However on the higher ridges the forests have been conserved to a sufficiently adequate extent. Clearing can be expected to continue particularly on unprotected public land and thus the forest continues to be degraded. There are several preserved forests such as the Shivpuri forest, the Raniban, the Gokarn jungle and the Godavari Botanical Garden on the periphery of the valley. Of these, the 'Royal Botanical Garden' is an instance which extends over an area of 16 hectares on the Phulchoki hill. It was established in 1962 in order to protect the wild tree species and habitats so as to exhibit an example of protected samples of an entire natural ecosystem of the region.

Figure 4-4: **Landuse and land cover, Kathmandu valley**



Source: CEMAT (1993)

Forest coverage and agricultural activities have direct bearings on watershed management which in turn is related to surface water hydrology. In the past, the surrounding hills were covered with forest but have mostly been severely deforested in the recent past. However, one study concludes that because of little use of the surrounding hills of the valley for agriculture, the watershed condition is excellent (NELSON as quoted in Stanley, 1994). The study suggests that there is no significant diminishing of the forest area on the surrounding hills but its quality is found rather declining (Stanley, 1994).

4.1.3 Economic Setting

The economic activities in the valley include two broad groups: farm and non-farm. Agriculture is the predominant activity in the valley which employs about 37 percent of the gainful population. There is high pressure of population on the arable land as employment opportunity in other sectors is severely limited. The prime agricultural land in on the diminishing as a result of encroachment of urban expansion on it.

The cropping pattern on the farmland is mainly rice followed by wheat or potato. These crops are basically of subsistence-based cultivation. Vegetable gardening is predominantly of cash oriented farming to cater to the urban demand. The farmland along the hill is used for growing dry crops, such as maize, millet, oilseeds, potato, beans and the like. Agriculture is characterised by very intensive farming taking consideration the factors of use of fertilisers, irrigation, human labour and the contouring of farmland. There is very low man-land ratio. However the productivity per unit of farmland is very high since the same piece of farmland is used for multiple crops and inter-cropping within a year.

Irrigation is important since it is the main consumer of river water. Most of the rural areas of the Bagmati basin are intensively used for farming. Of the total arable land, the gross irrigable area is estimated to be 17, 145 ha, of which 12,000 ha, i.e. 70 percent is assumed to be irrigated. This includes canal irrigation and numerous small irrigation schemes. The demand of intensive vegetable gardening on water is far more than that of any other cereal crops.

Besides, many of the family members particularly of the small market settlements are engaged in various non-farm activities, including commerce and business, small scale industries, arts and crafts and so on. The carpet, textile, brick and tiles, marble, etc. are the prominent and thriving industries which are located mostly at the outskirts of the cities.

4.1.4 Social Setting

(i) Settlement

The area under settlement is only 4 percent of the total area (Tab. 2). The present settlement pattern is the consequence of historical population migration. Historical documents reveal that the early settlements in the valley are known to have developed mostly on the elevated plains mainly because of the fact that there was a need for proximity to cultivated fields but often some distance from the flood, as well as for preserving the rich agricultural land in order to avoid its inefficient use. At present, the valley settlements belonging to the native inhabitants of Newar communities are characterised by compactly built houses with population ranging from 1,000 to

5,000. On the other hand, the patterns of the hill settlements mostly occupied by such castes and ethnic groups as Bahun and Chhetri, and Tamang are characterised by scattered houses or isolated homesteads. These patterns seem to have often influenced by the availability of arable land, terrain and source of water. The poor soil quality of the surrounding hill environments was naturally insufficient to support large concentrations of people. Furthermore, the hill people seem to prefer to settle along the hill slopes because of their agro-livestock farming system because the hill environment is suitable to grow pasture and trees for grazing as well as fodder supply to the livestock and fuel wood for cooking.

Recently, there are emerged squatter settlements mainly along the rivers. Their number is said to be rising rapidly in recent years, though there is little known about the number and status of squatters (CEDA quoted in Stanley 1994). One of the main reasons is that there are many short term or seasonal migrants coming from the surrounding hills and outside of the valley, including construction workers, skilled and unskilled labourers, vegetable vendors, etc. In the valley cities they live temporarily on the site where they are working. The number of such transient people are difficult to predict because there is nowhere recording. However, they are quite important from the environmental view point since many of them live close to the river without adequate facilities.

(ii) Population

The 1991 census gives the Kathmandu valley region a total population of 1105,379. This exceeds over its 1981 population by 379,131 or an increase of 31,594 persons annually (Table 4.2). The gross population density of the valley region is 1,230 persons per km² and for the city areas, it comes to 9,200 persons per km².

Table 4.2: Growth of population, Kathmandu valley (1981-1991)

		Census		
Area	Locality	1981	1991	% growth
Urban	Bhaktapur	48,472	61,405	2.6
	Kathmandu	235,160	421,258	7.9
	Lalitpur	79,875	115,865	4.5
	Sub-total	363,507	598,528	6.5
Rural	Bhaktapur	111,295	111,547	0.0
	Kathmandu	187,077	254,083	3.6
	Lalitpur	104,466	141,221	3.5
	Sub-total	402,838	506,851	2.6
District	Bhaktapur	159,767	172,952	0.8
	Kathmandu	422,237	675,341	6.0
	Lalitpur	184,341	257,086	3.9
	Valley total	766,345	1105,379	4.4

Source: *CBS (1995, 1985).*
Note: (a) The district area of Bhaktapur, Kathmandu and Lalitpur is 119, 395 and 385 km² respectively; (b) The area of municipality boundary of Bhaktapur, Kathmandu and Lalitpur is 154, 4745 and 157 hectares respectively (PADCO 1986); and (c) Rural area refers to village development committee (vdc).

There was a considerable difference in the growth of population between urban and rural areas during the last decade of 1981-1991. Table 4.3 shows that there was higher growth of population in urban area (65%) as compared to both rural (26%) and the valley region (44%). Also evident is that there was a negative growth of population in the rural area by 18 percent while a positive growth of population occurred in urban area by 21 percent. It means that there was a rural to urban migration. One of the consequences of urban population growth is the rising in density of population in urban area.

The present population of the valley is composed of diverse ethnic communities, such as Newar, Bahun and Chhetri, Tamang, Magar, and others. The Newars, the native inhabitants of the valley region, now make up only about two-fifths of the valley population while all other migrant groups constitute three-fifths. Of the non-Newars, the Bahun and Chhetri and other Nepali speaking groups make up forty-seven percent, Tamang 6 percent and others 6 percent.

Table 4.3 depicts that the gross density of population per hectare of the present area in 1991 has gone up 399 persons in Bhaktapur city; 89 persons in Kathmandu city and 73 persons in Lalitpur city from 260, 56 and 37 persons in those cities respectively in 1971. Thus, the urban population density has increased more than double between 1971 and 1991. As a result, the cities have spread recently over river terraces and flood plains as though originally they were located on the elevated plains between rivers. This has caused to rapidly filling up the remaining agricultural land, open spaces adjacent to major rivers. So, there is lack of open space for public recreation in the cities and river banks are now being polluted for that purpose. But however the flood plains and banks could be rehabilitated to provide attractive green belts and therefore saved from further deterioration of river water quality.

Table 4.3: Change in gross population density in urban areas of Kathmandu Valley

		No. of persons/ha by census year**		
Locality	Area (ha)*	1971	1981	1991
Bhaktapur	154	260.3	314.5	398.7
Kathmandu	4,745	56.3	49.6	88.8
Lalitpur	1,579	37.4	50.6	73.4
Total/Average	6,479	38.4	56.1	92.4

Source: *PADCO (1986); ** CBS (1974, 1984 and 1995).

The urban expansion has also created several non-farm activities. One such activity is carpet factory which has contributed a large amount of carpet dyeing and washing effluent as well as domestic sewage to the river. Such development could lead to further deterioration in river water quality if not managed properly.

5 THE BAGMATI RIVER SYSTEM: DRAINAGE PATTERN AND AESTHETIC VALUE

This chapter consists of three sections. In the first section, discussion on the Bagmati River system and its hierarchical order is made. An overview of aesthetic value of the river is highlighted in the second section. The third section deals with the description of profile regions of the Bagmati river system, the sample sites' characteristics and field water quality classification.

5.1 Overview of the Bagmati Drainage System

5.1.1 Drainage Characteristics

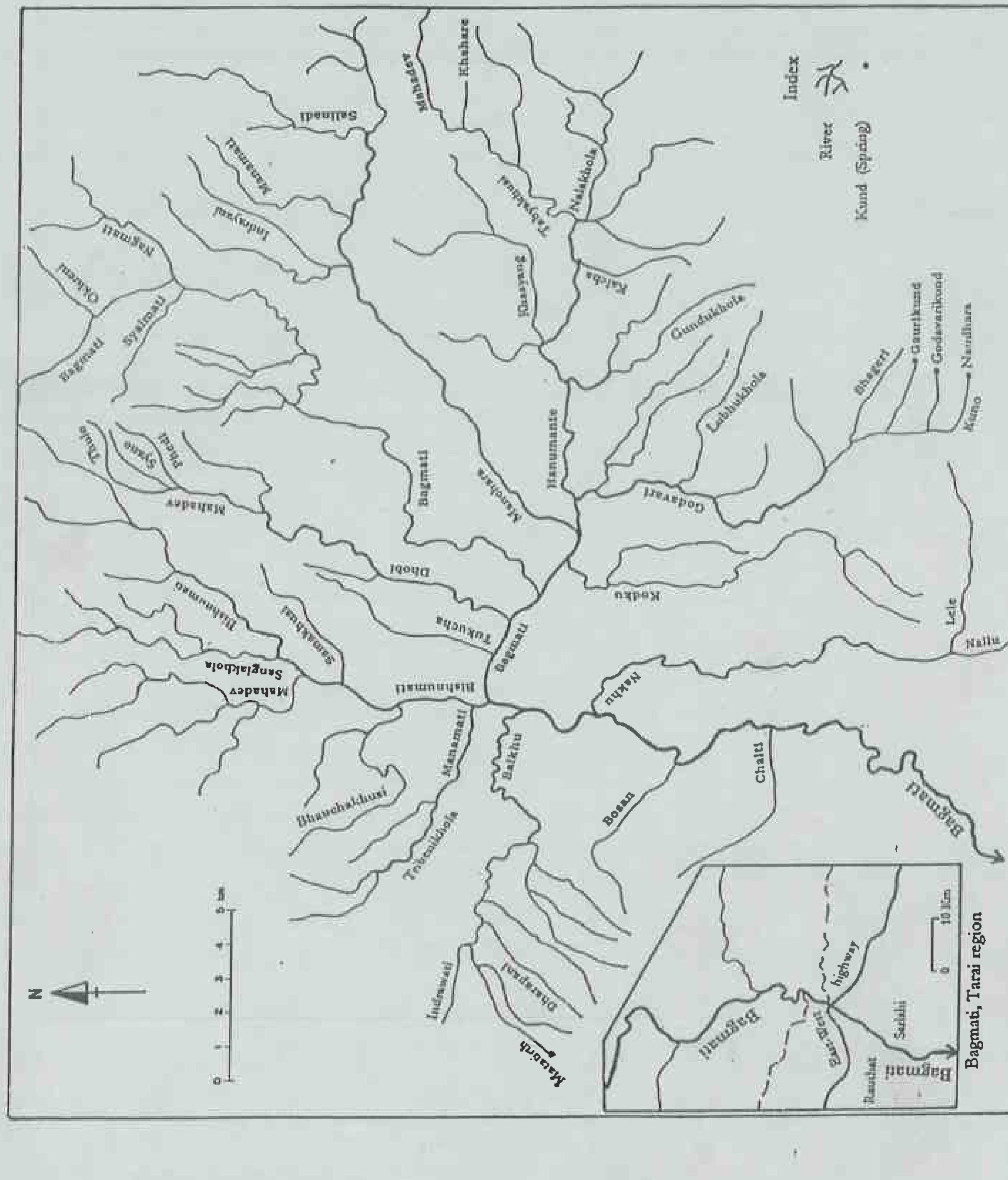
Stream can be defined as a long, narrow body of flowing water occupying a trench like depression, or channel, and moving to lower levels under the force of gravity (Strahler and Strahler 1978). So, stream is a lotic system. Streams may be basically of three types: perennial, intermittent and ephermal. The first type is permanent stream and the latter two are temporary in nature. The drainage system is the total system of down slope water flow from the point of arrival at the ground surface. It consists of a branched network of stream channels, as well as the sloping ground surface that contribute overland flow and inter-flow to these channels. The drainage basin includes this entire drainage system. As depicted in figure the Kathmandu valley basin is drained by the multitude of tributaries that feed the main channel of the Bagmati river. The drainage characteristics of the Bagmati river and its tributaries are shown in Table 5.1. Below is a description of these characteristics.

Table 5.1: Place of origin, elevation, and length of the Bagmati river system

Name of river	Length (Km)	Elev.(m)	Origin places
Bagmati	35.50	2732	Shivpuri Bagdwaar
Bishnumati	17.30	2300	Shivpuri Tarebhir
Bosan	6.10	1800	Pokhari Banjyang
Dhobi	18.20	2732	Shivapuri dada
Godavari	14.80	2200	Phulchoki dada
Hanumante	23.50	2000	Mahadevpokhari dada
Indrawati	16.80	1700	Dahachok dada
Indrayani	7.00	2000	Bhangari dada
Kodku	14.90	2000	Tileswor dada
Mahadev	9.20	2000	Aale dada
Manamati	6.10	2000	Bhangari dada
Manohara	23.50	2375	Manichur dada
Matatirtha	5.00	2000	Matatirtha dada
Nagmati	7.90	2443	Shivpuri dada
Nakhu	17.60	2200	Bhardeu ridge
Samakhusi	6.40	1350	East of Dharampur
Sangla	10.70	2000	Aale dada
Syalmati	4.80	2200	Shivpuri dada
Tribeni	10.70	1700	Bhirkot
Tukucha	6.40	1325	Within ring road (Maharajganj)

Source: *Field Survey (1995-96); Schneider (1989).*

Figure 5-1: The Bagmati river system



Source: *Field survey (1995-96); Schneider (1989).*

(i) The Bagmati river

The Bagmati river originates on Shivapuri *lekh* (ridge) at an elevation of about 2,650 meters and drops to 1,340 meters over a distance of about 8 kilometres (HMG 1969). In the upstream region near Sundarijal, two streams: the Nagmati and the Syalmati come to join this river. The valley basin begins some kilometres below Sundarijal over which it flows to the south, turns to the west and again turns to the south and the west and then finally to the south-west. In the valley basin, the Manohara river with its tributaries such as the Salinadi, the Manamati, the Indrayani, the Hanumante and the Kodku joins the Bagmati river at Koteswor. Before the Bagmati turning to the south at Teku join it other tributaries like the Dhobikhola (Rudramati), the Tukucha (Ichchhumati) and the Bishnumati. Three other tributaries such as the Balkhu, the Nakhu and the Bosan join the Bagmati river before leaving Chobhar gorge. The length of the Bagmati river from its origin Shivapuri ridge to the Chobhar gorge is about 35 kilometers. This is the most intensively exploited river in the valley, being used both for drinking water supply and hydro-electric power generation. The dams constructed at Gokarna and Pashupati have also been used to provide for irrigation facilities. Its upstream region is settled with sparse population. But while it passes through the valley basin, the density of population on its both banks increases greatly. There is again low population density beyond the urban area in the south-west. At Sundarijal its catchment area is about 15 km^2 and at Gaurighat is 68 km^2. The minimum discharge recorded at both sites were 0.13 and 0.08 m^3/s respectively (HMG/UNDP 1992). The Bagmati and its tributaries are spring-fed, depending on the rainfall pattern.

(ii) The Bishnumati river

This river also originates from the Shivpuri ridge at an elevation of about 2,430 meters and falls to about 1,000 meters over a distance of about 3 kilometres. It has a drainage area of 87 km^2 covering basically north-west portion of the valley. Before meeting the Bagmati river at Teku, the tributaries that join the Bishnumati river are the Sangla Khola, the Mahadev Khola, the Samakhusi and the Tribeni (Manmati). All these rivers have been utilised basically for drinking water supply for the valley population. Before entering the ring road in the north of Kathmandu city, this river is less affected by population. But however in the city it is intensively used for different purposes. Its catchment area at Budhanilkantha is about 5 km^2 and the discharge ranges from 0.8 m^3/s to 0.9 m^3/s, with an average of 0.007 m^3/s (HMG/UNDP 1992). The total length of the Bishnumati river from its origin place to Teku Dobhan where it meets with the Bagmati river is about 17.3 kms.

(iii) The Manohara river

Originating at the Nagarkot ridge at an elevation of about 2,000 meters in the east of the valley, the Manohara river has a total length of 24 kilometres up to Koteswor at which it meets the Bagmati river. It has a drainage area of about 75 km^2. Mixing with it as tributaries are the Salinadi, the Manamati and the Indrayani (also known as the Mahadev). The Manohara river together with these tributaries then flows in a south westerly direction and at Imadol, the Hanumante (its source stream is also known as the Mahadev and as the Tabyakhusi in Bhaktapur city) with its tributaries: the Godavari and the Kodku mixes with it before joining the Bagmati. The Manamati and the Indrayani and the Salinadiflow from the north-east to the south. The Hanumante flows from the east to the west while the Godavari has a south-north direction flow. The Kodku flows from the south to the north and joins the Manohara at Imadol. Drinking water supplies and irrigation are two important uses of these rivers. The Hanumante flows through the south of Bhaktapur city towards west where it has been used intensively by the city people.

(iv) The Nakhu river

When the Nallu and the Lele streams join each other at the Tikabhairav confluence point they form one river called the ***Nakhu*** river. This river originating at the Bhardeu ridge in the south flows to the north and turns to the west to join the Bagmati river at the Nakhu jail. Its total length from its origin point to the Bagmati river meeting point at Nakhu jail is measured about 17.6 kilometres but within the valley it has only 9.4 kilometres. Its catchment area at the Tikabhairav point which lies outside of the valley is about 42 km^2 where the maximum and minimum discharges have been recorded at 3.9 and 0.15 m^3/s (HMG/ UNDP 1992). Its water is being used primarily for irrigation. Expansion of new urban settlement development has taken place around the Nakhu jail area just at the outer limit of Patan city.

(v) The Balkhu Khola

The Balkhu Khola originates near the Bad *bhanjyang* at an altitude of 1,700 metres about 10 kms west of Kathmandu city. This stream with a total length of 16.8 kilometres flows from the west to the east to join the Bagmati river at the Kuleswor ring road. Its tributaries are the Matatirtha Khola, the Dharapani Khola (seasonal) and the Sataganne. The Balkhu river system is estimated to have 37 km^2 catchment area at the dam site (HMG/UNDP 1992). New urban developments have taken place along this river though it flows through peripheral of Kathmandu city towards the east and then southward to meet the Bagmati river.

(vi) The Bosan Khola

The Bosan Khola with the length of 6.1 kilometres is the smallest one. Originating at Pokhari *bhanjyang* at the elevation of 1,800 metres in the south-west of the valley, it independently meets with the Bagmati river. It is the last perennial tributary of the Bagmati river before leaving the Kathmandu valley.

5.1.2 The Bagmati River Order System

The drainage basin of the Bagmati river system is analysed in terms of drainage density and drainage network. The drainage density is obtained by dividing the total length of all perennial channels in the valley basin (ΣL) by the drainage basin area (Ad). The formula (Goudie et. al 1994) is:

$$Dd = \frac{\sum L}{Ad}$$

The value obtained from this equation is that the higher the drainage density (Dd) the faster the hydrograph rise and the greater the peak discharge. The high density value means a fine drainage basin and low value means a coarse basin. The drainage basin characteristics such as rock type, soil, topographic feature, vegetation and land use in general are important to influence the drainage density.

In this study, the Bagmati drainage basin is defined by considering the surrounding ridge line of the Kathmandu valley from which all streams flow into the valley basin. The area of the valley basin is 656 km². Based on the topographic map of Kathmandu valley at the scale 1:50,000 (Schneider 1989), the length of each of the streams of the Bagmati river system considered in this study has been obtained. As there was no information on the length of the streams, a rule of thumb technique was used. Under this method, the thread measurement technique was employed to measure the curvilinear length of each stream from its origin point to meeting point and measured the total thread length by ruler and converted it into total length with reference to the given map scale.

Another component of drainage basin is drainage network. It is the system of river and stream channels in a basin which can be measured in terms of stream order and drainage density of that basin. This quantitative measure is used to describe the type of drainage pattern of the study region. According to channel process, the drainage network of the Bagmati basin is regarded as composed of basin perennial and ephemeral streams. The stream order of the Bagmati river system in the Kathmandu valley is based on river drainage shown in Figure 5-1.

The river morphology and ecology changes with respect to the order, this change could be assessed more precisely with the help of river order system (Wimmer and Moog 1994). According to Strahler's river order principle (Strahler 1957), the streams are classified into different order. The smallest, permanently flowing stream is termed as low-order which have no tributaries and high order streams or rivers have tributaries of intermediate streams. The small streams are first-order streams. The union of two streams of order n creates a stream order $n+1$. Thus when two first-order streams join they become a single second-order stream. No increase in order occurs if more lower-order streams join a higher-order stream. Two second-order streams joined create a third-order stream and so on. So, streams increase in order and size as they flow downward. As computed, the Bagmati River reaches fourth order in the valley basin or before it reaches the Tarai plain.

Table 5.2: The Bagmati river network analysis: number and length of channels of different order

Order	No. of stream	Average length (km.)	Total length (km.)
1	80	1.6	133.3
2	35	2.8	98.9
3	9	4.7	42.8
4	1	6.6	6.6

Note: This analysis is based on field survey and Kathmandu valley map (Schnieder 1989). It is to be noted that in first order not all small streams are included and hence the number of streams in such mountain source region seems to be low or their average length show relatively larger value.

The drainage density, Dd, for the Kathmandu valley basin is 0.387 per square kilometre.[3] This value for the valley as a whole indicates medium to fine density (Goudie et. al 1994). With the reticulated small streams over the surrounding hills of the source region, the Bagmati drainage pattern seems to be dendritic but in the valley basin makes a centripetal drainage pattern. Table 5.2 provides information on the stream network of the Bagmati river system. This analysis is

[3] The value is obtained by using the above given equation where $\Sigma L = 253.9$ and $Ad = 656$.

sought in order to describe a major stream link in a drainage network and one can readily get an identification of the discharge from this network.

The stream network analysis shows that in the Bagmati river system, the Manohara stream system with its many tributaries and different levels as well as its relatively longer travel distance reaches the highest stream order, i.e. fourth order before joining the Bagmati river at the point between Koteswor and Imadol in the centre of the valley basin. For instance, the stream *Salinadi* is defined as second order when it passes through the south of Sankhu and likewise the stream *Indrayani* is defined as second order before reaching the locality Brahmakhel. The union of these two second order streams at Brahmkhel creates third order stream and known it as the *Manohara* river. The first order stream *Manmati* joins the *Salinadi* downward of Sankhu but does not affect to increase its order. The *Manohara* and the third order *Hanumante* join each other at the locality Imadol to create fourth order stream and still it is called as *Manohara*. At Sankhmul Dovan a few hundred metres north of Patan city or south of Minbhawan the *Bagmati* and the *Manohara* mix each other and the river is known as *Bagmati* as fourth order. The streams *Bishnumati, Balkhu* and *Godavari* can be defined as third order while the streams *Dhobi, Nakhu* and *Kodku* as second order.

5.2 Aesthetic Value of Rivers

Public perception is often related to aesthetic value of river water quality which is generally measured in terms of taste, odour, colour and clarity. Depending upon these four factors, people decide whether to use water for drinking or other domestic purposes.

For Nepalese people, river has three functional importance. First, river water is widely used for drinking, bathing and washing. Second, the river bank is the site for temple and rest house for pilgrims and devotees of Hindu religion and trees surrounding them are preserved. These sites are often used as picnic spots where gatherings of large many people occur during occasional festivities. Third, the river banks are the places for cremation. With these importance, people are used to mean river as holy place and hence preserving its aesthetic value.

Besides these traditional social and cultural importance, most rivers are now being used for irrigation and electricity in general, and drinking water supply for the urban people in particular. Recently, with the growth of urban population, rivers are being used for different purposes, such as waste disposal, sewage and industrial effluents and as a result, the traditionally preserved aesthetic value in terms of social and cultural, and ecological importance of the rivers particularly in the large urban areas of Nepal is on the decline. Following observations are made with regard to the process of change in aesthetic value of the rivers in Kathmandu valley based on the information obtained from field Protocol of the river sample sites.

First, the spring sources called *kunds*, which are located on the hill slope, feed as continuous supply of water to the rivers in the valley. *Kunds* are protected sources and maintained as one of the important drinking water supply sources for the local inhabitants as well as for the urban dwellers of the valley. There is no direct access of public to these sources. But however, stone spouts are made coming out from the sources for public use such as drinking and bathing. These are also the most important holy places, as they belong to the sites of gods and goddesses and often used for religious festivities and picnics. Trees around the sources are protected and therefore there is a continuous supply of water throughout the year. They own a great aesthetic value in terms of social and cultural importance which is maintained still today.

Second, rivers and streams are holy places as temples of gods and goddesses, and pilgrim houses for religious devotees are erected on their banks or at the confluence points of two or more rivers. During the religious festivities of great importance, crowds of pilgrims are gathered around the temples to offer their due respect to the gods and goddesses. Several places along the most of the valley rivers are considered as holy places of high importance which has been a great help to preserve the aesthetic value of the rivers where they are located.

Third, the river sides are the cremation places. All human dead bodies are burnt at the side of the river according to the Hindu religious tradition.

Fourth, the river water has been used for canal irrigation through the construction of check dam in the river. For example, about 12,000 hectares of farmland in the valley have been irrigated through the water of the rivers (HMG/UNDP 1992). Another important use of the rivers is the drinking water supply for the valley people. Almost all the valley's major rivers have been tapped for drinking water supply. About 458.93 million litres of water have been produced monthly for drinking water supply in the valley (NWSC 1995). These human interference's to the rivers have caused an enormous impact to bring about change in the biotic environment of the rivers. These activities demand the conservation of watershed in the valley. There are two watershed projects (the Bagmati Watershed and the Shivapuri Watershed) with regard to this, however.

Fifth, the recent activity that directly associated with the urban development is the quarrying of sands and stones out from the banks and beds of the streams. Several temporary check dams in the river courses are built so that the rivers allow to deposit the suspended sand particles on their bed, and hence the extraction of sands by men. The collection of stones and pebbles from the banks and beds particularly of the streams in the periphery of the valley cities is for the stone crushing factories to meet the growing demand of the urban development. Many heavy vehicles run along their courses to transport sand and gravel particularly during the dry season when the level of the stream water is low. These are principal factors for the devastation of river banks, thus causing the bank erosion and the loss of soils. These also enable the rivers to cut their banks and make wide particularly during the rainy season, causing enormous flood over the farm fields, and damaging the river side roads and bridges. Moreover, the rivers and streams in the outskirts of the cities are often the places for cleaning vehicles. All these activities are responsible for making the river water turbid and polluted.

Lastly, at present the river courses have been the sites for urban solid waste disposals and urban sewage. These recent developments are due mainly to the rapid growth of urban population in the valley cities. These have been a serious concern among the planners, policy makers, environmentalists and city-dwellers. Here, a brief overview of the traditional practice of solid waste and human waste management is outlined.

Indeed, the concept of waste management planning is fairly new to Nepal. Only since the 1980s, the modern waste management system began in the valley cities of Bhaktapur, Kathmandu and Lalitpur. This system through the combined effort of the Solid Waste Management and Resource Mobilisation Centre (SWMRMC) and the valley's three municipalities worked for the collection of solid wastes of the cities.

Before the introduction of new waste collection system, the traditional system of waste disposals practised by the Newar inhabitants of the valley cities for centuries was that they used to deposit the wastes at three major sites, such as (a) dumping place outside of the dwellings, called *chwaasa*, (b) pit disposal on the compound, or *saaga*, and (c) pit disposal under the stairs inside the house on the ground floor called *nauga* (figure 5.2) system and all the waste were disposed haphazardly outside the house. Biodegradable wastes were often used as compost or thrown in *saaga* on the compound. This *saaga* was emptied three or four times a year, or when it was full and the contents were used as fertiliser (IUCN 1992). Likewise, the human waste produced by the city-dwellers was collected by a particular scheduled caste or sometimes by farmers to be used as organic fertiliser, since there was no practice of using chemical fertiliser. It means that there was somewhat a balance relationship between the amount of organic waste production and its demand as fertiliser in agricultural use. Thus, the farming system was entirely based on this organic waste and therefore was the single most consumer of the wastes. This ecologically maintained system of farmland-organic waste relationship got to be diminished due to rapid growth of the urban population in the valley. As a result, the demand for land for housing increased, causing decrease in the farmland. Meanwhile, the use of inorganic fertilisers

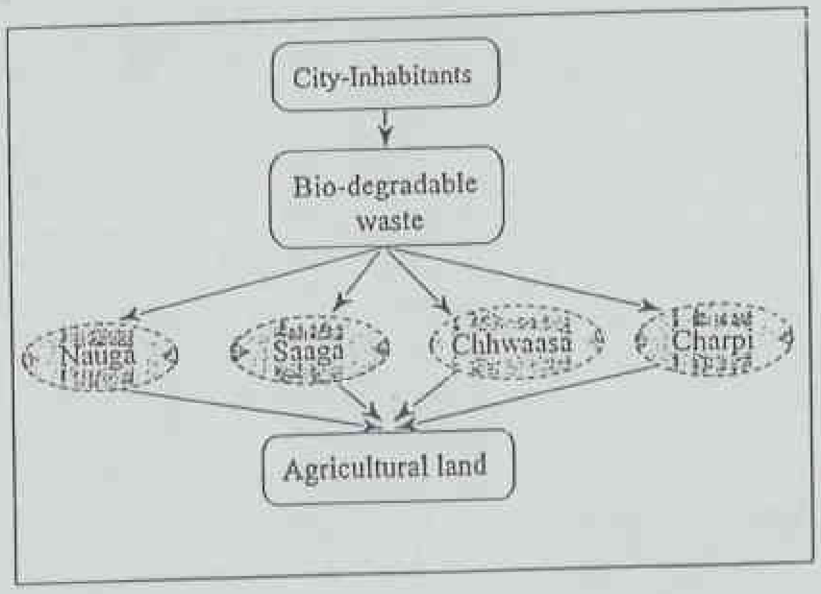


Figure 5-2: Peoples' traditional practice of solid and human wastes in Kathmandu valley

has been introduced in the farming system and because of modernisation, the traditional occupation of collecting human waste carried on by the occupational caste virtually ended. All these reasons caused to a drastic decrease in the demand of domestically produced organic fertiliser by the traditional agricultural system. This on the other hand made to create a system by which the human waste has to be flowed directly into river through sewerage network system. The increase of urban population also multiplied the amount of solid waste disposals. The habit that the solid wastes dumped outside the house on communally recognised places, dumped inside the courtyard or at open places, street corners or river banks and the wastes thrown on the street developed by the city dwellers through centuries, which now totalling about 63 percent of all waste generated, have posed a great problem to be collected and managed (UNEP/UNICEF quoted in IUCN 1992). A study showed that not a single ward of Kathmandu city was free from solid waste violation (Manandhar et. al 1987). So, with the increase of urban population in the cities and the increasing amount of refuses generated by urban living, the refuse condition has deteriorated. One of the consequences of the negative effects of uncontrolled waste in the urban environment has been a severe pollution to streams and rivers by run-off from the dump sites. The most obvious environmental damage caused by solid waste and sewerage is aesthetic; the dumping of waste has resulted in unsanitary, unsightly, and odour-producing conditions (Thapa and Ringeltaube quoted in IUCN 1992). Because of lack of awareness, and proper practice and habit of the city-dwellers in throwing the solid wastes generated by them into the already placed waste disposal containers on the one hand, and the inadequately located containers, as well as the lack of adequate dumping sites for the urban waste on the other have caused a serious problem[4] about how to tackle the ever growing solid wastes in the cities.

The above observations show an alarming situation of the level of water quality of the rivers in the valley. The first three social and cultural values point to preserving the aesthetic value of the rivers as holy places. These activities during festivity occasions cause turbid and pollution of the river water which remain however for short time period only and the natural process allows to purify its water. Obviously, the last two activities as associated with the urban development are considered as injurious to the preservation of aesthetic value of the rivers. They are not beneficial for ecological view point as they cause all four factors such as taste, odour, colour and clarity of aesthetic value of the rivers. There is an urgent need to protect aesthetic value of the rivers by taking measures against those undesirable activities so as to make the urban living environmentally a more desirable and attractive. The first two activities which directly concern with the preservation of aesthetic value of the rivers need to be sustained and backed by a strong commitment.

4 There seemed to have occurred discontent among the local people occasionally against the dumping of the urban solid wastes in their own area.

6 RIVER WATER QUALITY ANALYSIS THROUGH FIELD OBSERVATION

6.1 Field Observational Analysis

6.1.1 The Bagmati river profile region

Considering the location of the sample sites (Figure 6-1), the Bagmati river system has been divided into three major regions (Table 6.1). They are headwater, valley segment and lower reach. Each of these regions is defined as below.

Table 6.1: Profile regions of the Bagmati river system

Region	No. of sample sites
Headwater region	24
Upper reach	*12*
Lower reach	*12*
Valley segment	53
Upper reach	*19*
Middle reach	*24*
Lower reach	*10*
Lower reach	2
Total	79

Source: Field survey (1995-96).

The headwater region (HW) includes hill slope with an elevation of approximately ≥1360 meters, extending to the downslope from where the valley floor begins (Figure 6-2). This includes all the sample sites located on the surrounding hills of the valley and those along the river outside of the valley but come to meet the Bagmati river in the valley. This gives a total of 24 sample sites. The headwater region is further divided into two sections, namely upper reach section (HWU) and lower reach section (HWL) simply on the basis of the drainage feature. The valley segment (VS) of the Bagmati river system lies completely in the valley floor basin and includes a total of 53 sample sites. Taking account of the river flowing system, the valley segment is further broken down into three sub-segments such as upper valley segment (VSU), middle valley segment (VSM) and lower valley segment (VSL). The upper valley segment extends approximately from the adjoining bottom line of the surrounding hills to the outer city region which is arbitrarily defined by the ring road in case of Kathmandu and Lalitpur cities, and area surrounding Bhaktapur city. This segment includes the sample sites along the rivers before reaching the city area in the north, north-east and east of the valley.

Table 6.2: Distribution of sample sites by stream/river according to location

Stream	HWU	HWL	VRU	VRM	VRL	LW	Total
Bagmati	5	1	5	7	5	2	25
Balkhu	1	1	-	-	3	-	5
Bishnumati	1	1	4	5	-	-	11
Dhobikhola	1	3	-	4	-	-	8
Godavari	3	3	2	-	-	-	8
Hanumante	1	1	-	2	-	-	4
Kodku	-	-	4	-	-	-	4
Manohara	-	-	4	1	-	-	5
Nakhu	-	2	-	-	2	-	4
Tukucha	-	-	-	5	-	-	5
Total	12	8	13	11	7	14	79

Source: Field survey (1995-1996)

There are altogether 19 sample sites. The middle segment lies basically within the urban core including all three cities' outer boundaries. A total of 24 sample sites fall in this segment. The lower valley segment encompasses the area lying outside the ring road in the south and south west of the valley. In this section, the tributaries join the Bagmati outside the ring road but not flowing through the urban core and the Bagmati together with its tributaries flow towards south. There are 10 sample sites in this section. The lower reach (LR) of the Bagmati river system encompasses the area outside the valley and lies completely in the flat plain of the Tarai region. Two sample sites are located in this section. Table 8 gives number of sample sites by stream or river according to river profile region.

The Bagmati river system has also been categorised into different sub-river systems such as (1) the Bagmati sub-system including the upper Bagmati itself, Nagmati, Syalmati, Bosan, and Chalti; (2) the Bishnumati sub-system including the Bishnumati itself, Mahadev, Manamati, Sangla and Samakhusi; (3) the Balkhu comprising the Balkhu itself, Dharapani and Indrawati; (4) the Dhobikhola composing of Phedi and Mahadev; (5) the Manohara consisting of Bhagerikhola, Hanumante, Indrayani, Manamati, and Salinadi; (6) the Godavari; (7) the Kodku; (8) the Nakhu making up of Lele and Nallu; and (9) the Tukucha. Four *kunds* such as Gauri, Godavari, Matatirth and Naudhara are separated from the river system analysis. These sub-river systems are made for analysis purpose.

6.1.2 Description of the sample sites' characteristics

The description of the sample sites' characteristics is based on the information gathered from the field protocol form (Appendix. A). A detailed description of each site *in' situ* in tabular form is depicted in appendix B, D-G. Based on the general similar features of the sample sites, following three broad groups are obtained. They are such as headwater region, valley basin and lower reach and their distinctive characteristic features are described on the basis of the observation made during the post-rainy season. However, these characteristic features are compared with those of the sample sites observed during the pre-monsoon season.

Figure 6-1: Location of sample sites

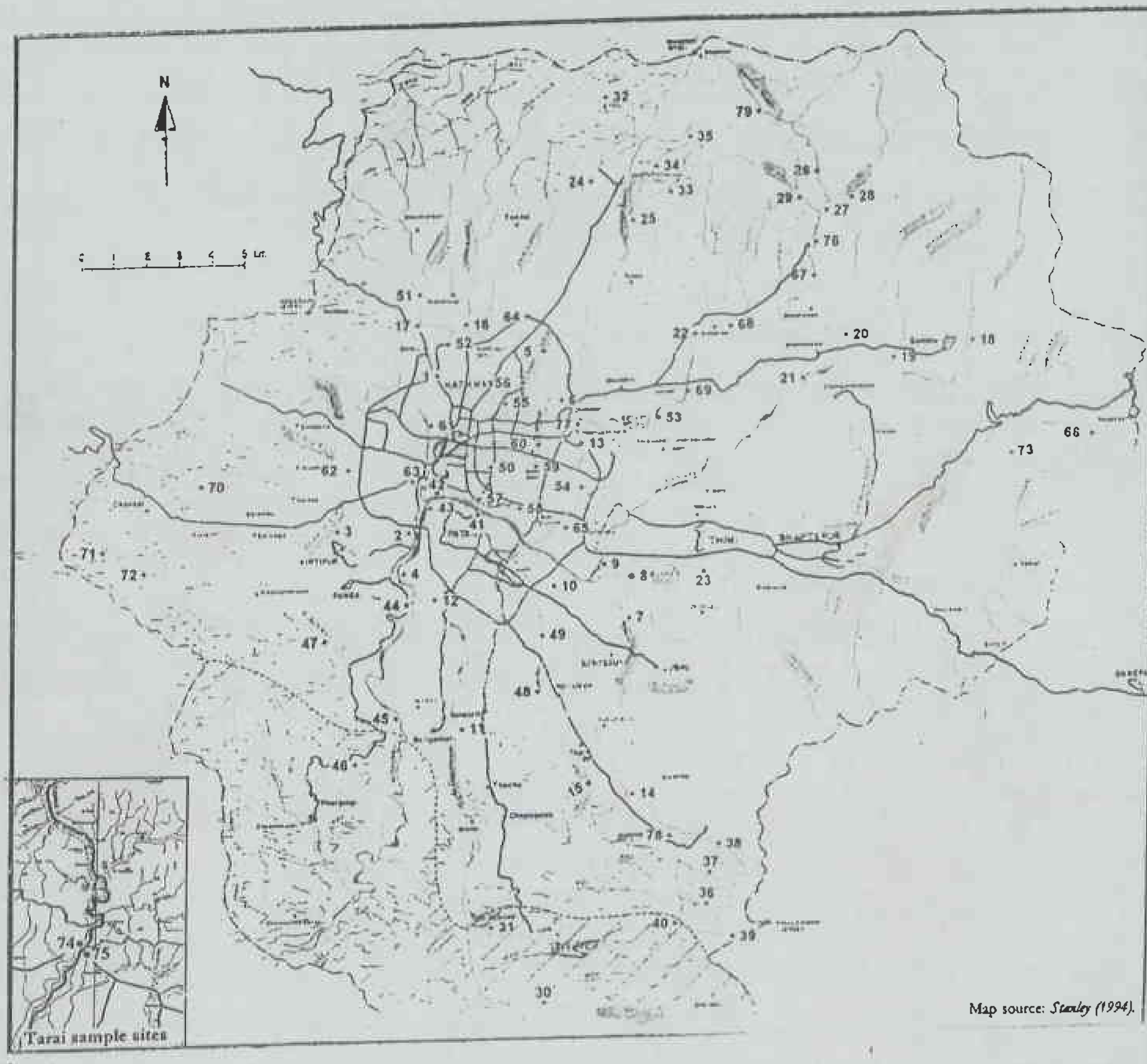
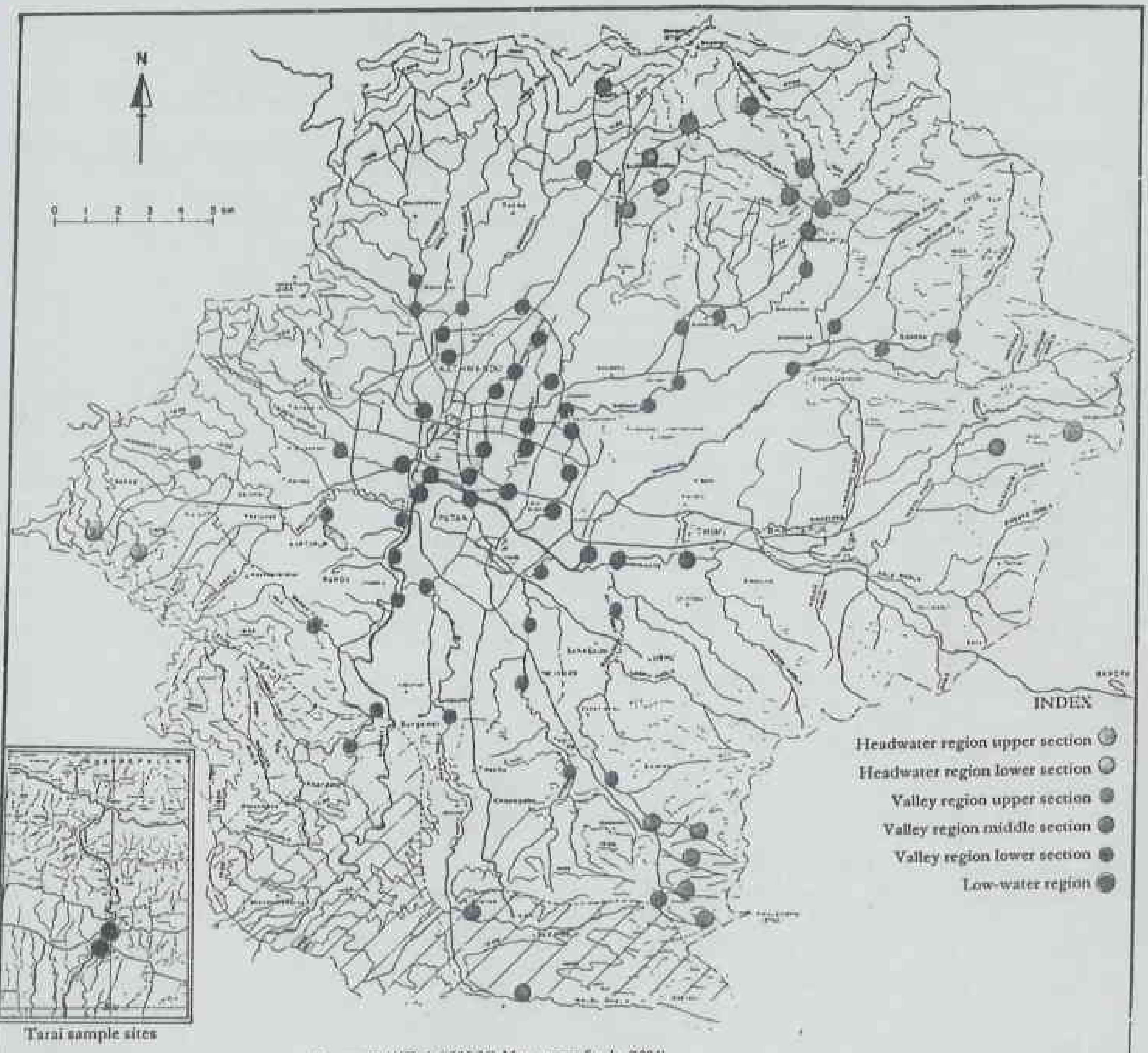


Figure 6-2: River profile region



Source: *Field Work (1995-96)*; Map source: *Stanley (1994)*.

(i) The headwater region

The headwater region as described earlier lies completely along the hill slope with elevation above 1360 meters. On the basis of stream drainage system, the headwater region is further divided into two sections: upper reach and lower reach. The upper reach consists of the sample sites related to the streams before meeting each other in the upper hill slope and *kunds* (springs) and the lower reach covers sample sites located along the streams which meet the main river in the lower hill slope. Of 24 total sample sites in the headwater region, half including sample site numbers 26, 27, 28, 29, 32, 35, 36, 37, 39, 66, 71 and 79 lie in the upper reach and the other half such as the sample site numbers 24, 25, 30, 31, 33, 34, 38, 40, 71, 73, 76 and 78 fall in the lower reach. The elevation of the upper reach sample sites ranges from 1560 to 2000 meters, i.e. 440 meters variation within relatively shorter travel distance. As all these sites are located on the Mahabharat hill slope, their geological structure as described earlier is characterised by meta-sedimentary and metamorphic rocks formed between Precambrian and Tertiary age. This section includes all four sample *kunds* such as Gaurikund (#37), Godavarikund (#36), Matatirtha (#71), and Naudhara (#39). However only a little information on these *kunds* was gathered due to restriction on access to them or simply they are completely man made or protected drinking water sources or sacred places.

During sample collection, the weather at all headwater sample sites was sunny, but the air temperature among them varied ranging from 14°c to 18°c. There is no clear distinction however in air temperature recorded between the upper and lower reach sample sites; for the former with temperature ranging from 15°C to 18°C and for the latter with 14°C to 18°C. The temperature recording at the sample sites was not at the same time but taken between 11:00 and 16:30 hours. As the streams flow through the mountain terrain, their average speed is generally characterised by rapid and turbulent, ranging from 1.1 m/s to 0.4 m/s depending straightway on the degree of terrain slope and the magnitude of water volume but inversely with the width of bank channel. The Bagmati, being the largest river, recorded the highest velocity of 1.1 m/s for its sample site Sundarimai, whereas the Nagmati, a tributary to the Bagmati only 0.4 m/s. The velocity of Mahadev Khola, also known as Tabyakhusi in Bhaktapur city, recorded 1 m/s. As the streams flow downwards, their velocity decreases, even though they receive additional water from their tributaries. The lower reach sites recorded velocity ranging from 1 m/s to 0.2 m/s. The site (#38) at the Bhageri Khola, a small stream, tributary to the Godavari with minimum of 2 meters width recorded 1 m/s, the highest velocity, while three sites such as #24, #25 and #40 along the Bishnumati and the Dhobi Khola recorded the lowest velocity with 0.2 m/s. In the latter case, besides natural factor such as gentler slope, human influence seemed to be an important factor to affect the velocity of flow. Household wastes thrown by man were observed at some of these sites, affecting the velocity of the streams. The headwater region sample sites recorded medium level of water as measured with respect to the baneful state of the current bank channel, except the *Kunds* which found to have maintained more or less the constant level. The physical components of the river are associated with the type of rock structure through which they are flowing. The physiography of the Mahabharat hill of the valley is made up of phyilites, quartzite, siltstone, sandstone, schist and marble (HMG/ICIMOD/ CDG/UNEP 1994) and hence the bank structures of the streams are hard to semi-hard with almost vertical or very steep to slight slanting slope. The rivers are more or less straight type with stable channel but unstable river bed. Their banks at this young stage are found well defined and hence streams flows are channelized. Minor incision seems to have occurred in some places, because of relatively soft rock structure. Except *Kunds*, which are made up of stone by man, all other streams consist of natural bank. In case of the streams, of which water is trapped for drinking purpose, the bank structures are made of stone or cemented wall in some areas along their bank. The stream width, depending on the stream size and terrain, ranges from a maximum of 40 meters to a minimum of 11 meters at Sundarimai of the Bagmati. Other small streams show comparatively smaller bank width with less than 15 meters at maximum and 1 meter at minimum. Similarly, the depth of the stream also depends upon the stream size and bed rock structure. The streams at this stage act primarily to erode the bed rock relative to the channel cutting through which they are flowing. The Bagmati at Sundarimai site has higher depth with maximum of 1.5 meters to minimum of 0.5 meter. Other streams have depth less than 1 meter at maximum and 0.1 meter at minimum. However, there is a wide range of local variation in width, depth and velocity among the sample sites in the headwater region. The headwater or upland region is the sediment production zone. The streams are characterised by few in number and short distances. Their channel bed material consists basically of boulders, coarse gravel, and rock outcrops. As observed, the estimated proportion of boulder constituted 10 to 60 percent and with more or less similar proportion between cobbler and large pebble ranging from 15 to 30 percent. Other materials such as small pebble and gravel together occupied the smaller proportion. Transparency, which is dependent on stream load and bed rock, ranges from almost clear water depth to medium, i.e. over 20 centimetres. The colour of the stream water particularly in the upper region is clear sky blue to light green without the presence of any odour.

The streams are relatively narrow width. It means that riparian vegetation has shaded more of the streams. As stated above, this zone is the domination of broad leaf-type trees, from over 50 to as much as 80 percent on each site *in situ* is found to be covered with over hanging trees. In case of *Kunds*, almost all of the water sources is covered with tree shade. This means water temperature is relatively cool and stable ranging from 7° C. to 16° C for the sites. The upper sites show temperature ranging from 7°C to 13°C and the lower region sites lie above 13°C. Because of more tree shading leaves and small logs are found entering into the streams in the upper region. Shading and scour from coarse sediments have restricted the growth of algae and other plants. Thus, organic matter from outside the stream appears to supply most of the food for fungi, bacteria, macroinvertebrates and others with a varying magnitude of proportion. Dominant animals found *in situ* in the headwater sites are Plecotera, Ephemeropera, Trichoptera, etc.

There are observed scattered human settlements and their influence on and around the streams is sporadic and less magnitude, which are mostly related to terrace farming and livestock grazing. In the lower part, land has been turned into terrace farming. Domestic and agricultural effluents are found in the streams at lower region. The stream water is found to be used basically for domestic use (drinking, bathing, washing dishes and clothes). Much of the water volume of most of the streams is being trapped in reservoirs for urban drinking water supply. In addition to this river water has been used for fish pond farming at Godavari and hydropower generation at Sudarijal. At the lower elevation pebble collection, for example along the Naldu river outside the valley is found at greater extent for stone crushing factory. and waste deposition has also been noted at some sites at this section The sites of the upper region lie basically in water quality class I and those of the lower region in class I-II.

(ii) The valley basin

The streams in the valley basin enter into maturity state. The general characteristics of the valley streams are that the flow has increased, side cutting is more active than bed cutting thus widening bank channels, and they act as to transport sediment from bank erosion and from upstream supplies. The bed materials are composed of fine to coarse sediments, mostly of sand and silt. During the rainy season, deposition of sediment occurs because of heavy suspended sediment load relative to velocity and bank width.

The streams in the valley floor are highly variable physical characteristics. As though, depth and width is related to the amount of water flowing through it, variation in channel forms such as pools and riffles, wide meandering loops, sandbars, etc. creates variation in water width and depth. As the slope of the valley floor is gently towards the centre and the streams flow centripetally towards it, variation in bank width, depth and velocity has occurred among the sample sites in all sections of the valley streams. The elevation of the upper section sample sites ranges from 1295 to 1432 meters, of the middle section from 1200-1360 metres, and of the lower section from 1260 to 1365 metres. The elevation variation between minimum and maximum of the sites is 232 meters over relatively larger travel distance. The stream velocity with 0.11 m/s at the Imadol site along the Hanumante is very low while it with 1.5 m/s at the Chobhar along the Bagmati is highest. Thus the general pattern of velocity is that it is lower in the core city area of the middle section than in the upper section, but increases as the Bagmati together with its tributaries flow towards the south-west at the Chobhar gorge. The middle and the upper sections of the major streams in the valley are the most influenced by human activities. Household wastes, sewage and sand quarrying have frequently been observed which have greatly affected the speed and the aquatic vegetation of the streams. Air temperature ranges from 16°C to 24°C, depending on the altitude, vegetation cover and weather condition at the sites. In the upper section, the streams are seen to be somewhat straight, in the middle section they are meandering, and then again slightly straight in the lower section because of slope gradient and increased water volume. On the whole, the water level seems to be medium to low. The Bagmati has made its maximum width at Tripureswor-Teku area with over 250 meters while at the Chobhar with mere about 15 meters. The width of the Samakhusi and the Tukucha has greatly reduced and continues to decline because of increasing human encroachment on their banks. These streams now have 3-4 meters width at maximum. The bank channels of the Bagmati and the Bishnumati in the middle section have been greatly degraded because of sand quarrying, vehicle running with sand load, garbage deposition and farmland expansion. The bank structure is earthy and easily erodable in most cases. Only in some places along the Bagmati where cremation is performed and where pilgrim houses are made, the bank is made of stone staircase. The channel type associated with the Bagmati and the Bishnumati is terrace. The bed material particularly of large streams or rivers including the Bagmati, the Manohara, the Bishnumati is composed primarily of sand and silt. The Bagmati produces probably the largest sand amount in the valley. In these large streams, sand is estimated to be 80 percent of their bed material composition. Small pebble and gravel are seen predominantly in the small stream beds as well as in the large rivers particularly in the upper section.

There has occurred frequent natural impacts such as flooding and bank erosion by the rivers, but more dominant influence is the anthropogenic. Sand quarrying, pebble collection, speed breaker, embankment, etc., have been observed in several pockets in the upper and middle sections. Because of turbidity, transparency is very low, and water colour is greyish and yellowish in most cases. Smell is of faecal, sulphur and rotten. Patches of reductive feature have been seen in both cases of underneath of pebble and gravel, and mixing up with sand and silt in most cases.

Though the climatic condition of the valley basin permits to grow broad leaf trees, because of unprotection of the banks of the rivers and streams in most cases, there is virtually no tree shading over them. Assume that the mature stream has highly variable physical characteristics such as coarse substratum, diversity in channel, diversity in nutrient sources, variable discharge and wide range of temperature which favour a diverse fauna since the range of conditions encompass the optimum conditions for a large number of species. However, this situation does not exist in the valley streams despite they flow through mature stage. There is enormous impact of human activities on riverine ecology causing increasing organic and chemical pollution in the stream water. This together with increased turbidity restrict the growth of aquatic plants and therefore animals subsisting on vegetation are rare or virtually absent particularly in the middle section. However vegetation coverage of macrophyte, filamentous algae, fungus and other algae does exist in some proportion in the small steams in the upper and the lower sections and hence there are animals relying on those aquatic flora.

The water is used basically for agriculture, domestic and building construction. The middle section receives mainly the domestic and organic effluents while the upper and the lower sections receive basically agricultural and industrial effluents. The dominant animals found at the sample sites include Oligochaeta, Chironomidia, etc. Most of the sample sites fall in the water quality classes of III-IV and IV. However, the Bagmati in the downward or the lower section is able to recover its quality to some extent. This self purification of the Bagmati is not only because of mechanical and oxidation processes but also due to mixing up of relatively fresh water streams with it in the lower section.

(iii) The Lower Reach

After crossing the valley, the Bagmati river with its tributaries go back once again to the primary stage over the lower Mahabharat and the Chure hills in the south. Unlike in the source region, however the river with larger water volume cuts deeply its bed making relatively big channel depth between hill ranges and in some places deep gorges. Over the flat plain Tarai region after crossing the low height Chure hills, the Bagmati river is characterised by broad or wider channel, deeply filled with alluvium and marked with the evidence of frequent channel changes and meandering.

The Bagmati regains its maturity state in the Tarai plain which is described as an abandoned or former flood plain of alluvial deposit. Here, the bed materials are overwhelmingly made up of finer sediments such as sand, silt and clay. However, because of streams originating from the Chure hills, they bring coarse materials such as small pebble, gravel together with sand and silt to mix with the Bagmati. Thus small proportion of these coarse materials seems to be existed in the bed material composition. The water discharge is relatively stable. Deposition of finer sediments occurs, because of heavy suspended sediment load with respect to velocity and bank width. The river is characterised by much wider width, relatively low velocity and constant high temperature. The increased turbidity however restricts the growth of aquatic plants. The sample sites lie at elevation of about 260 meters. The water is basically used for agriculture. Other uses of water include domestic purpose, washing, bathing, etc. There is agricultural effluent into the river. Cremation is also performed along the river side. Agricultural land dominates in the land use patterns on both sides of the river. The river bank is made up of earth and water colour is blue and light grey with medium transparency. Dominant animals are Ephemeropera, Simuliidae, Odonata and Chironomidae. The sample sites lie in the water quality classes of II and II-III.

6.1.3 Description of river water quality classes (saprobic levels) due to organic pollution

The basis of water quality assesement in field is on the saprobic water quality model (Moog 1991). The charactiristic of each class is described as follows:

Water quality class I

Saprobity level: Oligosaprobic
Degree of pollution: no to very slight pollution
Water quality mapping color: blue

This saprobity level represents the clean water state. The waters are well oxygenated and of high purity. The trophic interactions are characterized by a balanced relationsship between producers, consumers and decomposers. Productive processes prevail the sum of reductive processes. The community of organisms is poor in individuals but there is a variety of species which show a small biomass and small bioactivity.

The water is suitable for all uses, especially drinking water supply, fishery, bathing and recreation.

1) clean water with only very little amount of organic matter and only very little concentration of nutrients.
2) clear water with exception of glacier feeded brooks (turbidity caused by weathering processes)
3) waters are well oxygenated with oxygen saturation about 100%
4) no reduction phenomena exist at all. Even fine sediments (silt, mud and sand) are of light or brownish colour and of high minerogenic content
5) substrate cover mainly consists of algae (mainly diatoms, specific blue-greens and red algae) whereas filamentous algae are not very abundant (exception: specific red algae), mosses (several species), planarians and insect larvae (in medium and higher reaches several species of Plecoptera occur). Net spinning Trichoptera extremly scarce.
6) highly diverse insecta fauna of only few specimens
7) only few chironomids of the subfamilies Diamesinae and Orthocladiinae are found, the number may exceed under the condition when the substrate is covered by clean water algae specific to that type.
8) Worms are mainly restricted to planarians and Lumbriculidae (mainly Stylodrilus) and Haplotaxidae.
9) fish fauna in Europe and North American continent is dominated by salmonids
10) River type: Springs, spring brooks, summer cold upper courses.

Chemical water quality characteristic of Central European rivers

O_2-depletion	O_2-saturation	BOD_5 (mg O_2/l)	COD mg/l	PO4-P (µg/l)	NH_4-N (µg/l)
95-100	100-103	0-1	1-3	<35	<80

Water quality class I-II

Saprobity level: Oligosaprobic to ß-mesosaprobic
Degree of pollution: little pollution
Water quality maping color: blue-green

This saprobity level represents a water state with only moderate pollution. The trophic interactions are characterized by a balanced relationsship between producers, consumers and decomposers. Productive processes prevail the sum of reductive processes. The community of organisms shows a variety of species, the abundances increase.

The water is suitable for all uses, especially drinking water supply for native people (acustomed to use), fishery, bathing and recreation.

1) clean water with only little amount of organic matter and only little concentration of nutrients.
2) clear water with exception of glacier feeded brooks (turbidity caused by weathering processes)
3) oxygen saturation about 100%
4) No reduction phenomenon exist at all. Even fine sediments (silt, mud and sand) are of light or brownish colour and of high mineralogic contents.
5) Substrate cover mainly consists of algae (mainly diatoms, specific blue-greens and green algae, and red algae) whereas filamentous algae are not very abundant (exception: specific red algae),

mosses (several species), planarians and insect larvae (Plecoptera, Ephemeroptera, Trichoptera, Water-beetles). Net-spinning Trichoptera may occur.
6) Highly diverse insecta fauna of medium abundance.
7) Few chironomids of the subfamilies Diamesinae and Orthocladiinae are found, the number may exceed under the condition when the substrate is covered by clean water algae specific to that type.
8) Worms are mainly restricted to planarians and Lumbriculidae (mainly Stylodrilus) and Haplotaxidae.
9) Fish fauna ?
10) River type: Springs, spring brooks, summer cold upper and medium courses.

Chemical water quality characteristic of Central European rivers

O_2-depletion	O_2-saturation	BOD_5	COD	total P	NH_4N
85-95	103-110	0,5-1,5			

Water quality class II

Saprobity level: ß-mesosaprobic
Degree of pollution: moderate pollution
Water quality mapping color: green

The ß-mesosaprobic level indicates waters with moderate pollution load and good nutrient conditions. The relationship between producers, consumers and decomposers is balanced, productive processes still prevail. The community of organisms is rich in individuals (abundance, biomass) as well as in species numbers (diversity).

Conditioning for drinking water supply is generally possible for native people (acustomed to use), but in terms of international health standards near the upper limit of the class with advanced expenses for treatment.

1) Moderately polluted water with a higher amount of organic matter and higher concentration of nutrients.
2) Clear water with exception of glacier feeded brooks (turbidity caused by weathering processes) at higher and/or medium river sections. In lowland rivers suspended solids caused by natural processes may cause a certain turbidity. Turbid waters caused by anthropogenic induced erosion have to be considered as a special affection of the water quality level respectively the self purification capacity.
3) Good oxygen saturation. Oversaturation and depletion may occur respectively.
4) Only little reduction phenomenons may occur in very fine sediments at lentic sites. At the surface, the fine sediments (silt, mud and sand) are brownish or light coloured, in the deeper interstitial zone the sediments are of gray or blackish colour because of oxygen depleting organic matters.
5) Substrate cover consists of algae (all groups), mosses (few species) and macrophytes, filamentous algae may be abundant. The benthic invertebrate fauna consist of many groups (Molluscs, Crustacea, several insect orders). Net-spinning Trichoptera may be numerous at lotic sites, whereas Polycentropodidae may prevail in lower courses with a lower current?
6) Highly diverse insecta fauna of high abundance.
7) Growing abundance and diversity of chironomids: subfamilies Diamesinae and Orthocladiinae prevail in lotic sites, Tanytarsini and Chironomini in lentic sections.
8) Although worms of any family may occur, the oligochaete fauna consists mainly of Lumbriculidae (mainly Stylodrilus) and certain Naididae.
9) Fish fauna ?

10) River type: Moderately polluted brooks, upper and medium courses and unaffected lower courses.

Chemical water quality characteristic of Central European rivers

O_2-depletion	O_2-saturation	BOD_5 (mg O_2/l)	COD mg/l	PO4-P (µg/l)	NH_4-N (µg/l)
70-85	110-125	1-3	5-12	36-81	81-190

Water quality class II-III

Saprobity level: ß-mesosaprobic to alpha-mesosaprobic
Degree of pollution: critical pollution
Water quality mapping color: green-yellow

This transitional zone is characterized by fluctuations of respiratory and assimilatory processes prevailing. The stream may now enter a period of excessive productivity which lasts until he accumulated energy (food) reserves have been dissipated. A relative increase in the abundance of decomposers is noticeable as pollutional state increases. Species number respectively number of taxonomic groups may decline. Number of tolerant species may increase.

Conditioning for drinking water supply may be generally possible for native people (acustomed to use), but in terms of international health standards near or above the upper limit of the class with advanced expenses for treatment. Recreational and/or fiesheries use may be restricted due to oxygen deficits or algal blooms. Impounding the waters of this pollution level may lead to oxygen depletions at the substrates.

1) The water is obviously polluted with a higher amount of organic matter and higher concentration of nutrients.
2) Because of the pollution the water may be turbid locally or at given times. In lowland rivers suspended solids caused by natural processes may additionally cause a certain turbidity.
3) The oxygen content indicates oversaturation and depletion respectively which may causes fish kills or injuries to sensitive species.
4) Putrefactic conditions may occur in very fine sediments at lentic sites. At the surface, the fine sediments of lotic sites (silt, mud and sand) are brownish or light coloured, in the deeper interstitial zone the sediments are of blackish colour because of oxygen depleting organic matters. Black reduction spots (ferrosulfide) may occur beneath the stones (dont confuse with black spots caused by blue-greens).
5) Filamentous algae (e.g. Cladophora) or macrophytes may grow in high abundances, covering a big area of the river channel. Green algae diversity increases compared to class II. Sewage fungi might be seen by naked eyes, but not obviously and only during cold condition.
The Ciliates show the highest diversity and colonies of them can been seen by naked eyes covering substrates and/or animals.
The benthic invertebrate fauna consist only of more or less tolerant groups: Porifera, Bryozoans, Molluscs, Crustacea, Leeches, several insect orders (only a specific number of tolerant Plecoptera and Heptageniidae). Leeches start to prevail. Net-spinning Trichoptera may be numerous.
6) Moderately diverse insecta fauna of high abundance.
7) At specific sites a high abundance of chironomids may occur: besides tolerant species of the subfamilies Diamesinae and Orthocladiinae which prevail in lotic sites, sandy patches may be colonized by Prodiamesinae. In muddy areas Tanytarsini (mainly Micropsectra) and Chironomini (e.g. Polypedilum) prevail.
8) The oligochaete fauna may consist of Lumbriculidae (non Stylodrilus), Naididae may be numerous and certain Tubificidae may occur in remarkable numbers.
9) Fish fauna ?

10) River type: Polluted rivers where the assimilatory processes (production) are not always higher than the reduction processes.

Chemical water quality characteristic of Central European rivers

O_2-depletion	O_2-saturation	BOD_5 (mg O_2/l)	COD mg/l	PO4-P (µg/l)	NH_4-N (µg/l)
50-70	125-150	2,5-6	12-18	82-196	191-470

Water quality class III

Saprobity level: alpha-mesosaprobic
Degree of pollution: heavy pollution, highly polluted water
Water quality mapping color: yellow

The alpha-mesosaprobic level indicates highly pollted waters of which the oxygen budget is loaded up to the limits of aerobic conditions. Tolerant macroforms appear: sometimes mass development of leeches and Asellus.

Also for native people drinking of the pure water may be hazardous for health. Owing to the advanced expenses the conditioning for drinking water supply is uneconomical. Utilization for recreation is by reason of the hygienical state mostly impossible. Utilization for fishery in the better half of the class is possible but endagers the risk of fish kills. The use of industrial water is possible with adquate treatment. Hydropower use cannot be recomended.

1) The water is heavily polluted with a high amount of organic matter and high concentration of nutrients.
2) Because of the pollution the water may be turbid locally or at given times. In lowland rivers suspended solids caused by natural processes may additionally cause a certain turbidity. Due to the effluents a certain water colour may be developed (brownish after paper industries; diverse colors after textile factories, etc.). A peculiar smell may be developed due to the nature of the pollutants (domestic sewage smell, "sweet" smell of breweries waste; poultry industry, etc.).
3) The oxygen content indicates oversaturation and heavy depletion respectively which periodically causes fish kills or injuries to sensitive species.
4) Putrefactic conditions occur in very fine to fine sediments at lentic sites. At the surface, the fine sediments of lotic sites (silt, mud and sand) are muddy, in the deeper interstitial zone the sediments are of blackish colour because of oxygen depleting organic matters which cause septic conditions. Black reduction spots (ferrosulfide) occur beneath the stones and may cover bigger areas.
5) Filamentous algae consist often of Stigeoclonium. Tolerant macrophytes may grow in high abundances, covering a big area of the river channel. Tolerant blue-greens and tolerant diatoms (e.g. Nitzschia palea) may cover bigger areas in lentic zones. Sewage fungi (Sphaerotilus, Fusarium, Leptomitus) visibly grow on hard substrates or cover benthic invertebrates.
The Ciliates show more or less abundant colonies of sessile species (Carchesium, Vorticella) which can been seen by naked eyes covering substrates and/or animals.
The benthic invertebrate fauna consists only of those few groups which are tolerant against oxygen deficiency but Porifera, Leeches, Asellus ? may occur in high numbers.
6) Poor fauna of high abundance.
7) At specific sites a high abundance of chironomids may occur: besides tolerant species of the subfamily Orthocladiinae mainly Tanytarsini (mainly Micropsectra) and Chironomini prevail.
8) The oligochaete fauna may consist of Lumbriculus, Naididae, Enchytraeidae and certain Tubificidae which may occur in remarkable numbers.
9) Fish fauna ? Reproduction not always possible, periodical fish injuries.

10) River type: Heavy polluted rivers where the assimilatory processes (production) are always lower than the reduction processes.

Chemical water quality characteristic of Central European rivers

O_2-depletion	O_2-saturation	BOD_5 (mg O_2/l)	COD mg/l	PO4-P (µg/l)	NH_4-N (µg/l)
25-50	150-200	5-10	18-22	196-261	471-620

Water quality class III-IV

Saprobity level: alpha-mesosaprobic to polysaprobic
Degree of pollution: very heavy pollution
Water quality maping color: yellow-red

This transitional zone indicates very heavy pollution, oxygen depletions and only restricted macrobenthic life consisting mainly of Tubificids and Chironomus larvae which start to build up large populations. The water is nearly unsuitable for every use with the exeption of the introduction of sewage, because even the employment for irrigation is douptful from hygienical point of view.

1) The water is very heavily polluted with a very high amount of organic matter and a very high concentration of nutrients.
2) Because of the pollution, point sources of effluents and drifting (filamentous) bacteria the water is turbid locally or at given times. Due to the effluents certain water colours and/or smells may be developed.
3) The oxygen content indicates oversaturation and very heavy depletion respectively which does not enable a permanent fish live.
4) Putrefactic conditions occur in fine sediments which are of blackish colour because of oxygen depleting organic matters which cause septic conditions. The underside of stones shows black reduction (ferrosulfide) at lentic sites and cover bigger areas at lotic sections. H_2S smell may be noticeable.
5) Algae consist mainly of Aufwuchs beneath the bacterial cover. Macrophytes cannot grow because of lacking ligth (turbidity). Sewage fungi grow in masses on hard substrates or cover benthic invertebrates. Sulfur bacteria may occur in visible spots (white to grayish cover).
The microbenthic fauna mainly consists of Ciliates, Flagellates and bacteria. The benthic invertebrate fauna consists only of those few groups which are quite tolerant against oxygen deficiency but occur in high numbers: Chironomus, tolerant Chironomini and Tanypodinae, Tubificidae, Enchytraeidae, leeches and few extremely tolerant species of other groups.
6) Very poor fauna of partly high abundance.
7) At specific sites (mainly lentic areas) a high abundance of chironomids may occur: besides tolerant species of the Chironomini the Genus Chironomus prevails.
8) The oligochaete fauna may consist of Enchytraeidae (Lumbricillus) and certain Tubificidae (Tubifex, Limnodrilus) which may occur in remarkable numbers.
9) Fish fauna ? Reproduction not always possible, periodical fish injuries.
10) River type: Very heavy polluted rivers where the assimilatory processes (production) are always lower than the reduction processes.

Chemical water quality characteristic of Central European rivers

O_2-depletion	O_2-saturation	BOD_5 (mg O_2/l)	COD mg/l	PO4-P (µg/l)	NH_4-N (µg/l)
10-25	150-200	9-18	22-30	62-327	621-780

Water quality class IV

Saprobity level: polysaprob
Degree of pollution: extreme pollution
Water quality mapping color: red

This saprobic zone describes river sections with extreme pollution caused by organic effluents. Macrobenthic life is restricted to air-breathing animals (eg. rat-tailed maggots). Microscopic organisms prevail (e.g. Bacteria, fungi, protozoans). The water cannot be used with the exeption of possible sewage inputs.

1) The water is extremely polluted with a tremendous amount of organic matter and a very high concentration of nutrients.
2) Because of the pollution, point sources of effluents and drifting (filamentous) bacteria the water is turbid at most times. Due to the effluents certain water colours and/or smells may be developed. Many animals or plants are smothered or shaded out by the suspended material.
3) The oxygen content indicates extreme oversaturation and depletion respectively which do not enable a permanent fish or water breathing benthic animal live.
4) The bed sediments consist of sapropelic muds. In lotic zones nearly all lower sides of the stones are covered by more or less big black patches of Fe-II-Sulfid. In lentic zones both sides of the stones are covered by these black patches. Finer bed sediments (mud, silt, etc.) are black. Processes of degradation prevail, in many cases a H_2S-smell may be noticeable.
5) Due to the enormous supply of anthropogenic "food" input, bacteria and other saprophytic microorganisms beginn to increase rapidly. Organisms consist of bacteria, flagellates and freeliving, bacteriophagous ciliates, whereby the Colpidium-colpodae-asseblage is the most typical community of this water water quality class. Filamentous sewage bacteria are of lesser amount than in class III-IV, whereas sulfur bacteria have their greatest dominance and may grow in freely visible lawns. Compared to class III, the algal cover is reduced in quantitative and qualitative terms. Nearly all larger plants and animals are killed or cannot coloize these reaver reaches because of anaerobic conditions at certain times or because of darkness. The benthic invertebrates are restricted to species using breething-tubes and therefore beeing independent from the oxygen content of the water. These soft-bodied animals can survive because of the elimination of intolerant predatory animals that allows the larger scavengers to take full advantage of the situation.
6) With the exception of air breathing animals nearly no higher life.
7) Chironomids may occur only scarcely: besides tolerant species of the Chironomini the Genus Chironomus prevails.
8) The oligochaete fauna may consist of Enchytraeidae (Lumbricillus) and certain Tubificidae (Tubifex, Limnodrilus) which may occur in extremely low numbers.
9) No fish fauna.
10) River type: Extremely heavy polluted rivers where the assimilatory processes (production) are always lower than the reduction processes.

Chemical water quality characteristic of Central European rivers

O_2-depletion	O_2-saturation	BOD_5	COD	total P	NH_4-N
<10	>200	>14	>30	>327	>780

6.1.4 Field Water Quality Class

The water quality has been divided into four major classes and three additional sub-classes within the major classes on the basis of the saprobic water quality class (SWQC) model observed. Thus a total of seven classes in the field has been identified. Four *kunds* have been excluded from consideration because of their peculiar feature from the streams. The observation of the sites was made in both seaşons, i.e. pre-monsoon and post-monsoon.

However, the field water quality classification is the most difficult job, because it has to be based on a variety type of streams in terms of size, terrain, length, velocity and so on so forth. If a single stream for instance the Bagmati is taken, the field water quality classes would be more easier and convincing than to consider all streams together. However attempt is made to include a number of parameters to classify all the streams considered in the study. The components enclosed in the protocol and could easily be distinguishable in the field have been adapted to the situation prevailing in the study area. The definition of the parameters has been made in such a way that could accommodate the rainfed streams. Most of the parameters have been quantified as far as possible to qualify each major class in which the range values are given while in other cases where quantitative measure is not feasible, qualitative judgement is made. In the first case, mean and standard deviation based on the frequency and value of the numerical units have been derived and used as the basis. Subjective judgement too has been based on the range of qualitative parameters obtained from the Protocol. The description and the range values for sub-classes should be considered in between the major classes. The description of only the major field water quality classes is made for the Bagmati river system on the basis of SWQC model which are as follows:

Class I: It is defined as non to slighltly polluted water quality class. The aquatic vegetation is dominated by moss with 15 percent ±10, followed by diatom and filamentous algae. Macrophyte and sewerage fungus are non-existent and reductive feature is nil. In this class, the diversity of benthic invertebrates is recorded high and the relative abundance of each taxa ranges from 1-2 in most cases. The dominant taxa and their range of relative abundance associated with this water class are as follows: The human organic effluent is almost non-existent particularly in the uppermost headwater region This class is characterised by odourless and blue colour of water with clearly seen stream bed.

Coleoptera:	Elmidae (2); Psephenidae (1-2)
Diptera:	Athericidae (1-2); Tipulidae (1-2); Limonidae (1-2); Simuliidae (1-2).
Ephemeroptera:	Baetidae (1-2); Ephemerellidae (1-2);
niidae-Epeorus sp. (1-2);	Leptophlebiidae (1-2).
Heteroptera:	Aphelocheiridae.
Hirudinea:	Salifidae -Barbronia sp. (1-2).
Odonata:	Euphaedae (1-2).
Plecoptera:	Capniidae/Leucinidae (1-2); Nemouridae (1-2); Perlidae (1-2).
Trichoptera:	Glossosomatidae (1-2); Lepidostomatidae (1-2); Hydropsychidae (1-2); Rhycophillidae (1-2); Stenopsychidae (1-2); Uenoidae (1-2).

Other characteristics are also noted down in this region from the river morphology and physico-chemical state of the Bagmati river system. The streams are at primary stage in the mountain terrain where they flow as making the straight channel course. The area lies under forest coverage with above 80 percent and pasture land and others cover the rest. Plant shading is about 70 percent ±15. In the streams, the detritus cover including wood and leaf is estimated to be about 20 percent, on the whole. Much of the water source is being tapped in reservoir for drinking purpose and the people living there use the stream water for domestic purposes (drinking, bathing and washing). The water level is medium to high with respect to channel depth and width. The channel width varies from minimum 6 meters ± 4 to maximum of 15 meters ±7. The lowest range values apply to small streams and the depth likewise varies from minimum of 0.2 to 0.8 meter on average. The bank type is of fully natural, characterised by stable. The channel formation is v-shaped in most cases. The flow type is turbulent with velocity of over 1m/sec on average. The substrate composition is overwhelmingly made up of boulder (>40 cm) with ≈50 percent, followed by other smaller size stones. Silt is almost non-existent. Some sand with below ≈5 percent appears to exist. The mean conductivity is ≈25μS/cm ±10. In some cases, higher than this conductivity value is also observed. The dissolved oxygen level is on average measured at ≈10±2mg/litre

Class II:. This class is said to be moderately polluted water quality class. The odour of the stream water is earthy in most cases (≈90%) and in some cases fishy, too. The colour is turned to light grey with most cases (>70%) but in small streams blue and green colour are also observed. The transparency as measured in terms of light penetration into the stream bed is medium with about >20 cm. The diversity and abundance of taxa in this water quality class is found increasing. These include as followings:

Coleoptera:	Dytiscidae (2-3); Elmidae (1-2); Psepheniidae (1-2)
Diptera:	Chironomidae (2-3); Tipulidae (2); Limoniidae (2-3); Simuliidae (2); Tabanidae (1-2)
Ephemeroptera:	Baetidae (2-3); Ephemerellidae (2-3); Heptageniidae (2-3), Leptophlebiidae (2-3).
Heteroptera:	Aphelocheiridae (2-3).
Hirudinea:	Salifidae -*Barbronia sp.* (1-2); *B. weberi* (2).
Odonata:	Gomphidae (2-3)
Oligochaeta (2-3):	
Plecoptera:	Perlidae (2-3)
Trichoptera:	Glossosomatidae (2); Lepidostomatidae (2); Hydropsychidae(2-3).
Turbellaria (2)	
Potamidae (2)	

The characteristics noted down in this class for the Bagmati river system are as follows:. Here, streams are characterised by their early mature stage with straight and meandering course and rectangular channel type. Over the lower slopes, the influence of human activity on streams is found increasing. The natural influence of the streams includes bank erosion, flood and siltation to some extent. Plant overhanging on the stream or shaded area is estimated to be ≈40 percent in most cases if there is not conserved or planted trees. The water level is medium relative to channel depth and width. The bank structure is formed of natural with semi-stable. The stream flow is medium with mean velocity over 0.5m/sec There is a great variation in conductivity. On average it is measured at 150 ±70 μS/cm. As the streams flow down, the substrate composition differs with the increasing amount of smaller and finer size materials. So, in this class there exist large size materials such as boulder, cobble and pebble but decreasing in proportion. However still the boulder dominates in coverage with ≈25 percent. The amount of sand is estimated to be ≈25 percent together with very small proportion of silts (≈5%). The proportion of other medium and large size materials lies in between them. The dissolved oxygen amount is recorded at the value of 8 ±2.5 mg/litre. The stream water is used by the people for domestic purpose as well as for agriculture. There are some agricultural and human organic effluents. The reductive feature is estimated to be at 20 ±18 percent. The human activities such as pebble collection and sand quarrying in the streams are observed.

Class III: The water quality class is considered to be heavily polluted. The aquatic vegetation is composed of greater amount of algae (≈15 ±5%), macrophyte with ≈15 ±10% and filamentous algae with 7 ±3 percentage, on average. In detritus coverage, FPOM has dominated with ≈45 ±20 percent and CPOM with ≈20 ±10 percent. Reductive feature has shown an average of 35 ±30 percent with transparency below 20 cm. The colour is turned out to be gray in most cases with odour of earthy mixing with faecal. The turbidity seems to have been somewhat great affecting the penetration of light. The overall flow type is medium to slow with velocity of 0.4 m/sec ±0.1. The taxa belonged to this class are:

Coleoptera:	Dytiscidae (2-3)
Diptera:	Chironomidae (3-4), Tabanidae (2)
Ephemeroptera:	Baetidae (2-3), Leptophlebiidae (2-3)
Gastropoda:	Physidae (3-4)
Heteroptera:	Corixidae (2-3)
Hirudinea:	Salifidae -Barbronia weberi (2-3)
Odonata:	Gomphidae (2-3)
Oligochaeta (3-4)	
Trichoptera:	Hydropsychidae(2)

Other comments noted down for the Bagmati river system on this class are also described .In this class, the dominant characteristics are that most small rivers mix with large streams. Streams are flowing over the valley terrain at mature stage with meandering course formation. The water level is medium to low in most cases and medium in some cases. The substrate composition of the rivers is completely different from that of early mature state. The small particle materials have increased in proportion particularly in large streams, whereas larger size materials have remained to be relatively larger proportion in small streams. The sand amount is estimated to be ≈35 ±25 percent, followed by small and large pebbles. The siltation coverage is estimated to be 10 ±2 percent whereas the larger size boulder and cobble is found decreasing with below ≈5 percent. The streams flow along the meandering course over an average terrain altitude of 1300 ±25 meters. The stream channel width ranges from mean maximum of 6 ±3 meters to mean minimum of 3 ±1 meters and the mean depth with 2 meters ±1.5 at maximum and 0.3 meter at minimum. The bank structure is earthy with semi-hard in some cases. The oxygen dissolved amount is decreased at 6 ±2 mg/l while conductivity is increased with 220 ±65 on average. The people are found using the stream water for agriculture in most cases, as well as for domestic uses such as bathing and washing. The land use on the surrounding of the streams is found dominated by agriculture and then by settlement and fallow land. Flooding and siltation are the dominant stream activities where there is increased sand quarrying activity. There are observed effluents of agriculture, domestic and industries.

Class IV: The water quality class is considered to be extremely polluted. The reductive feature is often seen at proportion with over 80 percent. FPOM coverage is estimated to be with over 80 percent and CPOM with 30 ±25 percent. Of the aquatic vegetation, the coverage of both algae and fungus is estimated to be about one-fifth each. The stream water gives earthy odour together with strong smell of faecal and sulphur in most cases. The stream water colour is seen to be dark gray and gray with very low level of transprency (<10 cm). It means that the turbidity is high which reduces light penetration into the streams and thus limits the photographic rate. With such environments this water class is characterised by only a few taxa with high abundance of pollution tolerant taxa, they are such as:

Coleoptera: Dytiscidae (1-2)
Diptera: Chironomidae (3-5), Syrphidae (2-3), Culicidae (2-3)
Gastropoda: Physidae (2-3)
Heteroptera: Corixidae (2-3) - Air breather
Odonata: Gomphidae(1-2)- Air breather
Oligochaeta: (3-5)

General comment of this class for the Bagmati river system are noted as followed: The channel is of terraced type. This is the poorest water quality and spatially confined mainly to the urban core, where streams with medium to low and low water level flow slowly in most cases along the meandering course. The surface elevation is ≈1285 ±25 meters. The water is found to be used primarily for agriculture (>90%) and for washing vehicle, vegetables to sell and building construction. The stream water has received effluents of domestic and sewage at greater extent (> ≈70%) as well as of agriculture. The substrate composition is overwhelmingly composed of sand and silt with >60 percent in large streams such as the Bagmati, the Manohara, etc. Large size materials with smaller proportion (<5%) are seen in locations of those streams before entering the urban core. The stream width ranges from the mean maximum of 8 ±6 meters to mean minimum of 5 meters. The mean stream depth ranges with maximum of 0.7 meters to minimum of 0.3 meters. The bank structure is preponderantly made up of earth except in some man-made stone staircases. The streams form meandering course. The streams with medium to low level of water have a mean velocity of 0.3m/sec ±0.1. There is seen greater amount of interference of human activity into the streams particularly in sand quarrying and pebble collection. The effects of the streams on the ecology include flooding, siltation and bank erosion. Settlement and agriculture are dominant land uses on the surrounding. The dissolved oxygen level is very low with a mean value of 2 ±0.5. The conductivity is highest with a mean value of ≈500 ± 290. Because of the relatively slow water movements, the streams seem to have low effective in mixing oxygen into the water and thus affect the type of bottom. So, slow runoff, dissolution of rocks and sewage discharge are the main sources of the streams.

This field classification has been the basis for: (1) dilution of the lab analysis of the bacteriological and the chemical parameters and (2) weight (score) assigning to the taxa..

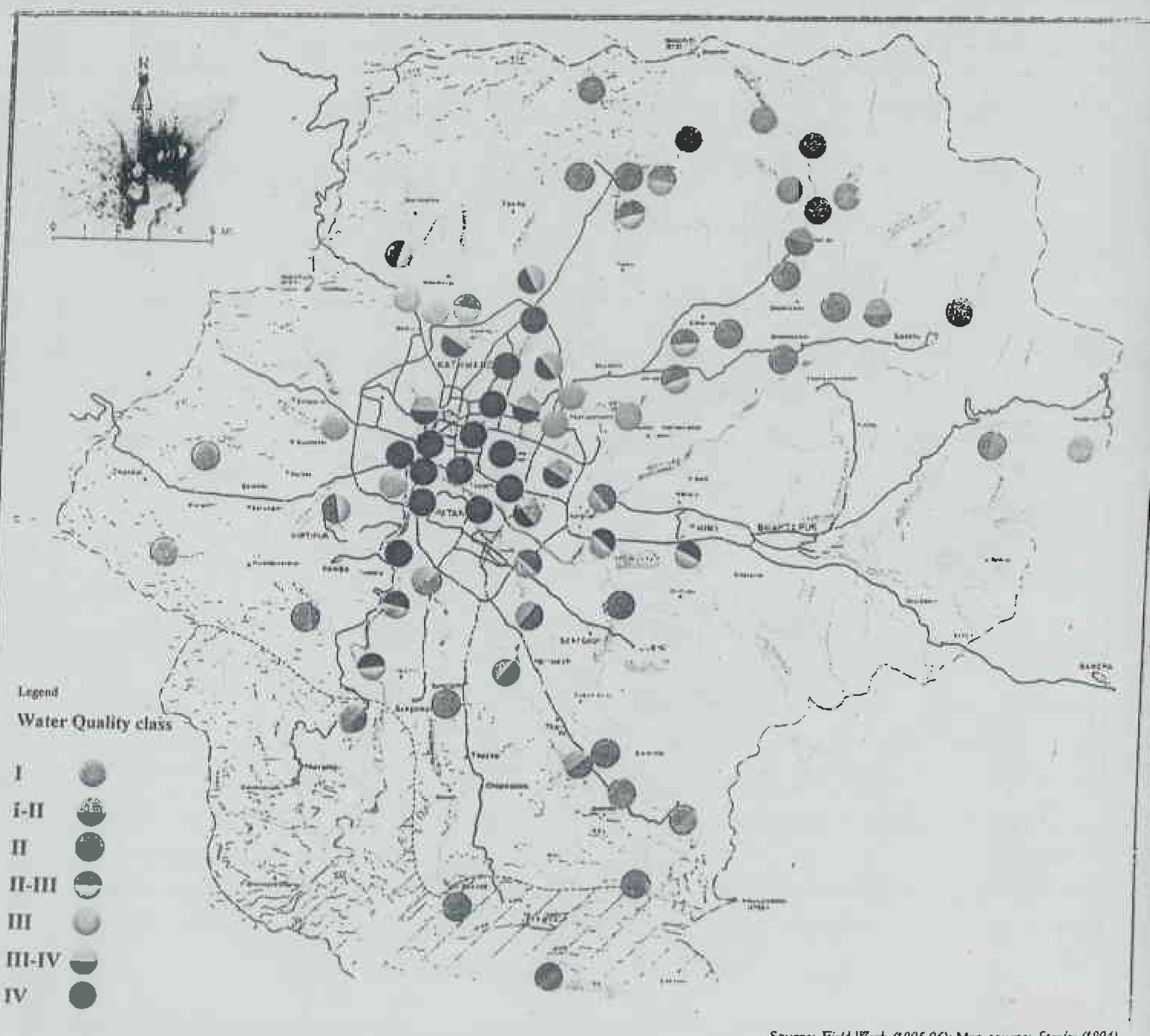
(ii) Classification of sample sites

a. By season:

Two saprobic water quality class maps of post-monsoon (Figure 6-3) and pre-monsoon (Figure 6-4) are prepared. Table 6.3 provides the number of sample sites by season.

The comparative analysis of the sample sites between two seasons show that the number of sample sites with all successive poorer quality classes have increased except for saprobic water quality classes (SWQC) II-III and IV. The largest number of sample sites for FWQ class IV is turned out to be poorest quality between post- and pre-monsoon season. In pre-monsoon, 2 sample sites of FWQ class I were decreased which represented the upper headwater region. This may be basically due to direct human interference into the upstream site. It was observed that a score of local people used to visit upstream sites for bathing, washing clothes and picnic because of sunny weather, clean stream water and beautiful natural sites. In FWQ class I-II, three sites remained to be virtually dried in premonsoon. An increase of number of sample sites of FWQ class II-III in premonsoon was due to increase of human interference and most of the sites lie in the lower headwater and the upper valley sections. Three main reasons have been observed for deteriorating stream water quality during pre-monsoon. They are (1) seasonal characteristic of rainfall, (2) spatial location and population density, and (3) human interference. Seasonal characteristic refers to the decrease in volume of stream water because of dry season, as all streams are rain-fed. Decrease of water volume means slow velocity and many of the physical and chemical components would be effective to play role in decreasing water quality. Second important factor is the spatial location of sample sites. As the streams flow downward through urban core, the highest population density area, the human interference into the streams has intensified and in turn, the number of poor water quality sites has tended to increase. The capacity of streams water becomes too weak to carry away the solid wastes and sewage deposited into them because of low volume and velocity relative to the magnitude of organic wastes. The intensity of human interference to streams also tends to increase in the upstream region during pre-monsoon particularly by the picnic goers.

Figure 6-3: Saprobic water quality class based on field observation (Post-monsoon)



Source: *Field Work (1995-96)*; Map source: *Stanley (1994)*.

Figure 6-4 Saprobic water quality class based on field observation (Pre-monsoon)

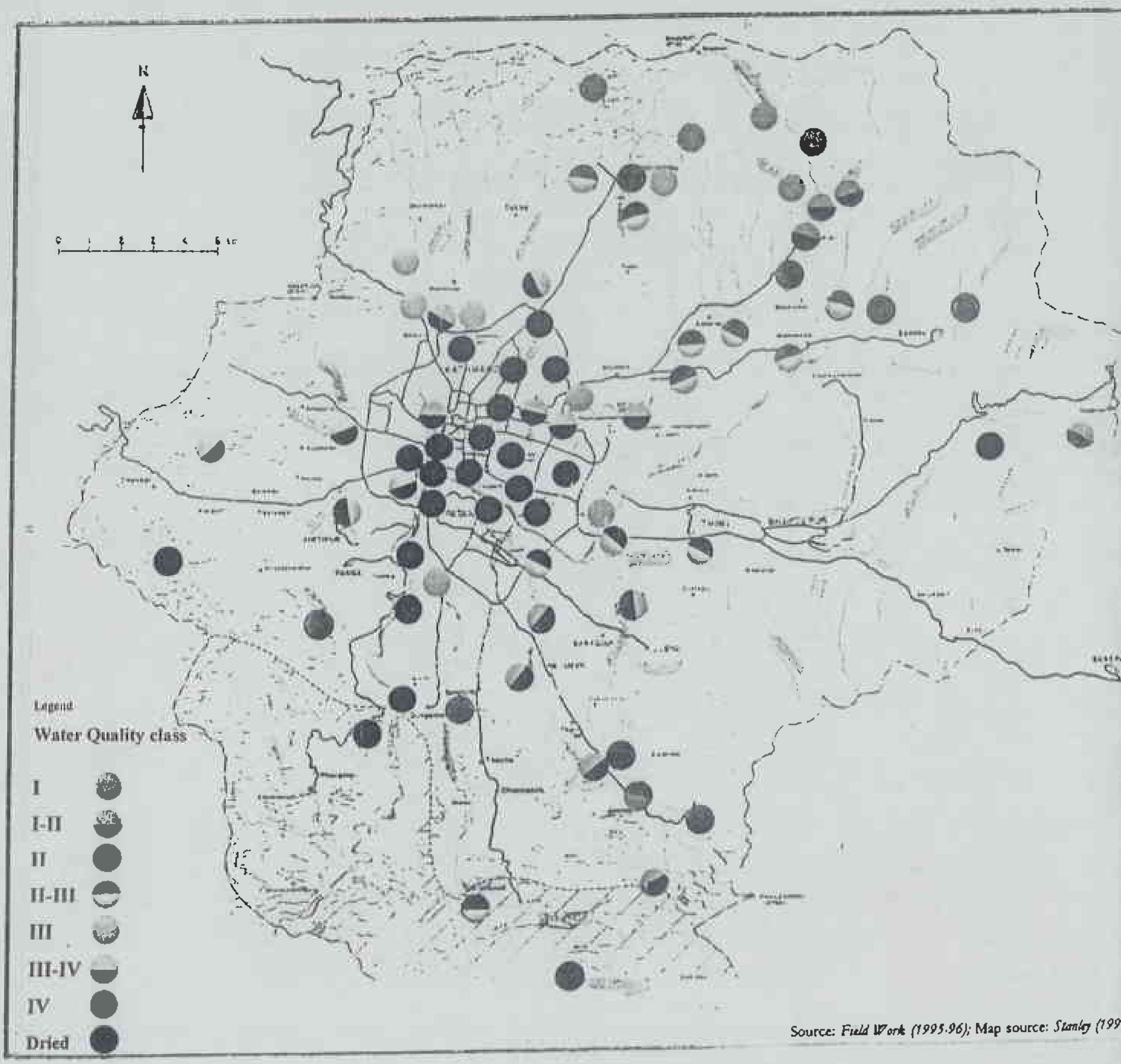


Table 6.3: Number of sample sites by season

SWQC	Post-monsoon	Pre-monsoon
I	8*	5*
I-II	9	5♠
II	14	10♣
II-III	11	12♣
III	7	7
III-IV	12	11
IV	14	20
Total	75	70

Source: Field survey (1995-96).

*4 Kunds are excluded; ♠ 3 dried-up; ♣ Each one from two classes of the Bagmati Tarai excluded.

(ii) By stream

The number of sample sites by stream according to field water class is depicted in Table 6.4. All five sample sites of the Tukucha lie in the valley's middle section since it begins and ends in the valley basin. The number of sample sites along the Bagmati is largest which fall in all water quality classes.

Table 6.4: Number of sample sites by stream/river according to saprobic water quality class

Stream	I	I-II	II	II-III	III	III-IV	IV	Total
Bagmati	5	2	4	1	3	5	4	24
Balkhu	-	1	1	1	1	-	-	4
Bishnumati	1	-	1	1	2	3	2	10
Dhobikhola	1	-	1	2	-	1	3	8
Godavari	-	2	3	-	-	-	-	5
Hanumante	1	1	-	-	-	2	-	4
Kodku	-	-	-	3	-	1	-	4
Manohara	-	2	1-	2	1	-	-	6
Nakhu	-	1-	3	1	-	-	-	5
Tukucha	-	-	-	-	-	-	5	5
Total	8	9	14	11	7	12	14	75

Source: Field survey (1995-1996).

7 BACTERIAL WATER QUALITY ANALYSIS

7.1 Introduction

River water in a mountainous country like Nepal is an important source for ensuring an ecological balance as well as providing utilisation such as drinking water, recreation, irrigation, fisheries, industrial water supplies and religious satisfaction. It is noted that most of the large urban streams in Nepal provide a medium for disposal of wastes and sewage dumping. At this juncture, it is important to assess water quality of the river.

Microbiological approach concerns with the analysis of hygienic quality of water in terms of faecal contamination. River water may be contaminated by two major types of sources, i.e. point source and non-point source. However whatever the sources the water contaminated with faeces contain pathogenic organisms and therefore hazardous to human health if used as drinking or other purposes. However, the routine isolation of each pathogenic bacteria is impractical because they are present in relatively small number and needs special technique to isolate. In order to know the presence of pathogenic bacteria, indicator bacteria are isolated from the water. Their isolation is comparatively easy and cheaper. The indicator organisms like total colliform, faecal coliform, *Escherichia coli*, faecal *streptococcus* and *Clostridium perfringens* that inhabit in large numbers in the gut of warm blooded animals and are excreted with faeces. The presence of these indicator organisms in water indicates faecal contamination which evidences the presence of pathogenic bacteria. If indicator organisms are present in large numbers, the contamination is said to be recent and heavy and in other word water may contain variant pathogenic organisms.

Micro-organisms are the main agents in the degradation of environmental pollutants, and thus they are ideal indicators of water quality because of their quick response to changing environmental conditions. The bacterial community has a significant role in the self purification of rivers. Its heterotrophic activities are the base for the self-purification process in aquatic ecosystem which show a strong influence on the concentration and speciation of dissolved organic molecules in the water (Ryszard 1991). River like other water bodies has its own decisive capacity of processing the amount of refuse. However, if the amount of refuse added to it exceeds than its capacity then it leads to the loss of self purification process, causing disagreeable consequences in the water. One prime effect of this is not only death of almost all higher organisms but also of many micro-organisms and as a result, a microbial community consisting of only few species develops which can carry out only partial breakdown of the organic pollutants. This adverse effect occurs also through the direct introduction of poisonous substances into waters from the sewage and refuse from industrial plants.

7.2 Microbioloigcal parameter analysis

Microbiological parameters such as heterotrophic count (also known as plate count), *Escherichia coli*, and faecal streptococcus count have been considered for the assessment of river water quality. *Salmonella sp.* has also been considered for the assessment of river water quality.

The heterotrophic bacteria refers to any bacteria which use organic matter as carbon source as well as energy source. This signifies that the number of heterotroph is squarely dependent on the nutrient level of the river water. The heterotrophic bacterial community plays a decisive role in degrading organic matter in river ecosystems. This organic matter is mainly derived from allochthonous rather than from autochthonous sources (Findlay et al. 1991). However only a small part of the whole heterotrophic bacterial community in surface waters can be grown on nutrient agar plates. While two other parameters - *Escherichia coli* and faecal streptococcus - occur in the intestinal tract of all warm blooded animals. Their presence in the river water indicates the faecal contamination. In other words, the degree of faecal pollution has a direct relation with their number. There is some distinction however between these two bacteria. The *E. coli* indicates bacteria which is freshly contaminated faecal origin while the survival rate of faecal streptococcus is higher than *E. coli* particularly in saline and alkaline environment (Rivilla and Gonzalez 1989; Lessard and Sieburth 1983) and because of the longer survival its existence shows in both fresh and unfresh faecal contamination of warm blooded animals as well as vegetation (Geldreich and Kenner 1969).

Four spring sites are excluded from the general stream water quality analysis in order to make it representative and comparative among the river sample sites. For the spring sites, a separate description is made. However, the numerical values of the bacteria of the spring sites will be a reference value to compare it with the bacterial values of the streams sites.

7.2.1 Analysis of Bacterial Parameter

Three bacterial parameters they are heterotrophic count (HPC), *E.coli* count(EC) and Faecal streptococcus (FS) are considered for the present study. The enumeration of bacteria is made in terms of colony forming unit (cfu). The heterotrophic plate count (HPC) is inumerated as cfu/ml at 22°C, and *Escherichia coli* and faecal streptococcus counts are recorded as cfu/100 ml . The analysis of bacterial parameter is made on four main basis they are (a) saprobic water quality class, (b) river profile region (c) season and (d) river. The three bacterial parameters are counted from 75 and 70 sample sites from post and pre-monsoon season respectively, from SWQC I to IV. To get more precision in the result three replicates samples from each site is used for analysis of the bacterial parameter.

The distribution pattern of each of the three bacterial parameters for each site is analysed in terms of minimum and maximum and descriptive statistical parameters such as mean, standard deviation and coefficient of variation (± one standard deviation). The analysis of variability of the parameters is measured as a percentage of mean to standard deviation based on the coefficient variation formula as follows (Chapman 1992):

$$CV = \frac{S}{\overline{X}} \times 100 \quad \textit{where } S = \textit{standard deviation}, \ \overline{X} = \textit{mean, and } CV = \textit{coefficient of variation.}$$

The value has been computed from the average value obtained from three replicates of the water sample of each site. This information for each site is shown in appendix J and K. The analysis of bacterial quality with the variables are made as follows:

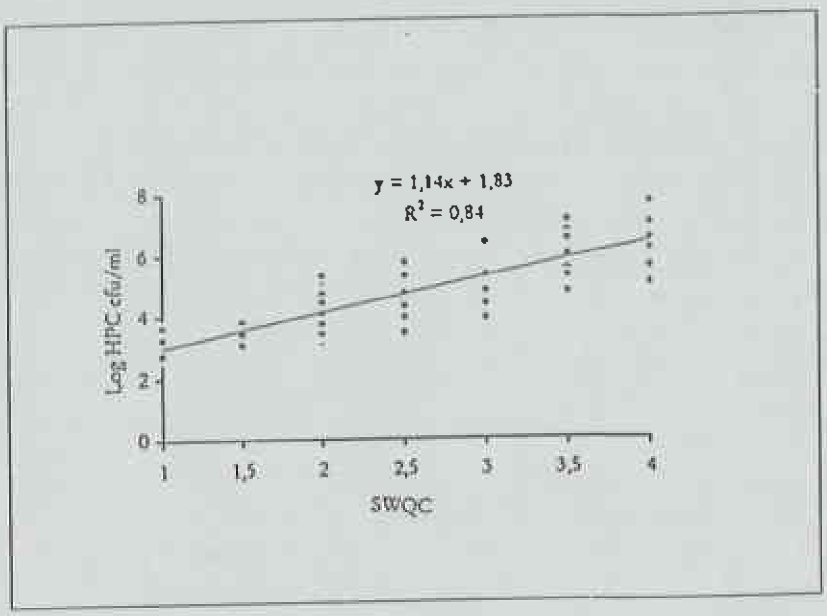
(1) Bacterial quality based on saprobic water quality class

Quantification of bacterial numbers is one of the measures to understand the ecological role of bacteria in aquatic environment. Several scientists have attempted to classify the river water into different quality levels but the range of bacterial numbers proposed for different quality levels is different (Bahr 1953; Liebmann 1959; Wachs 1969; Kohl 1975; Jung 1988 and Popp 1991 cited in Popp 1994). The present study has attempted to know the bacterial water quality with reference to saprobic water quality class and to find out the bacterial range for each saprobic water quality class. The bacterial range of present study does not fall in the range given by Bahr, Liebmann and Wachs specially for water quality class I and there is overlapping in the range for each water quality class in Popp's range. So, for the present study, the range computed for each SWQC is compared with Kohl and Jung's range for HPC to know the bacterial variation with respect to their range and E.coli is compared with only Kohl's (1975) range. In addition to this, different standard such as WHO, EC and PESCOD have been used to find out the water quality with reference to SWQC.

Correlation between bacterial parameter and SWQC

Prier to analyse bacterial quality with respect to SWQC, It is compared with log mean value of HPC, *E.coli* (EC) and faecal streptococcus (FS) separately and the coefficient of determination $r^2 = 0.84$, $r^2 = 0.80$ $r^2 = 0.6$ are found out respectively. The strong correlation of SWQC with HPC shows that the water quality deterioration is due to organic pollution (figure 7.1) and the correlation of other two parameters indicate that the pollution is from domestic sewage.

Figure 7-1: Heterotrophic plate count and SWQC



(a) Heterotrophic Plate count (HPC)

From the table 7.1 depicts HPC with minimum and maximum range, mean and coefficient of variation(CV) for each SWQC in post-monsoon season. It is observed from table 7.1 that the range of bacterial count are lower in post monsoon season (Figure 7.3). The percentage of coefficient of variation of HPC took place from 18 % - 154 % in post-monsoon and 43-148 % in pre-monsoon seasons shown in table 7.1. The change of ratio of bacterial count between successive good water quality to poor water quality class is 0.1-0.3. and average percentage is 27.

Table 7.1 Heterotrophic count and SWQC

	HPC (cfu/ml)						
	PO			PR		Total Mean	
SWQC	Min-Max	Mean	%CV	Mean	%CV	Min-Max	Total mean
I	539 - 912	718	18	2370	43	$5x10^2$- 2 $x10^3$	1514
I-II	1230-9120	3095	68	4075	56	$1x10^3$ · $9x10^3$	3585
II	1584 -20417	26000	154	32884	146	$2x10^3$ - $5x10^4$	29442
II-III	2740-56234	24132	74	127720	106	$3x10^3$- $7x10^5$	75926
III	8233-210667	141033	97	643243	146	$8x10^3$ - $2x10^6$	392138
III-IV	67500-1000000	550514	53	2541148	148	$6x10^4$ -$3x10^6$	1545831
IV	109667-5560000	2396718	70	8007903	131	$1x10^6$ -$8x10^7$	5202310

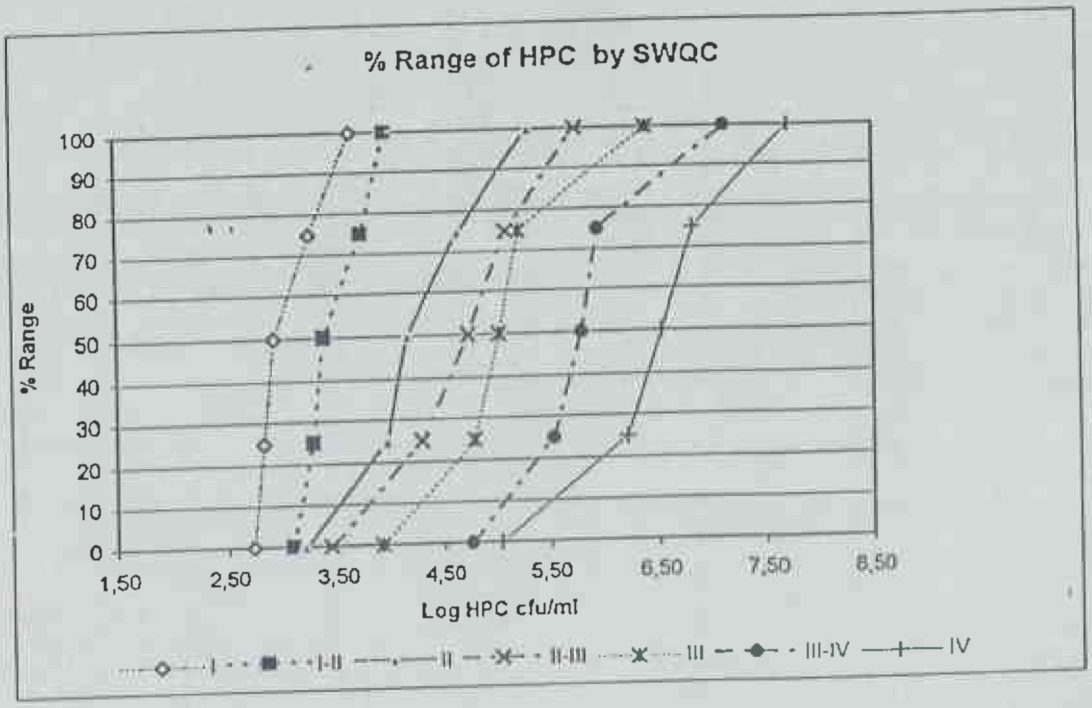
Source: *Field survey (1995-96)*. PO = Post-monsoon, PR = Pre-monsoon.
CV = Coefficient of variation, HPC = Heterotrophic plate count

Table 7.2: Percentage variation of log mean HPC cfu/ml with respect to SWQC

SWQC→ % of range	I	I-II	II	II-III	III	III-IV	IV
5	2.73	3.09	3.20	3.44	3.92	4.76	5.04
25	2.83	3.28	3.96	4.29	4.79	5.54	6.22
50	2.92	3.38	4.15	4.74	5.03	5.80	6.53
75	3.26	3.73	4.63	4.85	5.21	5.95	6.82
95	3.31	3.96	4.70	5.88	6.40	6.73	7.71

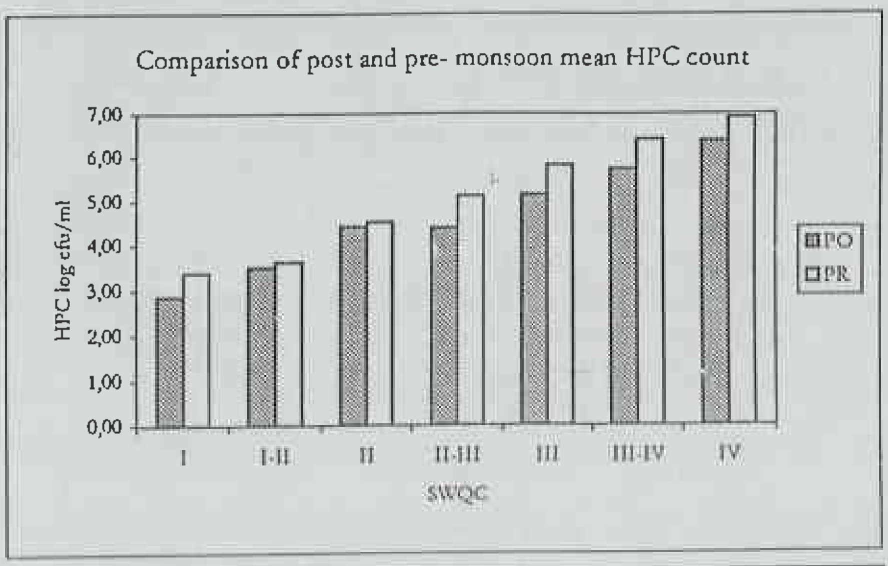
The colony forming unit in log for each parameter is represented by range, graph, and box plots. Table 7.2 shows the mean % of variable of sample site for each SWQC. In table 7.2 represents the log mean percentage range of bacteria with respect to SWQC. The range value for each SWQC is represented in 5 percentage to 95 percentage. The information of table 7.2 is used to compare range of bacteria for each parameter in percentage with respect to bacterial number used in central Europe for each SWQC. The variation in range of bacterial count by sites with respect to SWQC in Post monsoon and pre-monsoon is shown in appendix M and N. Due to the differences of bacterial number in the two seasons, there appears about 50 percentage overlapping in each SWQC. The mean shown in table 7.1 is quite distict for each water quality class.

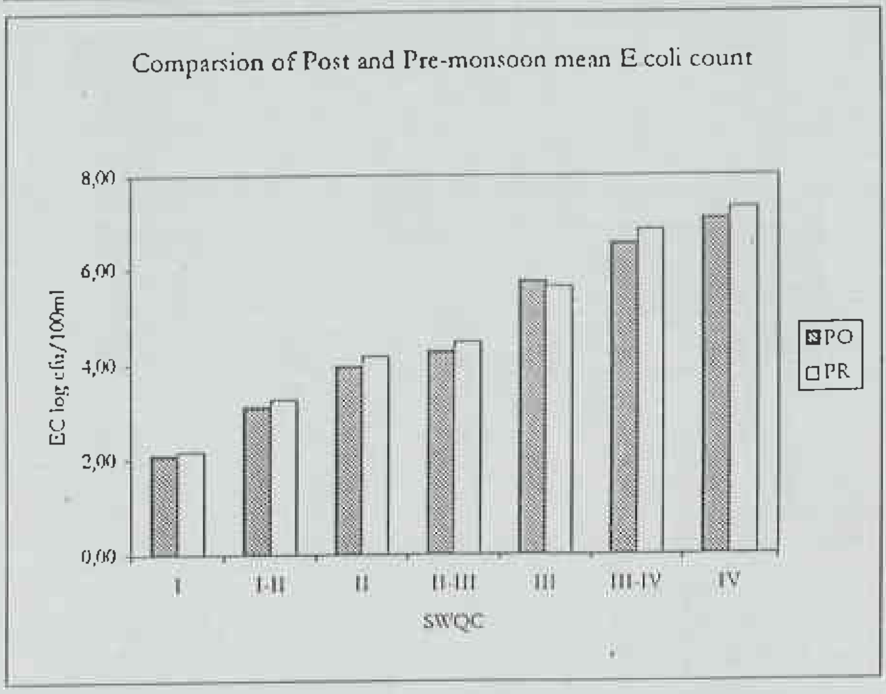
Figure 7-2: Percentage Range of HPC and SWQC

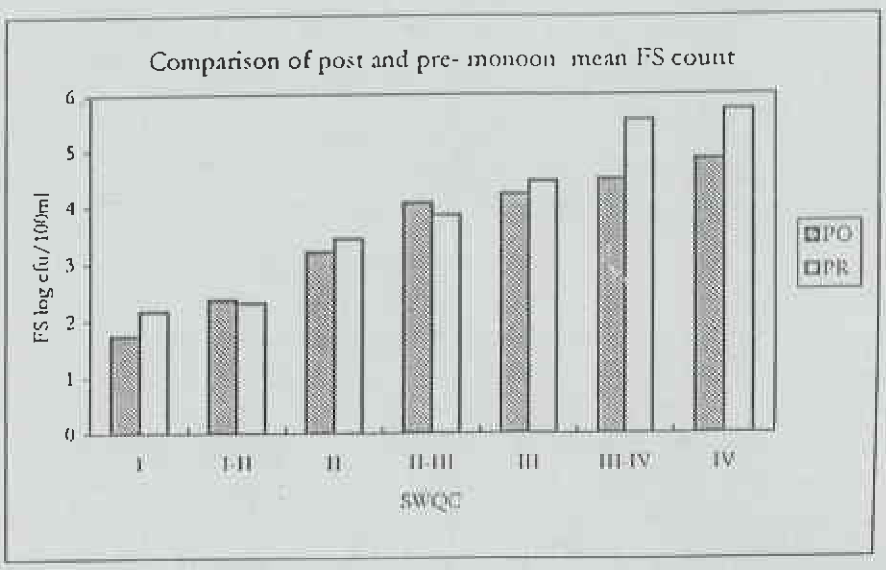


The numerical range of heterotrophic plate count (HPC) is less than 1000 cfu/ml in 100 percentage sites of SWQC I which lie within the range given by Jung in post-monsoon but it is less than 75 percent in pre-monsoon season (Appendix M and N). None of the sites lie within the range proposed by Kohl (1975) for this class. The minimum number recorded for this class is 539 cfu/ml. Similarly, for SWQC II, 75 percentage sites lie within the range of Jung (cited in Popp1994) in both seasons. While 95 percentage and 75 percentage samples lie in Jung and Kohl range respectively for WQC III in post-monsoon season and 75 percentage sample sites in pre-monsoon. It is seen that about 75 percentage sample sites of saprobic water quality class lies within the range but each quality class shows overlapping in the range (Figure 7.2).

To make more precise the range of bacterial number to saprobic water quality class the changes in the number of bacteria for each parameter between the seasons are compared. While comparing saprobic water quality class with post-monsoon and pre-monsoon samples there appeared variation in bacterial number in all the three parameters. As shown in figure 7.3 the numerical value is higher in most cases in pre-monsoon season. This variation in HPC may be due to higher temperature in pre-monsoon season than in post-monsoon which facilitates faster multiplication of bacterial growth (Rheinheimer 1992), and for *E.coli* and streptococcus counts are mainly due to the comparatively higher human interference to the river which is observed. This shows that each saprobic water quality class has wider range of bacterial number which is shown in appendix J and K.







PO = Post monsoon ; PR = Pre-monsoon; HPC= Heterotrophic plate count; EC= E.coli count; FS= Faecal streptococcus count

E.coli

Table 7.3 indicates E.coli count and its minimum and maximum range, and percentage of coefficient of variation for each SWQC. For each SWQC the range as well as the bacterial count is lower in post-monsoon season than in pre-monsoon season. While comparing the coefficient of variation among water quality classes there appears minimum coefficient of variation in term of SWQC I with minimum 47 percentage and maximum in II-III with 180% in post-rainy season and minimum 25 % in SWQC II and maximum 200 % in SWQC I-II. The average ratio change is found out in the range of 0.03 -0.9.

Table 7-3: E.coli count and SWQC

	EC (cfu/100ml)						
SWQC	Post-monsoon			Pre-monsoon		Mean	
	Min-Max	Mean	CV	Mean	CV	Min-Max	Mean
I	60 -173	117	47	140	71	$50 - 2x10^2$	129
I-II	83 -4466	1190	172	1785	200	$80 - 2x10^3$	1488
II	389-32359	8259	117	14077	25	$10^3 - 3x10^4$	11168
II-III	630-104712	16898	180	27871	70	$3x10^3 - 6x10^4$	22385
III	3235 - 1621810	506388	147	400720	154	$8x10^3 - 2x10^6$	453554
III-IV	575439-10471285	3378337	84	6663044	156	$2x10^5 - 1x10^7$	5020691
IV	3630780- 17833300	11000000	49	12600000	117	$3x10^6 - 2x10^7$	11800000

CV = Coefficient of variation

Table 7-4: Percentage variation of log mean E.coli cfu/100ml with respect to SWQC

SWQC→ % of Sample site↓	I	I-II	II	II-III	III	III-IV	IV
5	1.78	1.92	2.59	2.80	3.20	5.10	6.55
25	1.95	2.21	3.26	3.43	4.46	5.97	7.13
50	2.08	2.77	3.58	4.10	4.66	6.43	7.34
75	2.25	3.64	4.06	4.59	5.56	6.93	7.93
95	2.30	3.95	4.53	5.02	6.54	8.53	8.69

Source: *Field survey (1995-96).*

Colony forming unit (cfu) of E.coli/100 ml is compared with Kohl' range for saprobic water quality class. The rang of E.coli in present study is found out high while compare with the faecal coliform rang given for saprobic water quality class I. None of the sites of SWQC fall in water quality class I of Kohl´s range. Only 50 % sites SWQC I falls in Kohl´s water quality class I-II. Below 25 % sites of SWQC II, II-III, III, III-IV lie within respective water quality class of Kohl´s range (table 7.4). While comparing European Community (EC) standards for surface water used as raw water for drinking standards and world health organisation (WHO 1995) guidelines for drinking water quality the SWQC I and 50% sites of I-II can be used after A2 treatment and remaining 50 % sites of SWQC I-II and more than 75 % sites of SWQC II can be used after A3 treatment (figure 7.4).

Figure 7-4: Percentage Range of *E. coli* and SWQC

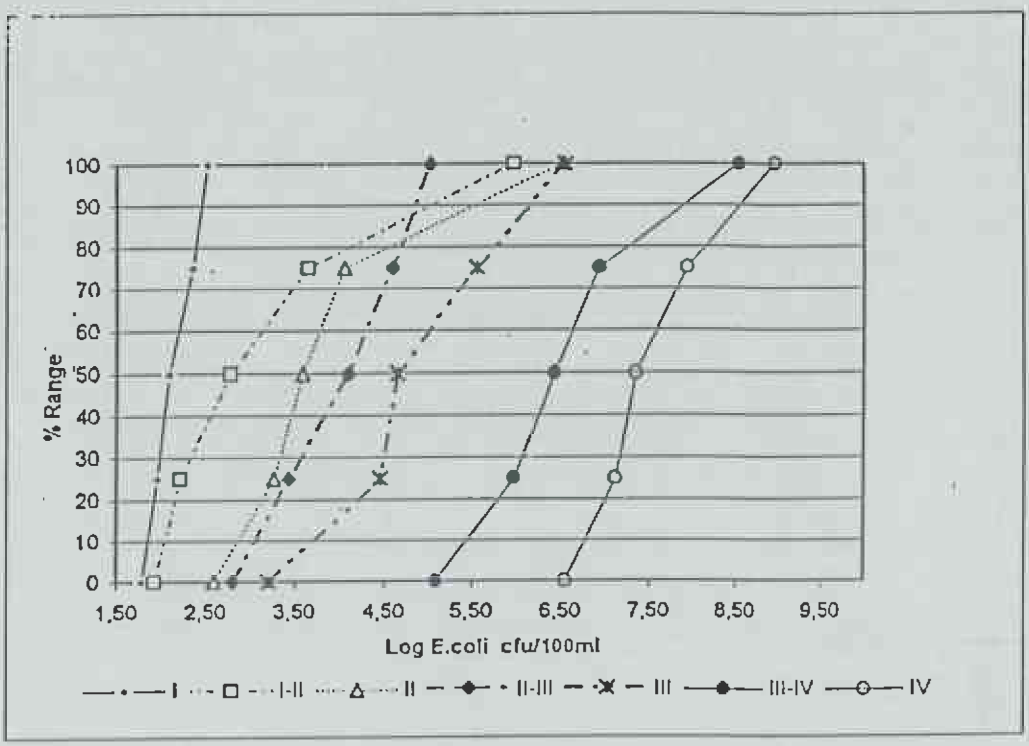
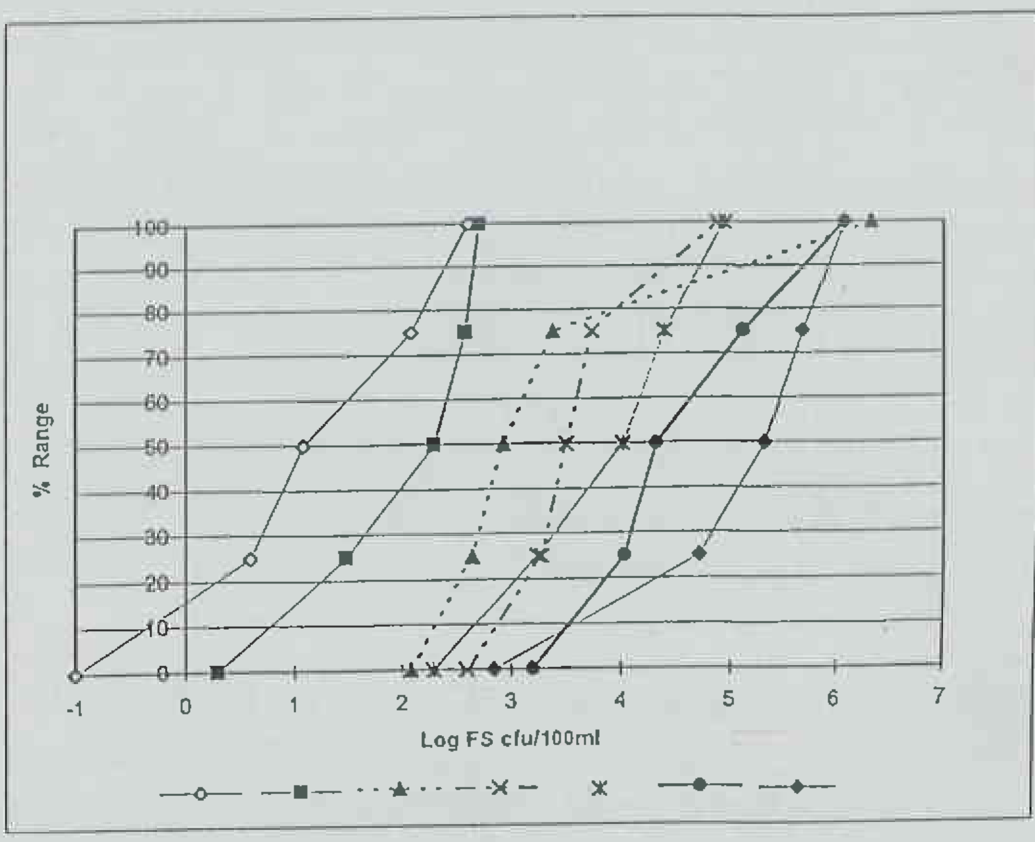


Figure 7-5: Percentage Range of Faecal streptococcus and SWQC



Faecal streptococcus

The table 7.5 depicts that the bacterial range for each SWQC like in case of E.coli, increases in pre-monsoon season compared to post-monsoon season. The coefficient of variation (CV) for each water quality class also varies with the season. The CV is maximum in class III with 163% and minimum in class I-II with 71 % in post-monsoon season and 260 % in class II and 75 % in class III with maximum and minimum respectively in pre-monsoon season.

Faecal streptococcus count (cfu/ 100ml) is less in all water quality class compared to the number of *E.coli*. The average ratio between faecal streptococcus and E.coli is 0.9-2.5, but it is difficult to conclude about pollution from human or animal faecal because of the different finding regarding the ratio of faecal coliform and faecal streptococcus (Poucher et. al. 1991). Regarding the number of faecal streptococcus count as shown in table 7.6, 25 % of SWQC I with A1[5] treatment and remaining 75 % sites of SWQC I and I-II with A2 treatment and more than 75 % sites of SWQC II with A3 treatment can be used as raw water for drinking water abstraction (Figure 7.5).

Table 7.5: Faecal streptococcus count and SWQC

	Faecal streptococcus count cfu/100ml						
	Post-monsoon			Pre-monsoon		Total Mean	
SWQC	Min-Max	Mean	CV	Mean	CV	Min-Max	Mean
I	0.1 - 100	55	120	148	101	$0.1\text{-}2x10^2$	102
-II	2 - 500	224	71	195	108	$2\text{-}5x10^2$	210
I	121-5030	1512	110	2578	260	$10^2\text{-} 5x10^3$	2045
I-III	400-75000	11086	104	6831	117	$4x10^2\text{-} 7x10^4$	8959
II	200-90000	16231	163	27020	75	$2x10^2 - 9x10^4$	21626
II-IV	9000-110100	29541	106	347509	118	$9x10^3 - 2x10^5$	188525
V	7000-169000	68291	81	521635	69	$7x10^4 - 2x10^5$	294963

Source: *Field survey (1995-96);* CV = Coefficient of variation

Table 7.6: Percentage variation of Log Mean FS count cfu/100ml with respect to SWQC

SWQC→ % of Sample site↓	I	I-II	II	II-III	III	III-IV	IV
5	-1	0.30	2.08	2.60	2.30	3.20	2.85
25	0.60	1.48	2.65	3.28	3.25	4.04	4.73
50	1.08	2.30	2.93	3.51	4.02	4.33	5.33
75	2.08	2.59	3.38	3.74	4.40	5.13	5.68
95	2.12	2.78	4.20	4.95	5.95	6.50	6.90

Source: *Field survey (1995-96).* SWQC = Saprobic water quality class

[5] EC standards for surface water used for potable abstractions for Faecal streptococcus (Directive 80/778/ EEC)
A1= Simple physical treatment and disinfection (20cfu/100ml)
A2= Normal full physical and chemical treatment with disinfection (1000 cfu/100ml)
A3= Intensive physical and chemical treatment with disinfection (10000 cfu/100ml)

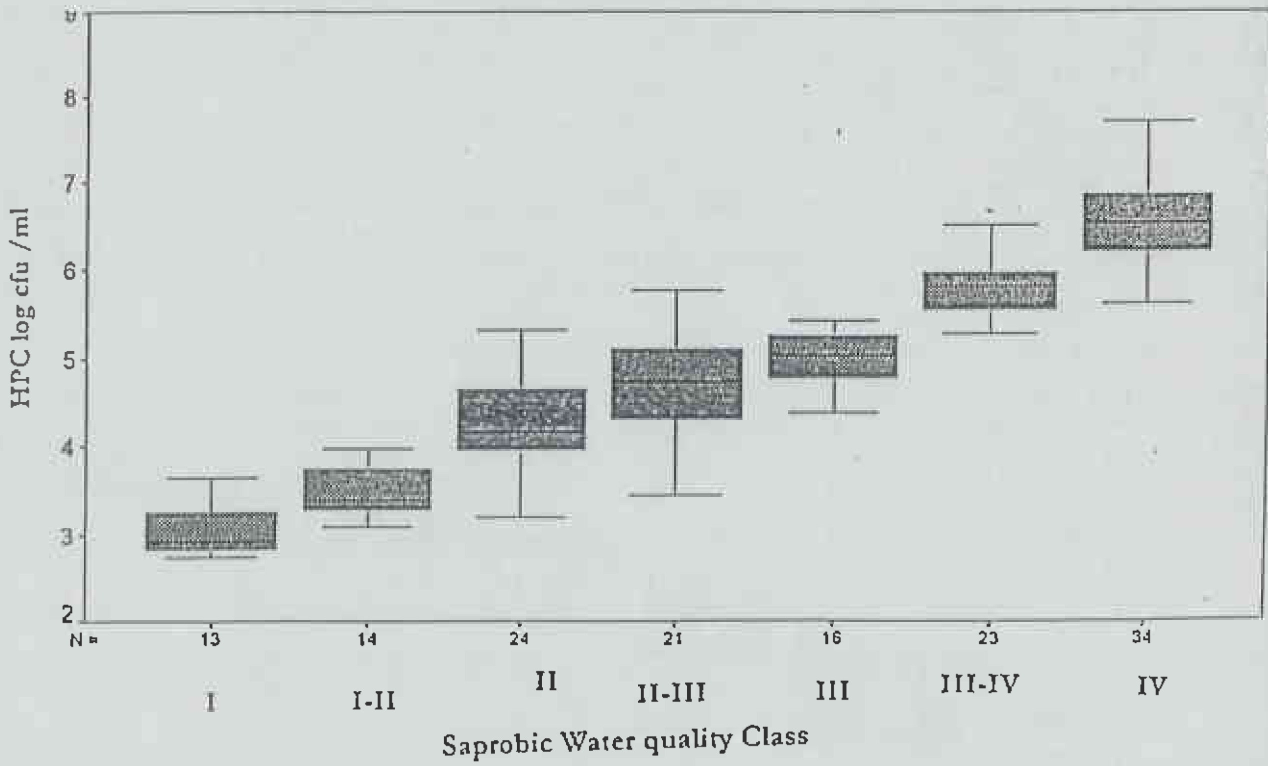
Graphical representation of bacterial parameters and SWQC

To make bacterial range representive with respect to SWQC in graphic, the values of each parameters are converted into log value. The two variables SWQC and log mean value of each bacterial parameter is computed separately by box plot with the help of spss program[6]. The darker line in the box shows the median value for each SWQC. The figure 7.6 shows that there is less spread in the observation in SWQC I, I-II , III, and III-IV. While in water quality class II, II-III and IV comparatively greater spread of value are seen for HPC. It is also observeved from the figure 7.6 that there is less overlapping among the major water quality classes such as I; II, III and IV. The distribution of HPC for each SWQC seem not symetrical except for WQC IV, which is seen maximum asymetrical in WQC I and I-II. The asymetrical values for each SWQC is mainly due to the consideration of HPC of both seasons.

Figure 7.7 shows that the median value of E. coli for each water quality class is clear and not overlapping. But there is a variation in the spread of observation among each water quality class which indicates that the minimum and maximum range for each class is not uniform. From the figure 7.7 it can be assumed that the distribution of E. coli for each water qaulity class is not symetrical because medium value is not at the centre of box except for water quality class III-IV

Similar trend is also noted in figure 7.8 while comparing with SWQC and faecal streptococcus. In this case also the median for each water quality class is not overlapping. The figure 7.8 shows there is a greater spread of value in SWQC I to II and also III to IV and very less spread in value in SWQC II-III.

Figure 7-6: Bacterial range and SWQC (HPC)



[6] The upper and the lower boundaries of the boxes are the upper and lower quartiles. The box length is the interquartile distance so the box contains the middle 50 percentage of value in a group. the darker line inside the box identifies the group median. The larger the box, the greater the spread of the observations. The lines emanating from each box (the whiskers) extend to the smallest and largest observations(marked by X) in a group that are less than one interquartile range from the end of the box.

Figure 7-7: *E.coli* range and SWQC

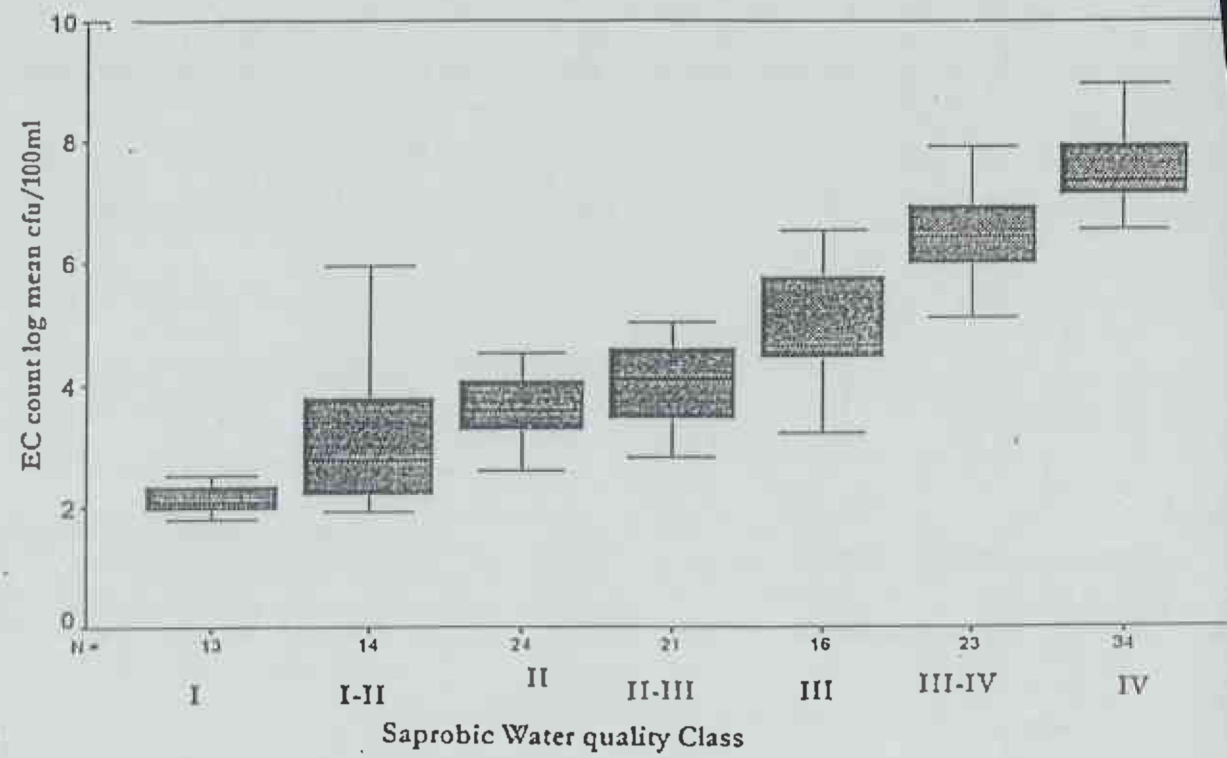
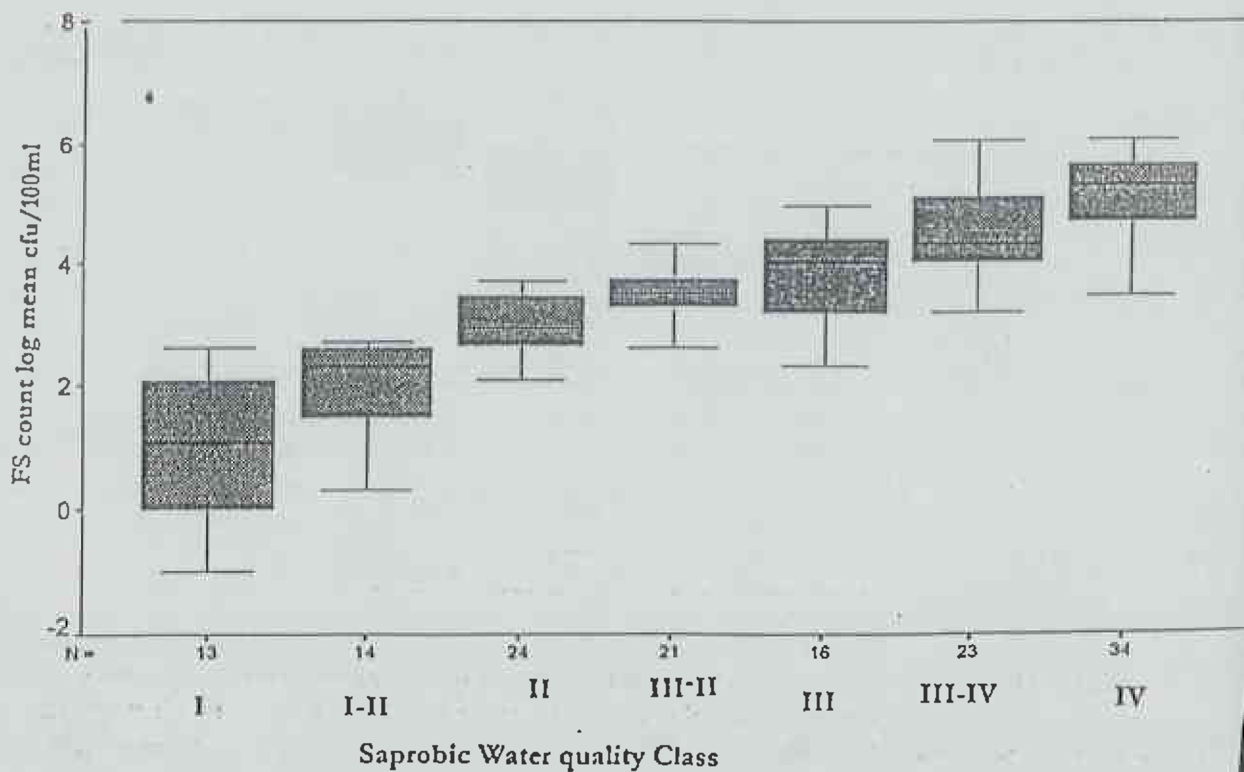


Figure 7-8: Faecal streptococcus range and SWQC



From the figure 7.6 to figure 7.8, it can be concluded for each bacterial parameter that the distribution bacteral number for each water quality class is not uniform but the median value of each parameter is not overlapped. There is less overlapping among the main saprobioc water quality classes.
From the above discussion it is clear that mean value and minimum and maximum range of each bacterial parameter can be considered for each SWQC because it has considered the bacteria mean and minimum and maximum range of two extreme seasons. For more precise bacterial range the study recommend for routine monitoring of bacterial parameter for each SWQC

The range of bacteria shown by SWQC with reference to all parameters, only SWQC class I and I- II can be used for raw water potable abstraction (EC standard) with treatment A2 and class II with A3 treatment.

(2) By river profile region

River profile region plays an important role in SWQC. To know the overall bacterial quality with respect to river profile region, the analysis of the same three bacterial parameter are used.

(a) Heterotrophic Plate count (HPC)

According to the results shown in Table 7.7, the distribution pattern of HPC is varied strikingly by location. It ranges from 539 cfu/ml to 912 cfu/ml in the upper headwater region in post-monsoon season. Both maximum and minimum values have increased for the sites located in the downstream and further increased considerably in the middle valley section. Undoubtedly, in the downward of the middle valley section, both values have decreased sharply.

The range of variation of heterotrophic plate count becomes clear when it is measured in terms of coefficient of variation (Table 7.7). The percentage coefficient of variation for the upper headwater region is the lowest, that is 18. The highest coefficient of variation has occurred in the lower valley section. It means this section includes many sites having relatively low cfu/ml but few sites with high cfu/ml. Similar pattern is seen in the lower headwater section, where the coefficient of variation is higher than in its neighbour sections, such as upper headwater section and upper valley section. The coefficient of variation percent of the two Tarai sites is slightly higher than that of the upper headwater section.

Table 7-7: Distribution pattern of heterotrophic count by spatial location based on post-monsoon season.

River profile	cfu/ml		Parameters		No. of
Region	Minimum	Maximum	Mean	CV %	Sites
HWU	539	912	718	18	8
HWL	1233	2.0×10^5	26040	212	12
VRU	7833	2.2×10^6	76286	145	19
VRM	29300	4.1×10^7	1.2×10^7	99	25
VRL	1000	2.1×10^7	2.9×10^6	229	9
LW	5600	19667	12633	24	2
Total/Average	539	5.6×10^6	5.3×10^5	213	75

Source: *Field survey (1995-96).*

The mean cfu total plate count has decreased significantly downstream of Kathmandu city and further decreased drastically beyond the valley region in the Tarai plain. Thus it is evident that in the sections downward of the middle valley section, the Bagmati river has improved its water quality in terms of cfu of heterotrophic count which may be because of self purification as well as mixing of additional hilly fresh stream water into the main river system.

While comparing the mean heterotrophic plate count i.e. colony forming unit (cfu) counted at 22°C for the region with WHO standard, the water at head water region is not recommended for direct drinking, (cfu/ml = 100 at 22°C), but it could be used for potable abstraction with treatment type A1[7] and A2 according to E.C standard but other regions are not recommended for potable abstraction.

(b) *Escherichia coli*

The results of the variability of *E. coli* distribution by spatial location, and their minimum and maximum values by river profile region are depicted in Table 7.8.

Table 7-8: Distribution pattern of *E coli* by spatial location based on post-monsoon season.

River profile	cfu/100 ml		Parameters		No. of
Region	Minimum	Maximum	Mean	CV %	Sites
HWU	60	173	117	47	8
HWL	83	103700	16714	187	12
VRU	1300	2163330	166158	297	19
VRM	39300	4900000	1757839	103	25
VRL	1000	366700	2883463	229	9
LW	386	633	509	24	2
Total/Average	60	4.1×10^7	6.2×10^6	147	75

Source: *Field survey (1995-96).*

The results from Table 7.8 exhibit a marked variation in coefficient percentage in terms of cfu/100 ml by river profile region, indicating low in the upper headwater region (HWU) and then rising and falling in downward sections; with maximum variation in the upper valley region (VRU). It means there exist few sites with relatively better water quality and many sites with poorer water quality in the VRU. The middle valley section (VRM) exhibits poorest water quality in all respects but however the coefficient variation (CV) is moderate. This signifies that most of the sites of this section have more or less similar number of cfu/100 ml. In other words, the range of variation among the sites is not so high. Though the percent of coefficient variation is lowest in the low-water region (LWR) which is mainly due to very few sample sites, it is the upper headwater region which has the lowest mean cfu/100 ml.

Like as in heterotrophic count, E. coli (cfu/100ml) number is also very high even in head water region, and water can not be recommended to drink directly from WHO standard(cfu/100 = 0) with reference its mean number. However, water from head water could be used as potable abstract after A2[8] and A3 treatment but water from other regions can not be recommended for any other purposes like irrigation or bathing. Even for irrigation E. coli number should not be

[7] EC standards for surface water used for potable abstractions for HPC (Directive 80/778/ EEC).
A1= Simple physical treatment and disinfection (100cfu/ml)
A2= Normal full physical and chemical treatment with disinfection.(5000 cfu/ml)
A3= Intensive physical and chemical treatment with disinfection (50000 cfu/ml)

[8] EC standards for surface water used for potable abstractions for E. coli (Directive 80/778/ EEC)
A1= Simple physical treatment and disinfection (20cfu/100ml)
A2= Normal full physical and chemical treatment with disinfection.(2000 cfu/100ml)
A3= Intensive physical and chemical treatment with disinfection (20000 cfu/100ml)

more than 100 cfu /100ml.if the water is used for unrestricted irrigation. This standard may be relaxed when the crop is not intended for human consumption (Pescod 1977).

(c) Faecal Streptococcus

Like heterotrophic plate count and *E. coli*, faecal streptococcus (FS) has also changed in cfu/100 ml among different sample locations. As noted earlier, faecal streptococcus is closely associated with *E. coli* as both of them belong to the bacteria indicating faecal contamination. The lowest minimum and maximum values are found in the upper headwater region and the numbers in both minimum and maximum increase downward stream sections (Table 7.7). There is highest FS coefficient of variation in percentage in the upper headwater region. The highest number of FS in the middle valley region indicates that the river water has received untreated sewage and organic wastes including vegetation. The general pattern of coefficient variation of FS corresponds with that of *E. coli* except in the upper headwater section.

Table 7-9: Distribution pattern of faecal streptococcus by spatial location based on post-monsoon season

River profile	cfu/100 ml		Parameters		No. of
Region	Minimum	Maximum	Mean	CV %	Sites
HWU	0.1	100	55	150	8
HWL	2	3030	691	137	12
VRU	121	90000	12449	197	19
VRM	200	168000	44742	111	25
VRL	500	110100	22413	151	9
LW	300	400	350	14	2
Total/Average	0.1	168000	20303	185	75

Source: *Field survey (1995-96).*

Water from head water region is not recommended for direct drinking in this case also (WHO standard for faecal streptococcus is 0/100ml) but recommended for potable abstraction with A2[9] and A3 treatment.

(ii) Seasonal pattern

Season is next important factor to cause variation in the occurrence of bacterial number in river water in the study region. The pre-monsoon climate of the valley is characterised by dry and hot with an average daily temperature variation of 30⁰C and 8⁰C. There is pronounced variation seasonally particularly in the river water volume and velocity between post- and pre-monsoon which is mainly typified by cool and moist. The low water volume and velocity of the streams in post-monsoon is mainly due to dry period as they are rainfed streams. Some of the tributaries of the Bagmati river system get dry. This characteristic feature obviously reflects in changing the occurrence of bacterial number between two seasons.

[9] EC standards for surface water used for potable abstractions for Faecal streptococcus (Directive 80/778/ EEC)
A1= Simple physical treatment and disinfection (20cfu/100ml)
A2= Normal full physical and chemical treatment with disinfection.(1000 cfu/100ml)
A3= Intensive physical and chemical treatment with disinfection (10000 cfu/100ml)

(a) Heterotrophic count

On the whole, the mean value of heterotrophic plate count (HPC) in pre-monsoon is far higher than in post- monsoon. The general trend of HPC in terms of mean, and minimum and maximum values by different location is more or less the same between the two seasons. The mean value in both seasons is found increasing downward streams up to the valley's middle section (VRM) and then decreasing. From the upper headwater section (HWU) to the upper valley section (VRU) the mean values in pre-monsoon appear to be higher than those in post-monsoon but downward of VRU the mean HC values are slightly increased in post-monsoon than in pre-monsoon.

Looking at the minimum values of HPC, there is a great variation between post- and pre-monsoon for all locations. But in case of maximum value, there is not so much variation between the two seasons, though a bit of higher value has occurred in pre-monsoon than in post - monsoon in most locations.

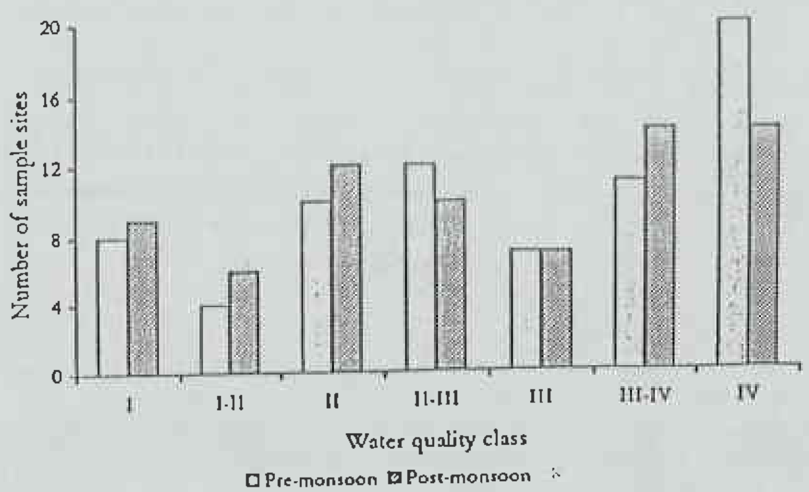
In terms of coefficient of variation (CV) analysis, the magnitude of percentage change for three profile regions in pre-monsoon is found less than in post-monsoon. Second, the degree of coefficient variation percent is increased downward up to the VRU and then is decreased towards lower region in VRM in both seasons. Thirdly, the VRL shows the highest coefficient of variation percent in post season while the HWU in pre-monsoon and again is increased in VRL only in post-monsoon.

Table 7-10: Heterotrophic count cfu/ml. by season

River profile Region	Mean		CV %		Minimum		Maximum	
	PO	PR	PO	PR	PO	PR	PO	PR
HWU	718	2680	18	51	539	1413	912	4350
HWL	26040	8.2×10^4	212	83	1233	4855	2.0×10^5	2.1×10^5
VRU	76286	3.2×10^5	145	231	7833	8500	2.2×10^6	3.1×10^6
VRM	1.2×10^7	7.8×10^6	99	179	29300	57500	4.1×10^7	5.2×10^7
VRL	2.9×10^6	1.9×10^6	229	160	1000	26000	2.1×10^7	9.7×10^6
LW	12633	*	24	*	5600	*	19667	*
Total/Average	5.3×10^5	2.2×10^6	213	329	539	1413	5.6×10^6	5.2×10^7

PO = post-monsoon; PR = pre-monsoon. * Sample sites not covered.

Figure 7.9: *Change in Saprobic Water Quality Class by season*



As noted earlier that post-monsoon is just after the rainy season and the observation shows that the water level of most of the streams remain to be medium and medium to low. On the other hand, pre-monsoon lies in dry season and therefore the water level is observed as low to very low. This change in water level due to variation in rainfall pattern is the fundamental reason to cause great differentiation in heterotrophic count between the two seasons; with higher value in pre-monsoon than in post-monsoon. The second important factor for higher heterotrophic count in pre-monsoon is being the more intensity of human interference to the stream. The amount of solid wastes and other organic wastes is found greater with respect to the volume of river water.

According to the saprobic water quality class, there is changed in the number of sample sites between the two seasons. Figure 7.9 shows that the number of sites that belong to Class IV, i.e. poorest saprobic water quality class has increased considerably in pre-monsoon as compared to that in post-monsoon.

(b) *E. coli*

In Table 7-11, *E. coli* count cfu/100 ml shows a great variation in maximum values between post- and pre-monsoon by river profile locations of the sample sites. In case of the minimum values there is less variation between the two seasons. So, there is definitely a great variation in mean and standard deviation of *E. coli* between the two seasons; with their far greater values in pre-monsoon than in post monsoon. But on the whole, there is less coefficient variation in pre-monsoon than in post-monsoon, which is due mainly to overall increase in *E. coli* count in all locations.

Table 7-11: *E. coli* count cfu/100 ml by season

River profile	Mean		CV %		Minimum		Maximum	
Region	PO	PR	PO	PR	PO	PR	PO	PR
HWU	117	420	47	79	60	117	173	891
HWL	16714	5.4×10^4	187	221	83	177	1.0×10^5	3.9×10^5
VRU	1.7×10^6	1.2×10^6	297	211	1300	2500	2.2×10^6	3.1×10^6
VRM	1.2×10^7	2.0×10^8	103	131	39300	3.5×10^6	4.1×10^7	9.0×10^8
VRL	2.9×10^6	3.5×10^6	229	1[10]37	1000	1600	$2. \times 10^7$	1.3×10^7
LW	509	*	24	*	386	*	633	*
Total/Average	6.2×10^6	4.1×10^7	147	217	60	120	4.1×10^7	8.9×10^8

* Sample sites not covered.
PO = Post monsoon season; PR = Pre-monsoon
S.D = Standard deviation, CV = Coefficient of variation

(c) Faecal streptococcus

Faecal streptococcus count cfu/100 ml shown in table 7.12 exhibits similar pattern of change of *E. coli* by river profile locations between the two seasons. The FS count increases progressively downward sections up to VRM in both seasons and then slightly decreases, but with slightly higher numerical values in pre-monsoon than in post-monsoon.

Table 7-12: Faecal streptococcus count cfu/100 ml by season

River profile	Mean		CV %		Minimum		Maximum	
Region	PO	PR	PO	PR	PO	PR	PO	PR
HWU	55	150	150	104	0.1	0.1	100	400
HWL	691	2686	137	197	2	450	3030	$1.8x10^4$
VRU	$1.2x10^4$	$5.6x10^4$	197	200	121	800	$9.0x10^4$	$4.4x10^5$
VRM	$4.4x10^4$	$3.7x10^5$	111	107	200	1600	$1.7x10^5$	$1.2x10^6$
VRL	$2.2x10^4$	$2.5x10^5$	151	141	500	1200	$1.1x10^5$	$1.0x10^6$
LW	350	*	14	*	300	*	400	*
Total/Average	20303	$1.3x10^5$	185	122	0.1	0.1	168000	$1.2x10^6$

* Sample sites not covered. Sample sites not covered.

PO = Post monsoon season; PR = Pre-monsoon; S.D = Standard deviation, CV = Coefficient of variation

(iii) Distribution pattern by steam/river

Attempt is also made to assess the results of the bacterial parameters among the individual streams or rivers as they are flowing through different terrain, rock types, flora and fauna and social and cultural phenomena from different directions to meet the Bagmati river system within and outside of the valley.

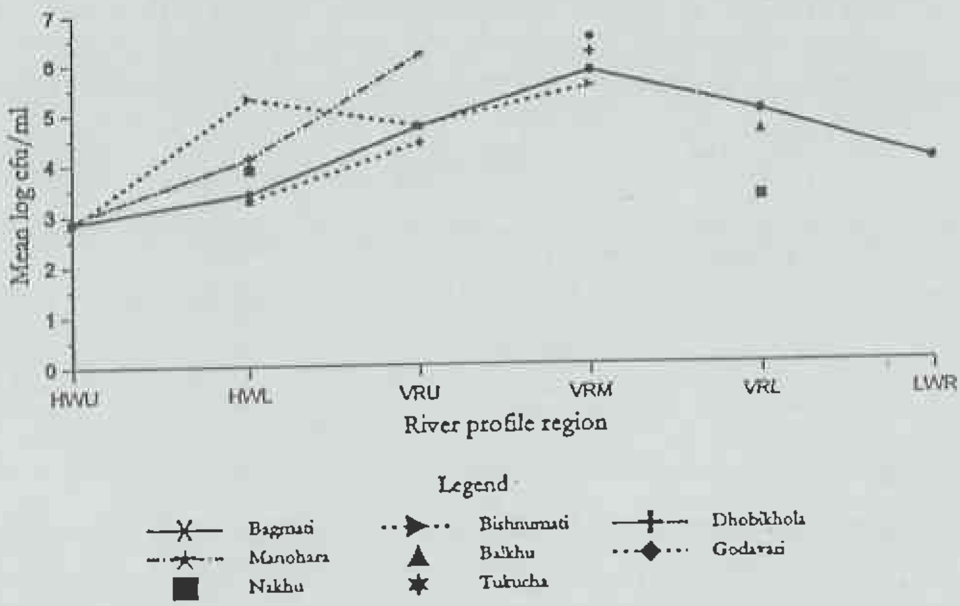
Each of the three bacterial counts of the sample sites along different streams/rivers such as the Bagmati, the Balkhu, the Bishnumati, the Dhobikhola, the Godavari, the Nakhu and the Tukucha together with their associated tributaries is shown in separate figure 7.11. The sample sites located in the small upstream are included in their associated main streams. For instance, the sample sites along the Nagmati and the Syalmati are included in the Bagmati and likewise those along the Mahadev and the Manamati are included in the Bishnumati. The sample sites of all tributaries including the Hanumante are included in the Manohara and so on. The sample sites of the streams that fall in only one river profile region or in two or more intermittent regions are shown in the figure 7.11 by marks.

(a) Heterotrophic count

depicts that there is rising and falling of total plate count among the streams by river profile region. The total plate count of almost all sample sites in the upper headwater section begins with slightly less than mean log 3 cfu/ml. The numerical value is highest for the sites along the Bishnumati in the lower section of the headwater region. Next to it is the Manohara in

the lower headwater section which is followed by the Nakhu in the downstream section. The Manohara shows the highest mean heterotrophic plate count (HPC) value when it arrives in the upper valley section while the Tukucha, whose all sample sites lie within the valley middle section, shows the highest total plate counts with mean log cfu of 6.5/ml among the streams in the valley middle section. It is followed by the Dhobikhola. There is rising in the level of HPC for the Bagmati together with its upstream tributaries up to the valley middle section and then the level decreases. But this level is higher than its downstream tributaries such as the Balkhu and the Nakhu in the lower section of the valley region. The level of HPC further decreases in the downstream in the Tarai region but remains higher than that of the valley lower section.

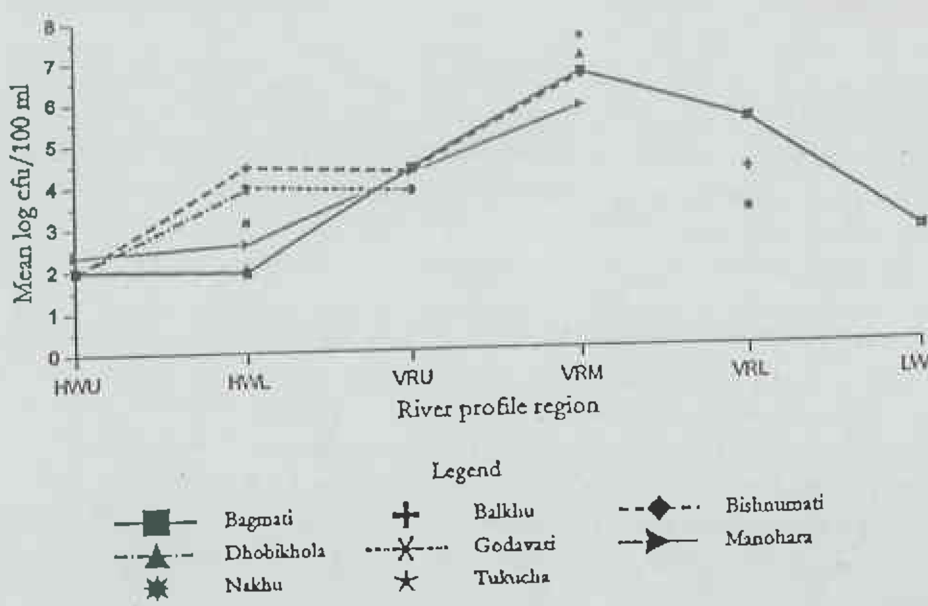
Figure 7-10: Heterotrophic count by river



(b) *E. coli*

The *E. coli* count has risen gradually for all sample sites of the rivers from the upper headwater section with more or less similar trend of change in down stream (Figure 7-11). The figure shows that there is sharp rising of *E. coli* count for all the streams in the lower section of the headwater region and the value reaches maximum in the valley middle section where the Tukucha has recorded the highest value and followed it by the Dhobikhola. The Manohara shows the lowest. The *E. coli* value declines afterwards in the downstream and further declines in the low-water region, but however the value is remained to be higher than those recorded in both headwater sections of the Bagmati.

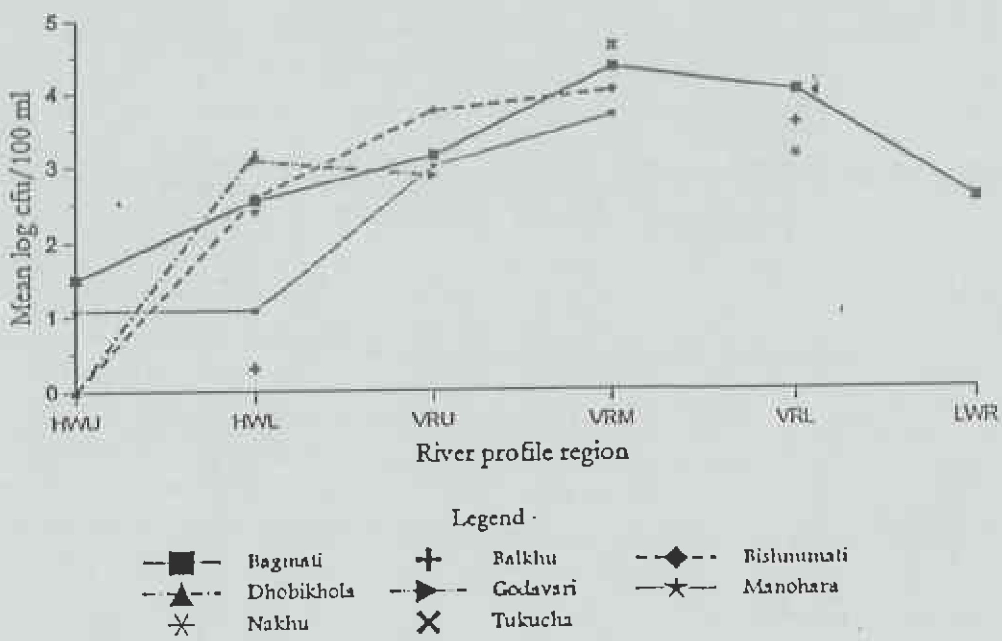
Figure 7-11: *E. coli* count by river



(c) Faecal streptococci

Like *E. coli*, the trend of change in the value of faecal streptococci (FS) also shows fluctuating with rising and declining (Figure 7-12). In FS the valley middle section shows the highest recording of values for all the upstream rivers. Two streams such as the Bishnumati and the Dhobikhola show 0.1 cfu/100ml value in the upper headwater section but their values surpass over other upstream in the lower headwater section. The Tukucha and the Dhobikhola show the highest FS value in the middle valley section. The Bagmati and other downstream rivers show declining value of FS in downward sections.

Figure 7-12: Faecal streptococci count by river



It is evident that the sample sites along the rivers considered in this study show more or less similar trend for the three bacterial parameters. The general trend pattern is that the Bagmati together with its upstream tributaries show rising value up to the valley's middle section and then declining, where downstream tributaries meet with it. Of the rivers, the Tukucha and the Dhobikhola are the most polluted in terms of three bacteria, as they show the largest values.

(d) Bacterial quality state of springs

The description of bacterial condition of springs or *Kunds* is made in this section because of their peculiar physical characteristics as compared with those of the streams. All four *kunds* considered in this study fall in the upper headwater region. They are well protected drinking water supply sources. Naturally, the sate of the water is best quality. Table 7.13 demonstrates that all four have shown zero faecal streptococcus, and two sources - Matartirth and Naudhara - have also shown zero *E. coli* which means their water is free from faecal contamination while other two sources such as Godavari and Gaurikund have recorded *E. coli* 60 and 5 per 100 ml respectively. This appears not unnatural since they are less protected than the former two sources and where there has been observed often the human influence such as of religious devotees.

Table 7.13: Mean numerical count of three bacterial parameters in springs

(a) *Post-monsoon*

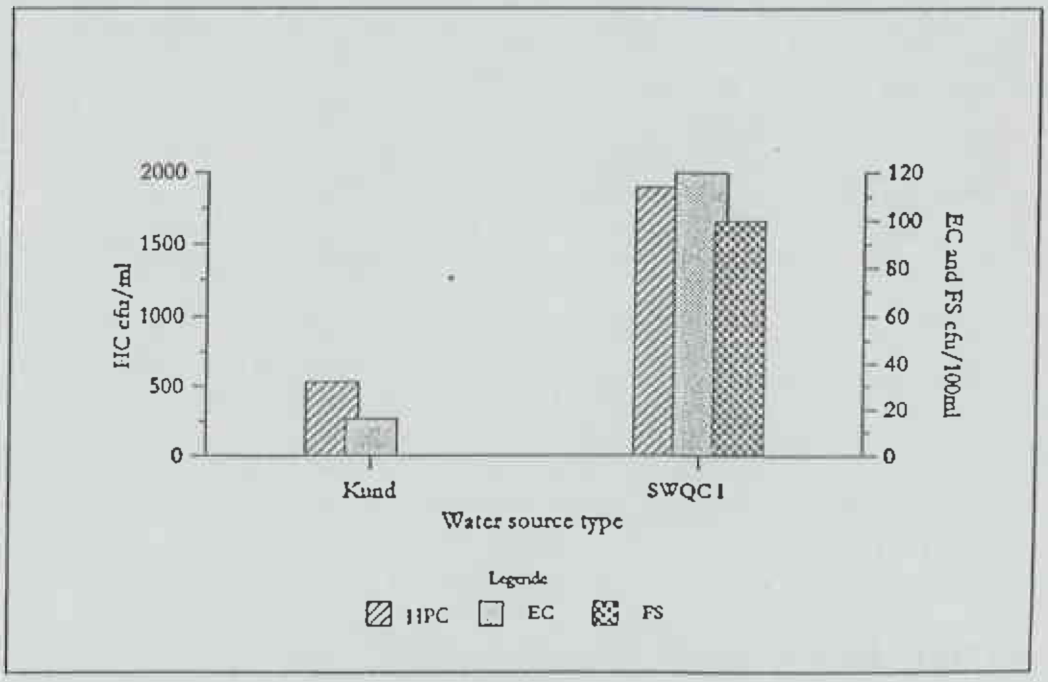
Source names	HPC/ml	EC/100ml	FS/100 ml
Gaurikund	140	5	0
Godavarikund	337	60	0
Matatirthkund	1573	0	0
Naudhara	90	0	0

(b) *Pre-monsoon*

Source names	HPC/ml	EC/100ml	FS/100 ml
Gaurikund	201	7	0
Godavarikund	2000	30	0
Matatirthkund	1950	3	0
Naudhara	91	0	0

Source: *Field survey (1995-96)*

Figure 7-13: Comparison of three bacterial parameter numerical values between *kund* and stream water with SWQC I



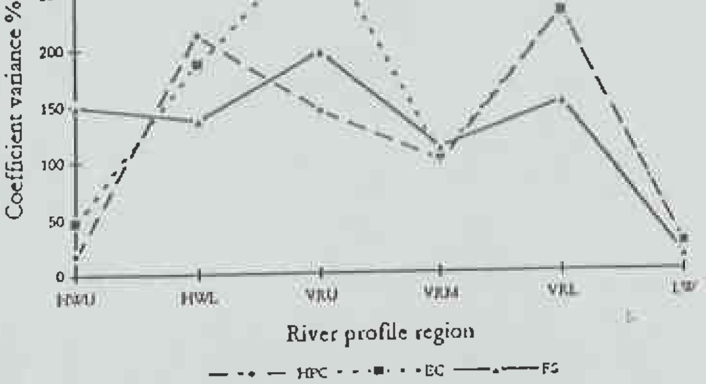
As stated earlier that the water of the *kunds* is protected from general human interference and is used as safe drinking water. However unprotected *kunds* are not normally safe for direct use for drinking as few number of *E. coli* bacteria are recorded (Figure 7-13). Stated also is that the bacterial numerical values of *kund* can be taken as reference for best water quality in the present study.

As the comparison of the bacterial numerical values between HPC, EC and FS of the stream water quality class I and *kunds* is made in Figure 7-13, all values of the stream water quality class I are well above those of *kunds*. It indicates that the best quality stream water in the headwater region is not protected from the general human and other interference. So, bacterial point of view, the stream water in upstream is not safe for drinking purpose. However, it can be used as raw water abstraction.

7.2.2 Discussions on the Bacterial Results

It is evident that no streams are free from *E. coli* bacteria which is not indeed unnatural but the numbers are unusually high. Even in the upper section of the headwater region, the sample sites have shown *E. coli* with minimum of 60 cfu/ml. This result is verified with that of ENPHO's study (1996). In its bacterial study of the headwater streams of the Bagmati and the Bishnumati in the Shivpuri watershed area, the average number of faecal coliform ranged from 8 to 169 cfu/100ml. This can be related chiefly to the unprotected streams in the upper section, though most of their water is being tapped for drinking water supply. Two reasons seem to be important with this regard. One is the settlement pattern of the Tamang ethnic groups who have had settled there since long years ago. The Tamangs are the mountain people who prefer to live on higher elevation where there is cool climate. Their main occupation is agriculture and livestock farming. Since there is no pipe drinking water supply, they have to count on stream water for their domestic use. Second reason is the recreation. The watershed area is well maintained with the forest coverage. There are many picnic spots in the area. But there is no provision for waste disposals created by the picnic goers nor is the prohibition against the disturbance of stream water quality. A high heterotrophic count in the lower headwater section and the upper valley section (figure 7.10) is mainly due to the high intensity of disturbance of human activity in the Manohara and the Nakhu, in particular. There was observed several temporary huts being built on the banks of the rivers by the people indulging in sand and gravel quarrying activity from the rivers.

Figure 7-14: Coefficient of variation analysis of three bacterial parameters



- Another observation is that there is a change in distribution pattern of all three bacterial parameters by region as shown in figure 7.14. The figure brings out the following features:

First, there is a mixed result in terms of coefficient variation among the three parameters by river profile location. Except the Tarai sample sites, the least coefficient variation in percentage of HPC and EC has occurred in the upper headwater section while that of FS in the middle valley section. The highest coefficient of variation of HPC is seen in the lower valley section, and of FS in the upper headwater section. Second, the low variation of all three parameters has occurred in the valley's middle section. Their coefficient variation percentage values are converged at about single point in the graph in the middle section of the valley, though this section has shown the largest enumeration number of all the bacteria. This means that the sample sites located in this section has possessed more or less similar bacterial numerical values. In other words, the pollution level is more or less the same for all sites. Third, though the sample locations of the headwater upper section show the least bacterial numerical values, there is great variation among themselves. Fourth, the downward stream sites in the lower headwater region which are not protected, have shown higher bacterial numerical values. Fifth, the coefficient variation between HPC and EC among the sample locations has more or less similar and tends to vary greatly. While FS is not varied greatly among the locations, except the Tarai sites. And sixth, the trend of variation among the parameters by region is not the same. In case of HWU, FS is the highest variation and the HPC is the least; in the HWL, HPC is the greatest variation while FS is the least. In two regions: VRU and VRL, EC is the highest variation and HPC is the least. This in not unnatural because geographically they lie in the lower part of the foot-hills.

While comparing the immission value for river for different bacterial parameter as shown in table 7.13 water quality of Bagmati river system only upper head water region is within the immission value for a river. In case of saprobic water quality class from water quality class I ; I-II and 50 % sites of II and 25 % sites of II-III for all three bacterial parameters.

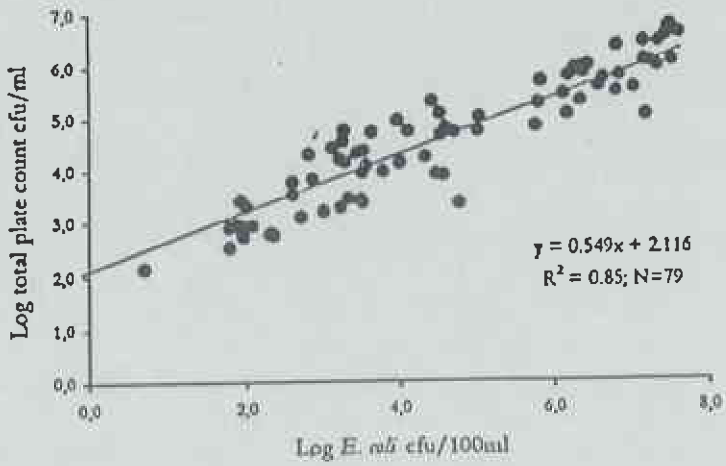
Table 7.14: Bacteriological Immission value for river water

Parameter	Immission value
Heterotrophic Plate Count (HPC) cfu/ml	10000
Total coliform cfu/100ml	10000
Faecal coliform cfu/100ml	2000
Escherichia coli cfu/100ml	2000
Faecal streptococcus cfu/100ml	400
Salmonella positive %	10

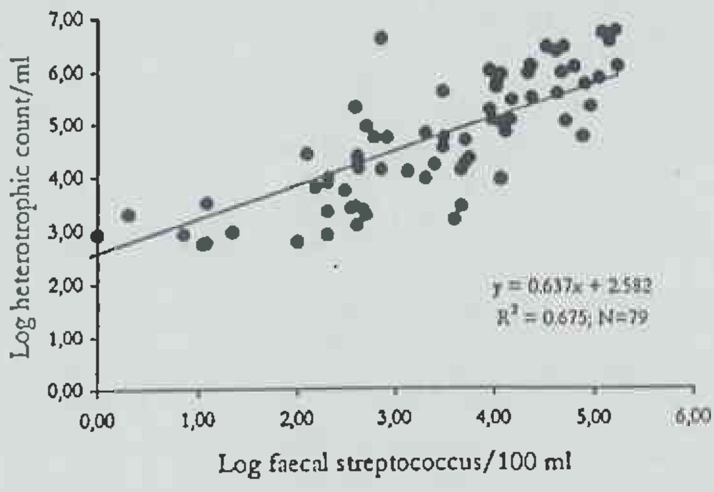
Source: Kavka (1994)

Figure 7.15: Statistical relationships among the bacterial parameters

(a) *E. coli* and total plate count



b) Faecal streptococci and total plate count



- It is observed that there is high positive correlation ($r^2=0.85$) between *E. coli* and total plate count in the study region (Figure 7.15 a) though these two bacterial parameters are used for different purposes former is mainly as hygienic parameter while latter to assess pollution of the river. The high correlation value support that the pollution is raw domestic sewage. The coefficient of determination between faecal streptococcus and total plate count is slightly low, but it is positive (figure 7.15 b).

7.2.3 Cross Section, Daily and Diel Analysis

In the cross section analysis, the study of the river pulse was performed at a specific site no. 43 of the Bagmati river for all three bacteria. Three replicates of the cross section, daily record for consecutive 7 days and dial change were taken and the mean value of each of the parameter was derived and plotted in individual graph (figure 7.15). The replicates from seven places (sample number) along the cross section of the same sample site number were taken while daily record for 7 consecutive days beginning from Monday through Sunday at ≈ 16:00 hour was taken. The dial record change was conducted every four hour interval beginning at 12:00 hour.

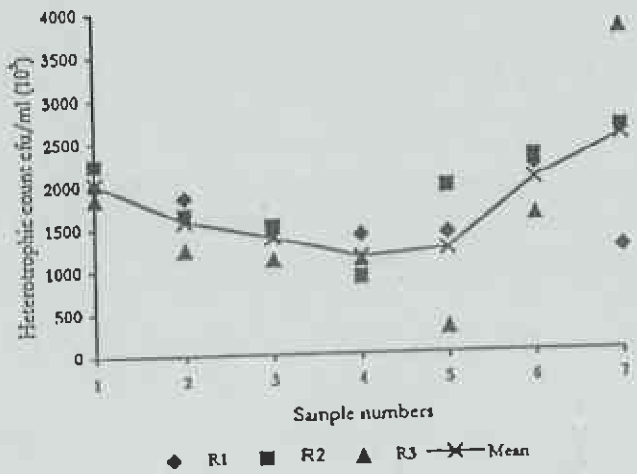
According to figure 7.15 a, the number of heterotrophic plate counts (HPC) along the cross section of the sample site is found to be differed markedly. For example, the number of HPC is greater at both sides of the river bank than in its middle section. This is due to confined river flow at the middle. The right bank has shown greater number of HPC than its left side. The reason is that the right side was observed to have greater access to human activities than the left side.

In figure 7.15b, on the day of Saturday the daily record of heterotrophic count is found highest whereas the lowest on Thursday. The diel change of heterotrophic count is found highest at noon and then decreasing and increasing in other sample times of the day. The number of HPC is found decreasing and reaches lowest at morning (figure 7.15c).

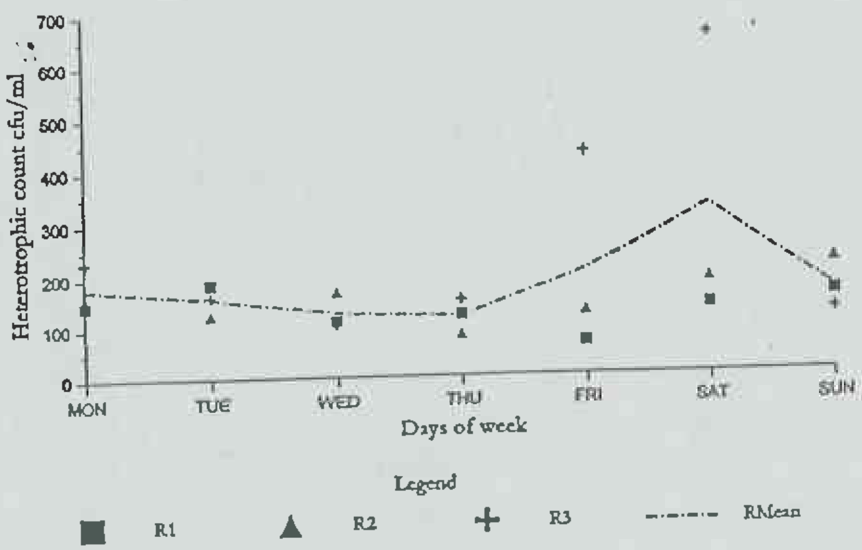
The rising heterotrophic count from Friday through Saturday is coincided with the weekend activity of the people. On Saturday, more activity related to river water such as bathing, washing or visiting temples can be observed than other days except religious or official holidays. The highest HPC at noon may be simply because of rising day temperature or the dumping of organic waste or passing domestic waste by the people early in the morning on the bank of river. A slightly rise of HPC at 20:00 hours may also be due to organic waste passing into the river by the people at evening.

Figure 7-16: Heterotrophic bacterial record in river cross-section analysis

(a) *River cross-section*



(b) *Daily record*



(c) *Diel change*

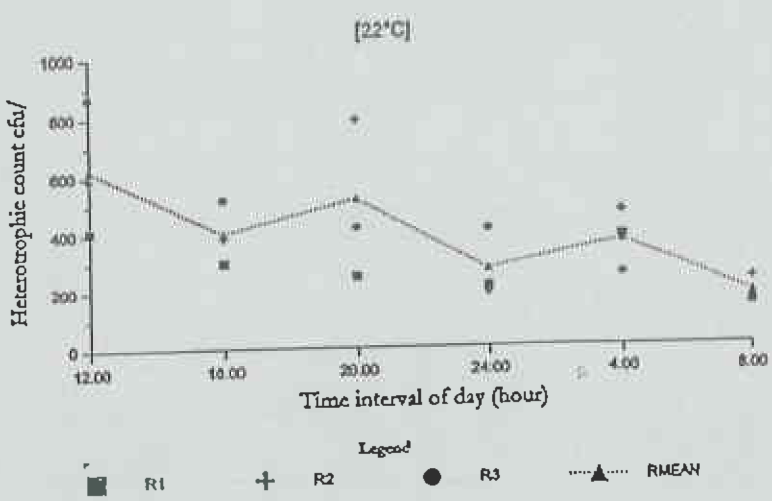
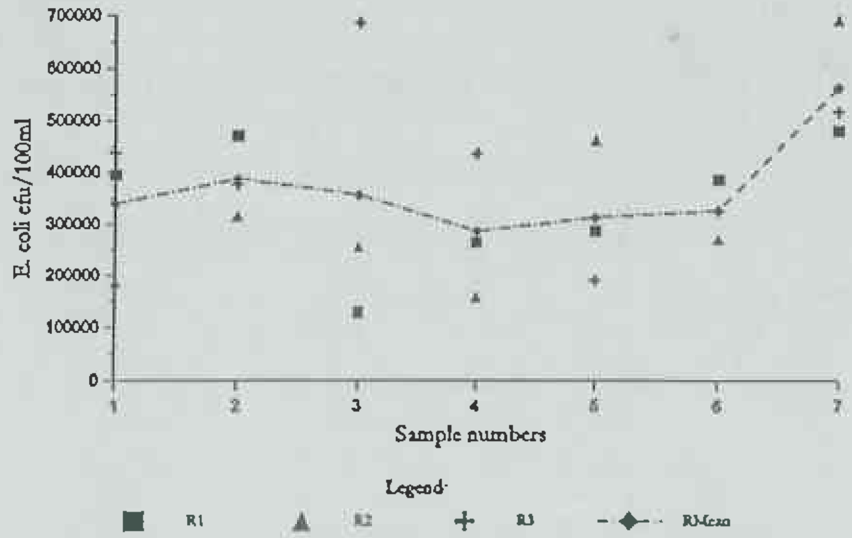
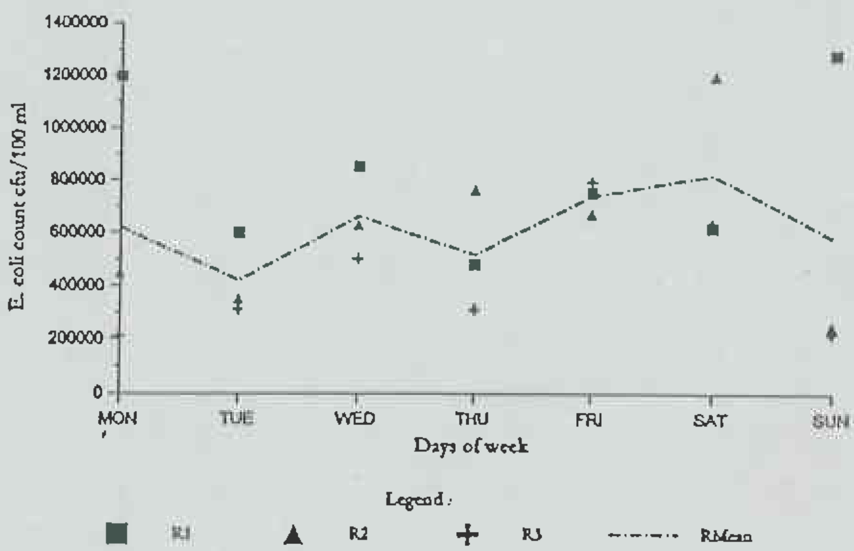


Figure 7-17: *E. coli* record in cross section analysis

(a) *River cross-section*



(b) *Daily record*



(c) *Diel change*

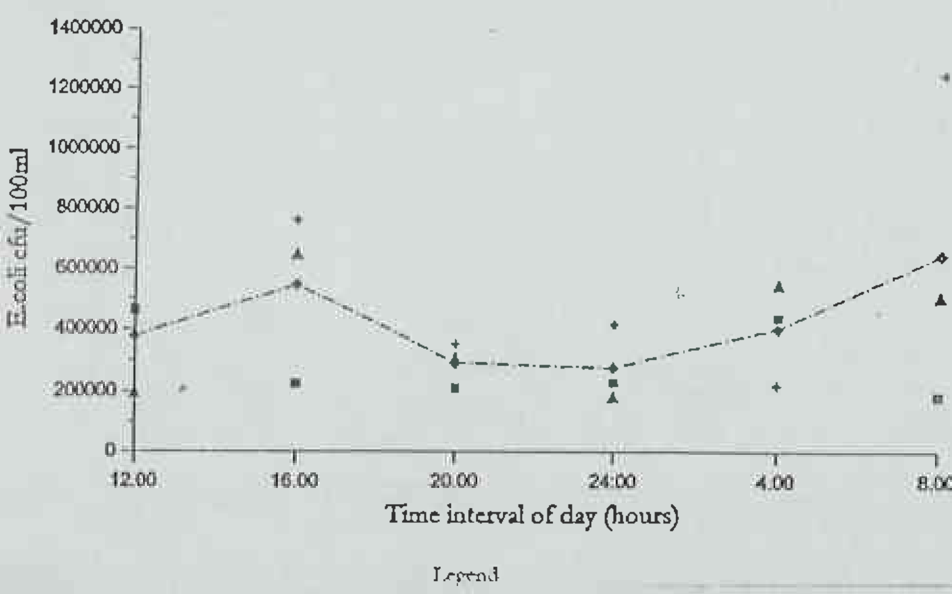
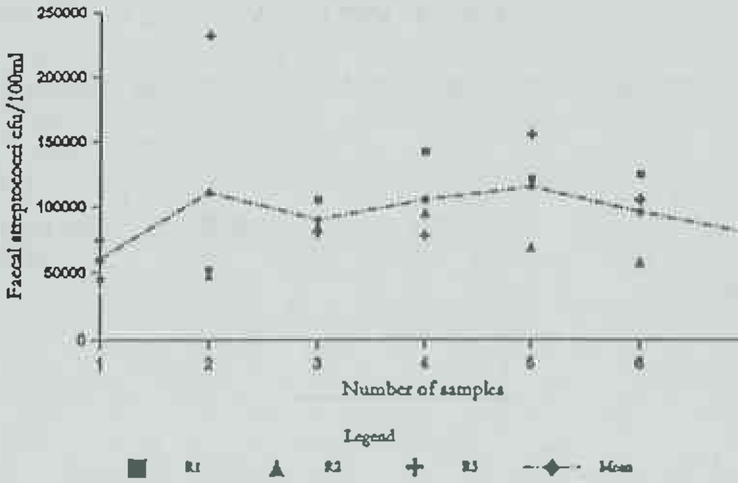
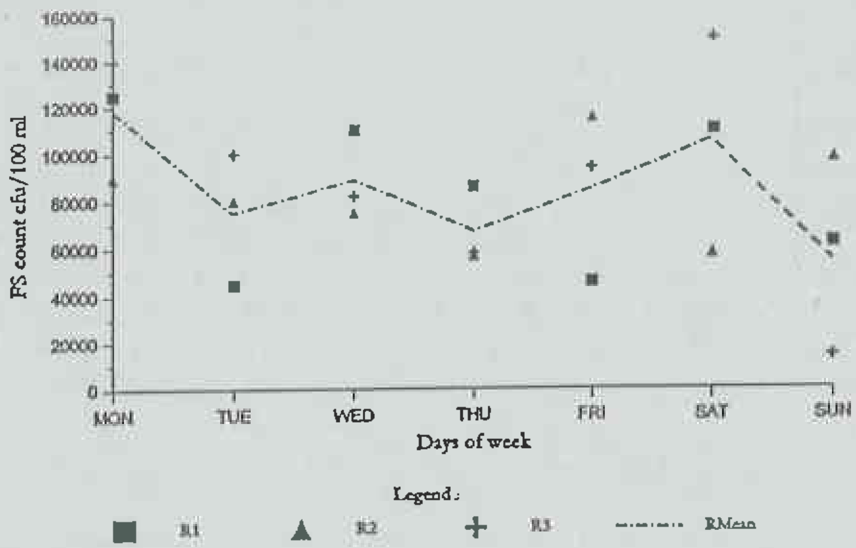


Figure 7-18: Faecal streptococci record in river cross section analysis

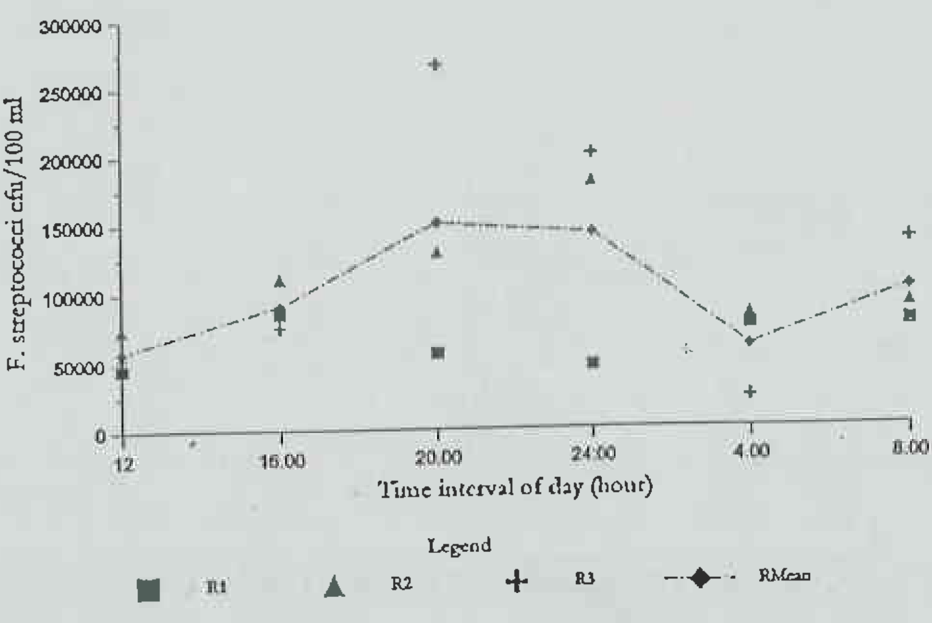
(a) *River cross-section*



(b) *Daily record*



(c) *Diel change*



Note that in Figure 7-17, the maximum change of *E. coli* has occurred on the river's right side and the minimum on the middle of the river course. Saturday has recorded the highest value whereas Tuesday has the lowest. A maximum of diel change has taken place at 08:00 it could be the reason that open defecation by the people very early in the morning on the bank of river.

Similar trend pattern has also occurred in all three river pulse activities for faecal streptococci (Figure 7-18).

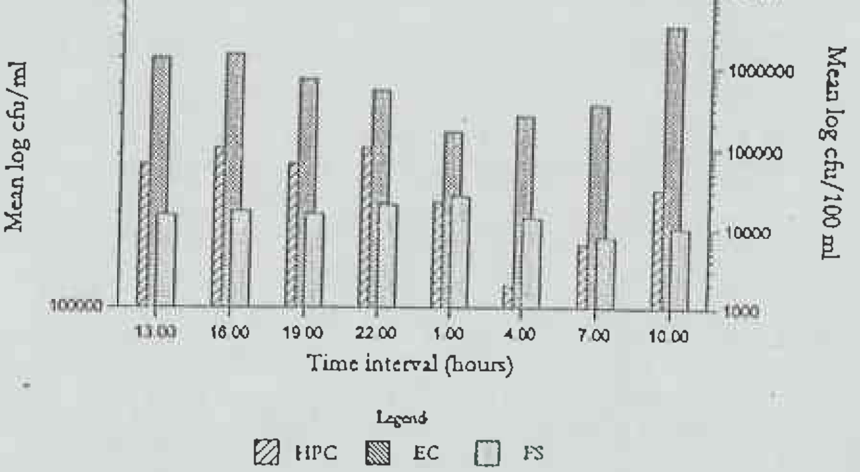
Though the results shown in the figures exhibit some pattern of change of bacterial numbers in the river pulse based on three replicates of one time sample, the sample observations are however not adequate to generalise how exactly the trend pattern occurs because of occurrence of several unrealised or unvisualized factors.

(iv) Diel record at Pashupati temple site

The site number 13 a few meters below the Pashupati temple located on the bank of the Bagmati river was also selected for river pulse analysis including only diel record change of all three parameters at every 3 hour beginning at 13:00 hour. The temple is one of the famous and most important Hindu religious places in terms of number of shelter houses for pilgrims or devotees, and others where religious activities of the Hindu devotees occur daily and burning of human dead bodies takes place almost daily.

In Figure 7-19, mean log cfu of heterotrophic count/ml is plotted along the Y_1-axis, mean log cfu of *E. coli* and faecal streptococci per 100 ml along the Y_2-axis and a-three hour time interval along the X-axis. The pattern of diel recording between *E. coli* and HPC is more or less similar such as declining trend of the values towards night time from afternoon and rising afterwards from early in the morning. Of these two, *E. coli* mean count has reached maximum with 3.3 X 10^5 at 10:00 in the morning while the mean HPC reaches its maximum value with 3.2 X 10^5 at 16:00 hours. The faecal streptococci record shows fluctuating trend with rising gradually from the time of first record up to 1:00 in the early morning, the next day at which time it rises with maximum value of cfu 2500/100 ml and decreases until 7:00 and then again rises.

Figure 7.19: Diel record at the Pashupati temple site



HPC = Heterotrophic plate count, EC = E coli, FS =. Faecal streptococcus

The general trend of diel record change of the bacteria can be related to daily activities. Worshipping of the Pashupati god and goddesses takes place daily early in the morning. Before the performance of this activity, bathing in the holy river Bagmati occurs. As there are limited public toilets or most general people of the temple area have no access to toilets, open defecation usually takes place early in the morning. Therefore the recording of *E. coli* has reached maximum until 10:00 in the morning and then gradually declines along with the declining activity of the people with the river water. There is no time limit of human dead body for cremation, and therefore the cremation takes place throughout the day and night, if any. The results are based on three replicates of only one day however. If such recording is taken for a week or longer in a routine basis, the results would be more convincing.

It is to be noted that the streams and rivers in Nepal are socially and culturally attached with the people for their day to day activity and from birth to death. Rivers are holy places and during several occasions in a year religious activities occur. As the right bank of river is the site for temples and pilgrim houses, as well as for cremation in most cases, these make more access of people to the right bank. Moreover, the river banks in such densely built urban area are the places for domestic waste disposal, open defecation and untreated sewage discharge.

It can be concluded that the general principle of water sample that should be collected from the middle part of the river for adequately well representation can be ruled out because the number of bacteria from mere this site count may be underestimated. This is evidenced by the result of this study. So, in Nepal it is difficult to generalise the bacterial count from mere considering one single side, i.e. middle, right, or left of the river. It is therefore suggested that mixed water samples along the cross-section be taken.

7.2.4 Bacterial Biomass analysis

The biomass of bacterial population is one the most basic parameters in microbial ecology. Knowing the biomass, population activity and nutrition level of water bodies can be evaluated. The biomass of a bacterial population defined as the mass of living bacteria in a given habitat (Bratbak 1993). The biomass is in practice very difficult to determine and most methods have therefore aimed at measuring a parameter that is assumed to correlate with biomass. These parameters include total cell counts as well as several different chemical constituents such as lipopolysaccaride, muramic acid, bacteriochlorophyll, specific lipids etc. The most popular method has been used to estimate bacterial biomass from cell volume in combination with total cell counts, the present study has also used this method to estimate biomass.

Direct bacterial count is calculated on the basis of Equation 1/ VII and detail methodology is given in chapter III.

$$N[Bak/ml] = \frac{Na \times Fg \times Df}{Fa \times V_{fil}} \quad \text{.......................... Eq 1/ VII}$$

Na = Counted Bacteria

Fg = Area of Filter $(188.69 \times 10^6 \mu m^2)$

Df = *Dilution factor(100 ml sample + 5 ml Formal* $= \frac{105}{100} = 1.05$

Fa = Counted Area of the Filter $(6084 \mu m^2)$ *and* V_{fil} *= Filtrated volume(ml).*

The bacterial biomass analysis is based on two methods: in first case the direct or total count of bacteria and bacterial volume are considered. The biovolume is obtained by using image analysis technique in combination with the epifluorescence microscope and the cell carbon content is calculated from the given equation Eq 2/ VII and also from the conversion factors for volume. Two conversion factors 350 fg C μm^{-3} (Lee 1993) and 200 fg C μm^{-3} (Bratbak 1984) are used separately to calculate biomass to see the difference in biomass. In the second method biomass is obtained by multiplying conversion factor to the number of total count. The constant for this is taken as 20 fg carbon $cell^{-1}$ (Lee and Fuhrman 1987).

The bacterial volume is computed by using the computer software program Kontrol electronic GmbH Kontrol Imaging system KS 400 (1995). The shape of bacteria varies from spherical to elliptical. In this study, the elliptical shape is considered in the equation to determine the volume of bacteria however, the equation is also applied to compute spherical shape of bacteria. The mean volume of bacteria is computed for each site and multiplying with the mean number of total bacterial count and with constants gives the biomass of bacteria of the site. To compute biomass as well as volume the equations are given below.

(a) equation to compute biomass of the bacteria

$$Biomass\ (\mu g\ C/l) = \frac{N \times a \times (V_m)^{b}}{10^3} \quad \text{.....................Eq 2/ VII}$$

Where N = Bacterial number/ml, a = 0.12, b = 0.72, and Vm = Mean volume (μm^3)

(b) equation to compute volume of bacteria :

Volume (elliptical shape) = (elliptical A) × [(elliptical B) × (elliptical B)] × 3.14 × (4/3).

Where A = Longest axis from the centre of elliptical shape; B = Shortest axis from the centre of the elliptical shape.

The relationship between heterotrophic count and direct count of bacteria is measured as the ratio of direct count divided by total count. The heterotrophic count as percentage of direct count is also computed. The ratio value is high in WQC I and the value is decreased as the WQC becomes poorer. As depicted in Table 7.15 the mean ratio of total count (TC) and heterotrophic plate count (HPC) computed for each SWQC indicates that there is high variation in the values i.e. the pattern of change in the ratio values is not regular according to the water quality class, nevertheless the ratio is highest in water quality class I and decreases with the deterioration of the quality and it is recorded lowest in SWQC IV. The percentage of heterotrophic count with reference to direct count is increased along with poorer water quality classes. This indicates that there is a decrease of oligotrophic microflora in polluted water which is dominant in unpolluted water (Gagin *et al.* 1990; Kavka *et al.* 1996).

Figure 7-20 shows that although there is a greater variation while comparing the number of direct bacterial count and water quality classes but the mean bacterial count increases with the deterioration of water quality classes. Biomass of the bacteria also increases with the deterioration of water quality class (Figure 7-21).

Table 7.15: Values of heterotrophic count, direct count and their ratio, and volume

SS	SWQC	HPC cfu/ml	TC cell/ml	TC/HPC	%	Volume	Biomass
27	I	1123	374333	333	0.3	0.14	10
28	I	1032	258000	250	0.4	0.13	7
29	I	1050	210000	200	0.5	0.18	7
32	I	887	221750	250	0.4	0.17	7
35	I	1013	168833	167	0.6	0.16	5
18	I-II	8834	1104250	125	0.8	0.11	26
19	I-II	28976	1819555	63	1.6	0.06	25
38	I-II	3117	389625	125	0.8	0.12	10
76	I-II	2537	202960	80	1.3	0.17	6
78	I-II	1944	216000	111	0.9	0.04	2
7	II	53217	4837909	91	1.1	0.15	140
24	II	43967	3097000	70	1.4	0.08	56
30	II	8490	1061250	125	0.8	0.09	21
31	II	14779	1343545	91	1.1	0.12	33
47	II	8392	849000	101	1.0	0.07	14
3	II-III	71058	2552900	36	2.8	0.04	27
12	II-III	3770	290000	77	1.3	0.18	10
21	II-III	13025	1184090	91	1.1	0.13	30
33	II-III	85378	6567538	77	1.3	0.06	93
48	II-III	68534	6230363	91	1.1	0.12	153
9	III	11617	1452125	125	0.8	0.10	30
16	III	121534	5787333	48	2.1	0.10	119
17	III	150167	9726357	65	1.5	0.12	239
53	III	260334	18595285	71	1.4	0.13	486
69	III	32167	1787055	56	1.8	0.05	22
8	III-IV	62500	5208333	83	1.2	0.07	82
10	III-IV	565479	17123250	30	3.3	0.01	60
13	III-IV	411500	11595238	28	3.5	0.05	154
62	III-IV	135834	6468285	48	2.1	0.04	67
77	III-IV	1163697	26547880	23	4.4	0.06	391
4	IV	2230503	40020120	18	5.6	0.04	430
5	IV	2716911	53272770	20	5.1	0.03	464
6	IV	1864470	48784428	26	3.8	0.06	710
41	IV	3860000	84516129	22	4.6	0.04	941
42	IV	4662486	86499440	19	5.4	0.07	1382

Note: SS = sample site number; SWQC = water quality class; Percent (%) = percent of HPC to TC; TC/HPC = total count/heterotrophic plate count. Const. = constant.

It is recorded lowest in SWQC I while highest in SWQC IV. Heterotrophic bacteria plays a significant role in metabolic activity in marine as well as freshwater systems, converting dissolved and particulate organic carbon into bacterial biomass and inorganic carbon (Garnier et al 1992)). In this context only a fraction of dissolved organic carbon is considered as biodegradable organic carbon (BDOC) which is used by bacteria to increase its biomass. The study of Servais (1985) shows that the proportion of biodegradable organic carbon (BDOC) is highest in sewage sample and in the samples from the highly polluted river. The numerical value of biomass is directly related to the percentage value of HPC in TC in most cases (Table 7.16).

Figure 7-20: Number of direct bacterial count and saprobic water quality class

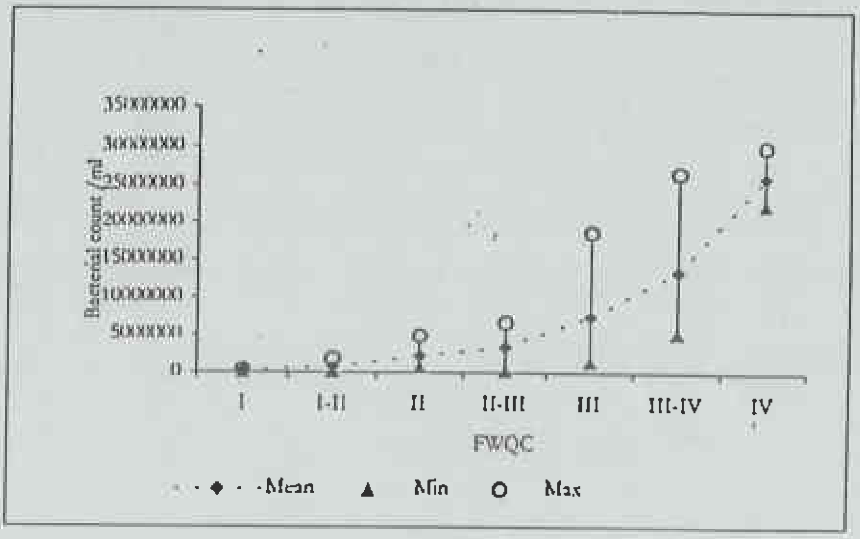


Figure 7-21: Biomass and saprobic water quality class

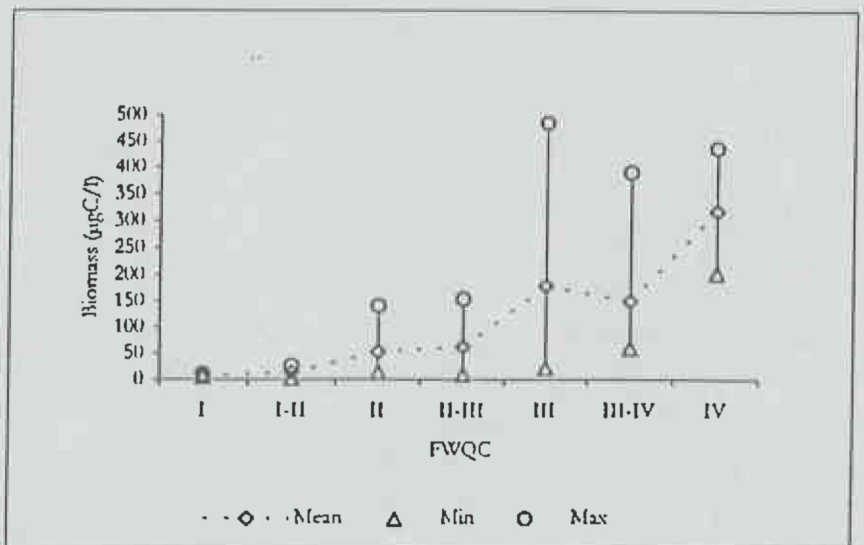


Table 7.16: Values of biomass by different constant

SS	SWQC	Biomass (μg C/l) with		
		Const. 20fg $cell^{-1}$	const. 200g C μm^{-3}	const. 350g C μm^{-3}
27	I	7	11	18
28	I	5	7	12
29	I	4	7	13
32	I	4	7	13
35	I	3	5	9
18	I-II	22	25	43
19	I-II	36	20	56
38	I-II	8	9	16
76	I-II	4	7	12
78	I-II	4	2	3
7	II	97	145	254
24	II	62	50	87
30	II	21	19	33
31	II	27	33	57
47	II	17	12	20
3	II-III	51	20	36
12	II-III	6	10	18
21	II-III	24	30	52
33	II-III	131	76	133
48	II-III	125	151	264
9	III	29	28	48
16	III	116	110	192
17	III	195	235	412
53	III	372	487	853
69	III	36	18	31
8	III-IV	104	70	122
10	III-IV	342	31	54
13	III-IV	232	123	215
62	III-IV	129	49	86
77	III-IV	531	324	567
4	IV	800	320	560
5	IV	1065	323	565
6	IV	976	585	1024
41	IV	1690	710	1242
42	IV	1730	1176	2059

Source: *Field survey (1995-96)*

Note: SS = sample site number; SWQC = water quality class; Percent (%) = percent of HC to DC; T/H = total count/heterotrophic count. Const. = constant

Table 7.17: Mean bacterial parameters with standard deviation and saprobic water quality class (SWQC)

SWQC	HPC cfu/ml	TC cell/ml	T/H	%	Vol
I	1021±77	246583±69929	240±56	0.4±0.1	0.15±0.01
I-II	9082±10249	746478±629866	101±25	1.1±0.3	0.1±0.04
II	25769±19004	2237741±1523910	96±18	1.1±0.2	0.1±0.03
II-III	48353±33255	3364978±2582171	74±20.2	2±0.6	0.5±0.05
III	115164±89387	7469631±6327798	73±27.3	1.5±0.4	0.09±0.03
III-IV	467802±392798	13388597±7812015	42.4±22	3±1.1	0.05±0.02
IV	3066874±1043340	62618577±19179241	21±3	5±0.6	0.05±0.01

Source: *Field survey (1995-96)*

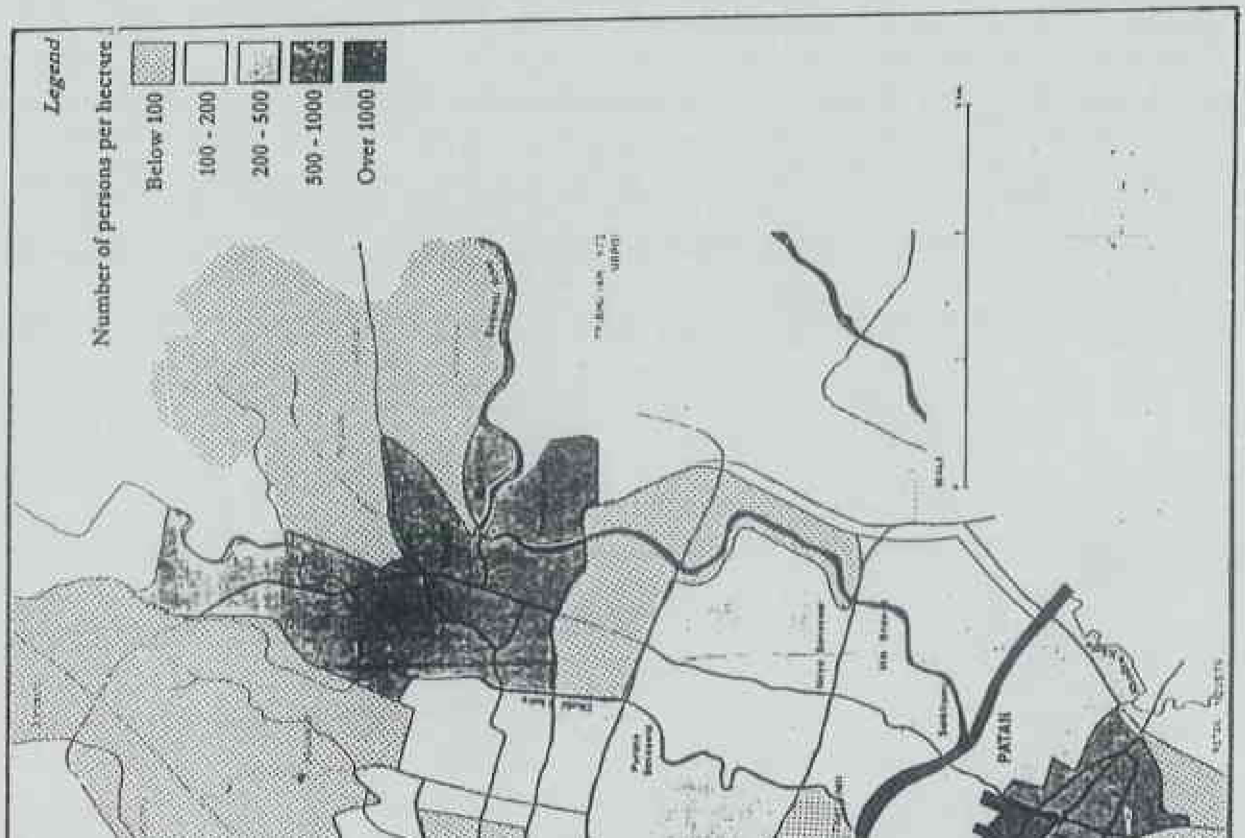
In the present case biomass has also been calculated with reference to the given çonversion factors as shown in Table 7.16 and Table 7.18. However, there is variation in the amount of biomass calculated with reference to these factors but it is difficult to conclude which one is the best (Lee 1993).

Table 7.18: Mean bacterial parameters with standard deviation and saprobic water quality class (SWQC)

SWQC	Vol	Mean biomass (μg C/l) with			
		Biovolume	Const. 20fg cell^{-1}	const. 200g C μm^{-3}	const. 350g C μm^{-3}
I	0.15±0.01	7±2	5±1.4	8±0.2	13±0.4
I-II	0.1±0.04	14±10	15±13	15±6	26±10
II	0.1±0.03	53±46	45±31	46±9	80±16
II-III	0.5±0.05	63±53	67±52	71±26	123±46
III	0.09±0.03	179±172	149±127	147±36	257±63
III-IV	0.05±0.02	151±125	268±156	122±32	214±57
IV	0.05±0.01	785±351	1252±384	602 ±315	1053±552

Source: *Field survey (1995-96)*

Figure 7-22: Gross population density Kathmandu and Patan cities, 1991.



7.2.5 Salmonella test

Salmonella originate mainly from faeces of humans, other mammals and birds. Wastewater treatment plants also release *Salmonella sp. Salmonella sp.* is one of the bacteria that causes water borne disease known as Salmonelosis. The disease is transmitted into human being through the use of faecal contaminated water.

Table 7.19:Positive and negative *Salmonella* test in the sample sites

Site No.	River	Locality	Date	SWQC	*Salmonella* test
3	Balkhu	Kalanki	1996-4-25	II-III	+
7	Godavari	Balkot	1996-5-25	II	+
8	Hanumante	Imadol	1996-4-15	III-IV	+
9	Manohara	Koteswor	1996-4-15	III	+
10	Kodku	Imadol	1996-4-5	III-IV	+
12	Nakhu	Nakhujail	1996-4-25	II-III	-
13	Bagmati	Pashupati	1996-4-10	III-IV	+
16	Bishnumati	Ringroad	1996-4-10	III	-
17	Mahadev	Hiletol	1996-4-15	III	+
18	Salinadi	Sankhu	1996-4-15	I-II	-
19	Manmati	Saranchok	1996-5-5	I-II	-
21	Manohara	Bramhakhel	1996-4-15	II-III	+
24	Bishnumati	Budhanilkantha	1996-5-4	II	+
27	Bagmati	Sundarimai	1996-5-4	I	-
28	Nagmati	Sundarimai	1996-5-4	I	-
29	Syalmati	Sundarijal	1996-5-4	I	-
30	Naldu	Tikabhairab	1996-5-12	II	-
31	Lele	Tikabhairab	1996-5-12	II	+
32	Bishnumati	Budhanilkantha	1996-5-9	I	-
33	Phedikhola	Budhanilkantha	1996-5-9	II-III	-
35	Mahadev	Budhanilkantha	1996-5-12	I	-
38	Bhangeri	Godavari	1996-4-25	I-II	+
47	Bosamkhola	Taudah	1996-4-5	II	-
48	Kodku	Harisidhi	1996-5-10	II-III	+
53	Bagmati	Kumarigal	1996-4-15	III	+
62	Manamati	Ringroad	1996-4-10	III-IV	+
69	Bagmati	Jorpati	1996-4-10	III	+
76	Bagmati	Sundarijal	1996-5-9	I-II	-
77	Bagmati	Gaurighat	1996-5-9	III-IV	+
78	Godavari	Godavari	1996-4-5	I-II	-

Source: ***Field sur vey (1995-96).***

The number of sample sites with positive as well as negative ST of the river profile region is illustrated in Table 7.19. Of 30 sites, sixteen showed *Salmonella*-positive test, accounting for 43 percent; the lowest percent occurred upstream (25%). Most of which lie in the valley basin region. These sites have been categorised as water quality class ranging I-II, II-III to III-IV. The remaining 14 sites with negative test represented water quality class lies in I, I-II and II. The large number of sample sites with positive *Salmonella* test in the study region is evident from the fact that according to the field observation most people found to have often used to defecate at the bank of the rivers. At the same sites, people use the river water for various domestic purposes. It is also observed that most of the positive *Salmonella* test sites are found in the valley basin region where population density per hectare is very high as shown in figure 7.21. The fact that the valley basin lies in the next lower region of the lower head water region. The velocity of river at the lower head water region is always higher than in the valley basin. This causes to wash away all the nutrients of the lower head water region and accumulates in the valley basin. In the valley basin, the supply of nutrient is further added from the source of urban refuse.

In this study salmonella test (ST) is used to detect *Salmonella during* pre-monsoon season. Only those sites were selected for ST where people have used the water for domestic purposes. The salmonella test kids have been used to detect *Salmonella* sp. from the sample sites. Altogether 30 sites have been chosen representing 5 from each of the six saprobic water quality classes except class IV, the water of which was not used for any domestic purpose.

Secondly, particularly during premonsoon or dry season, the volume as well as velocity of rivers becomes low. Despite the contamination of river water with faecal and household refuse, people have to use the river water for various domestic purpose. This has often resulted into several types of water borne disease (UNICEF 1987).

8 BENTHIC MACROINVERTEBRATE ANALYSIS

River is a living entity which reflects its condition or quality transparently. Researchers have developed different measures to assess its quality. One of the measures is the benthic macroinvertebrates parameter. This parameter has its own inherent qualities. These qualities include pronounced response to pollution, sufficient long life cycle to prevent a response to intermittent relief from pollution, and a sessile-attached mode of life that reduces the influence of neighbouring water conditions on the organism (Ingram, Keup, and Mackenthun 1966). Because of these qualities, bottom-dwelling organisms reflect conditions at the sampling point for an extended period of time. The diversity and abundance of benthic macroinvertebtrates represent the specific characteristic features of the different sites of a river. The pristine or unpolluted river is generally characterised by certain types as well as abundance of aquatic organisms based on climatological phenomena and stream hydrological features. On the other hand, in the human interfered rivers, pollution occurs as a consequence of use of river water by them for different purposes. This causes change in both the diversity and abundance of aquatic organisms. The general regularity is that the diversity of animals decreases and especially sensitive organisms are replaced by pollution tolerant animals and their abundance increases as the intensity of organic pollution increases (Nemerow 1974). In the following paragraphs, attempt is made to examine the characteristic features of benthic macroinvertebrates so as to indicate different river water quality classes in the study region.

8.1 Distribution of Macrozoobenthos

This section offers an analysis of the distribution of macrozoobenthos in the Bagmati river system briefly. The detailed information on number and type of taxa identified at varying possible level is listed in appendix R. Table 8.1 summarises the distributional characteristic features of the macrozoobenthos by the Bagmati river profile region.

Table 8.1: Distribution of macrozoobenthos by the Bagmati river profile region

	Headwater Region		Valley Region			Low Region
GROUP	Upper	Lower	Upper	Middle	Lower	
	Family	Family	Family	Family	Family	Family
Tricladida	1	1				
Gastropoda	3	4	2	2	2	1
Oligochaeta	1	1	2	2	2	
Hirudinea	1	1	2		2	
Crustacea			1		1	
Ephemeroptera	5	5	4	3	4	3
Odonata	6	7	1	1	1	2
Plecoptera	3	2	1		1	
Heteroptera	3	3	2	2	2	
Coleoptera	6	6	5	3	5	
Megaloptera	1	1	1		1	1
Trichoptera	12	8	3	1	3	1
Diptera	6	8	5	4	5	2
Total	48	47	29	18	29	10

Source: *Field survey (1995-96).*

In this study altogether 71 families, 136 genera and 157 species of macrozoobenthos have been identified. Incidence of occurrence of these animals is found varied markedly by the river profile region in which the physiographic variation and the socio-economic factors appear to be significant. In the whole study region, two Groups Trichoptera and Diptera are the most common in each of the three profile regions; each of these two has possessed the largest number of family accounting for 17 percent in the total. These are followed by Coleoptera, Odonata and so on. The occurrences of the biota in each of the profile regions are described as follows.

8.1.1 The Headwater region

(i) The upper headwater section

Table 8.1 shows that in the upper section of the headwater region, the highest number of family recorded is found in Trichoptera Group. This accounts for 25 percent of its total family. The families like Unenoidea, Stenopsychidae, Polycentropodidae and Philopotamidae are mostly restricted to this section. In Coleoptera Group, Elmidae is the common family represented by genus Grouvellinus species. Besides this, other families found in this Group are Eulichadidae, Psephenidae, Hydrophilidae and Dytiscidae. Six families and 22 genera are identified in the group Diptera. Among these six families, Athericidae, Chironomidae, Simuliidae, Tabanidae, and Tipulidae are common. There are identified five types of families in Ephemeroptera in the valley as a whole and all of which are found in this section. From these families altogether 15 genera and 26 species are identified. A total of 10 species have been recorded in the family Baetidae only, of which *Baetis sp7* has been identified for the first time. Out of three families recorded in the group Plecoptera, Capniidae and Nemouridae are found very common. Of these two families, the genus *Amphinemura sp.* belonged to family Nemouridae is very common.

The comparison of diversity of taxa among the rivers by river profile region have also,been made on the basis of the present level taxonomic identification[11]. Figure 8-1 a and b show the diversity of taxa in post and pre-monsoon seasons respectively. In post-monsoon season maximum and minimum diversity have been recorded by the rivers Manahara and Bagmati respectively on this region as depicted in Figure 8-1 a while the records of other rivers are in between them. Some changes in diversity are found out in pre-monsoon season. The Manahara and the Dhobikhola rivers have the same diversity indicating maximum and the rivers Bagmati and Bishnumati have the same number of diversity with minimum record in this region (Figure 8-1b)

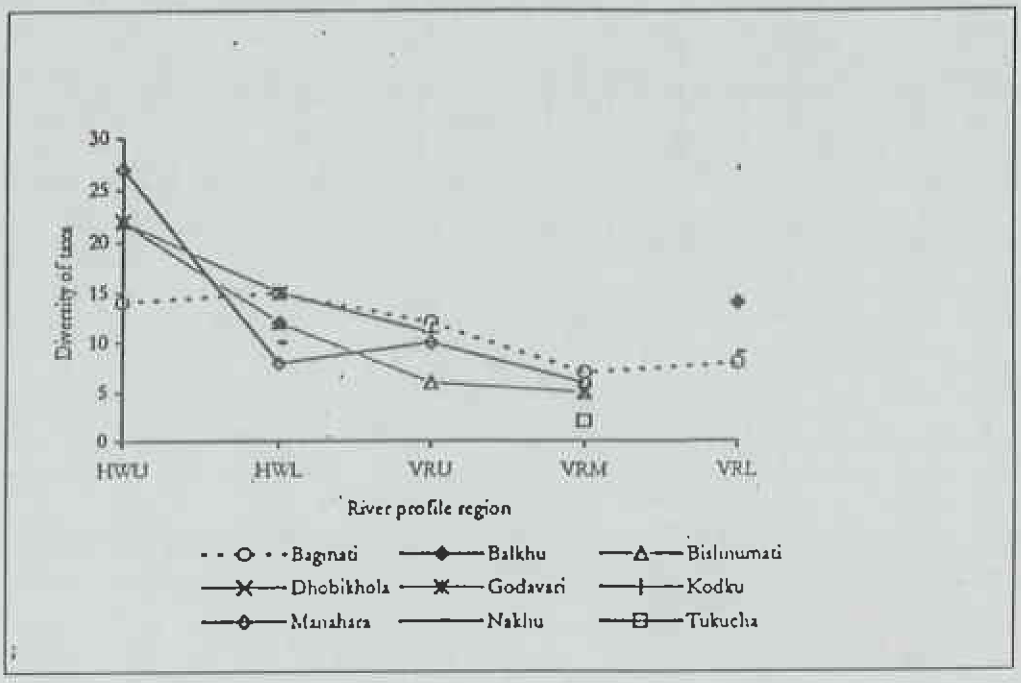
(ii) The lower headwater section

The groups Trichoptera and Diptera, each making up 17 percent in the total family has occupied the highest share. The common families of Trichoptera are Rhyacophilidae, Lepidostomatidae, Limnephilidae, Glossosomatidae and Hydropsychidae. The common families of Diptera include Atherecidae, Chironomidae, Limoniidae, Simuliidae, Tabanidae and Tipulidae. A maximum of 12 genera are recorded for the family Chironomidae. Another

[11] Due to the lack of much taxonomic information about Nepalese benthic macroinvertebrates, only possible level of identification have been made in this study. Some animals are possible to identify up to species level but some are up to genus and others to family levels only. Because of this different levels of identification, even in the best water quality class the diversity seems less. For example, in the Trichoptera group most of the animals have been identified up to the family level, and most of them occur in good water quality classes. Similarly, the animals belonged to the group Plecoptera are also up to family and some to the genus level and the animals of this group are also sensitive to pollution. Some other groups are able to go to genus and species group such as Coleoptera, Heteroptera, Gastropoda, Hirudinea and some Diptra (appendix: R)

Figure 8-1: Diversity of taxa by river

(a) Post-monsoon



(b) Pre-monsoon

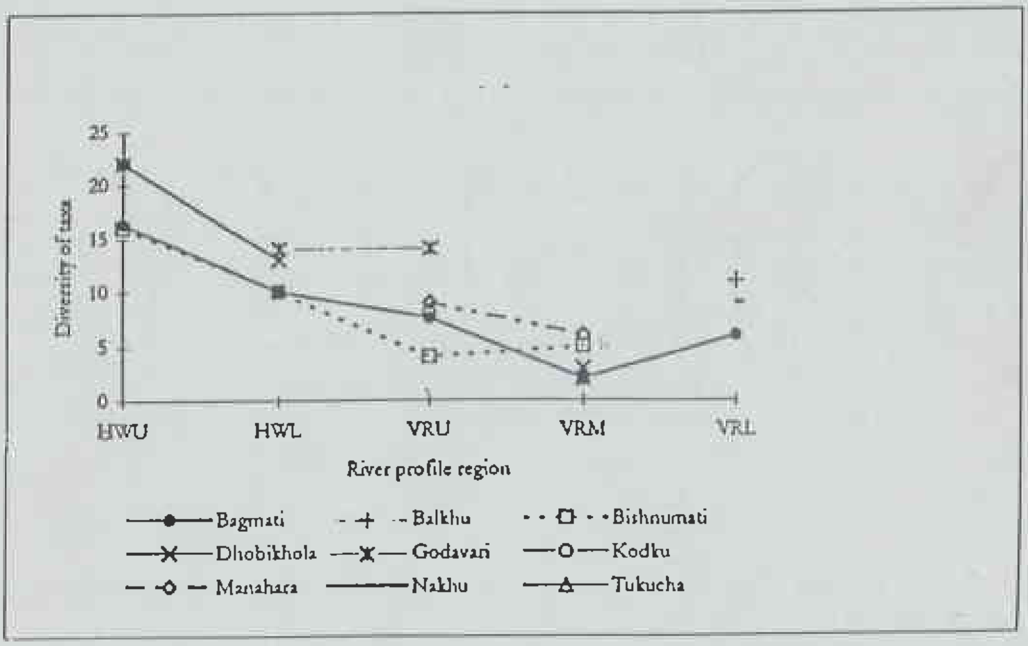
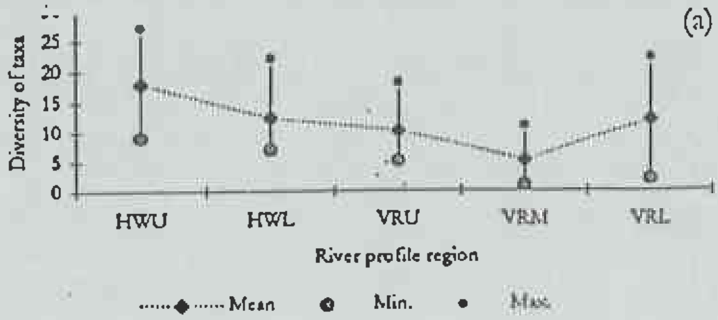


Figure 8.2 Diversity of taxa by river profile region

(a) Post-monsoon season



(b) Pre-monsoon season

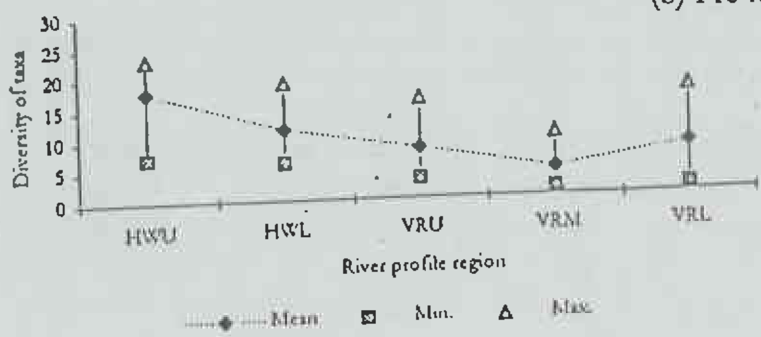
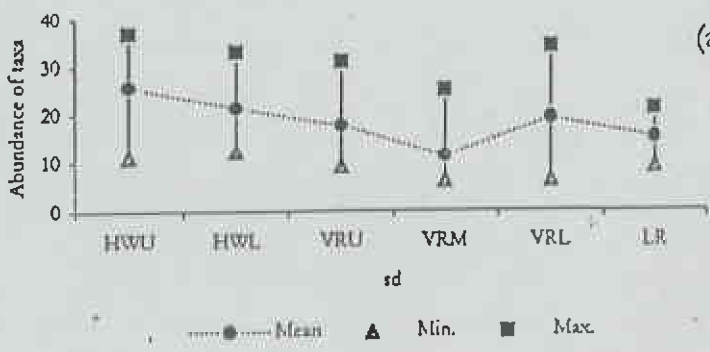
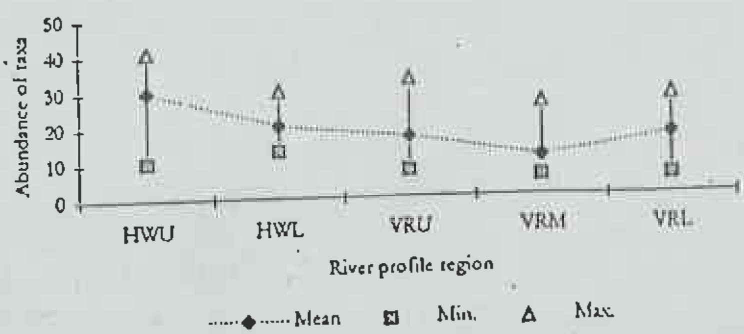


Figure 8.3 Total abundance of taxa by river profile

(a) Post-monsoon season



(b) Pre-monsoon season



important group found in this section is Ephemeroptera. Under this group, there are recorded five families in which 15 genera and 22 species are identified. Other taxa identified are Ephemerellidae, Leptophlebiidae and so on. *Torleya nepalica* for the former family and two genera, Habrophlebiodes sps and *Euthraulus sp* for the latter family are found very common. The new genus *Barbronia sp.* for the family Salifidae is found in this section.

In this region the rivers Bagmati and Dhobikhola have indicated same diversity of taxa showing maximum in comparison to other rivers in this region and the Manahara river the minimum in post monsoon season (Figure 8-1a) while in pre-monsoon season the Godavari river has shown the highest diversity followed by other rivers (Figure 8-1b).

8.1.2 The Valley region

(i) The upper valley section

According to Table 8.1 information, the largest number of families identified in this section, too are Coleoptera and Diptera. Each consists of 8 families and accounts for 17 percent in the occurrence of total families. Of these, the Coleoptera consists of two most common families such as Dyticidae and Elmidae and in each of these two families the common genera are *Neprioporus sp.* and *Grouvellinus sp.* respectively. A maximum of 14 genera are identified in Diptera and 8 in the Coleoptera. The very common families in the Diptera are Chironomidae, Limoniidae, Simuliidae, Tabanidae and Tipulidae. Next group is Ephemeroptera which consists of the common families such as Baetidae, Heptageniidae and Leptophlebiidae. This group is followed by Trichoptera, Gastropoda, Plecoptera and so on.

In post-monsoon season the Bagmati and the Dhobikhola rivers have indicated the highest and lowest diversity in this region while the rivers Godavari and Bishnumati showed highest and lowest diversity in pre-monsoon season respectively (Figure 8-1b).

(ii) The middle valley section

Like in other sections as noted above, family of Diptera constitutes the largest number in this middle valley section, too. It has also the largest number, i.e. 7 genera. Though Chironomidae is common in all sections stated above, the red variety Chironomus is dominant in this section. In addition to this, other families such as Culicidae, Syrphidae and Tabanidae are also common which are rare in other sections. The next group in this section are Coleoptera, Ephemeroptera and Oligochaeta. Of these, the family Tubificidae of Oligochaeta is the most common in terms of abundance. Other identified commonly available genera of Baetidae are Baetis sp2 and Baetis sp3. Similarly, *Euthraulus sp.* of Leptophlebiidae is commonly available in this section.

From Figure 8-1 a and b it is quite obvious that in this region range of diversity among the rivers is not high. Nevertheless, the rivers Bagmati and the Manahara have recorded highest and the Tukucha the lowest in post and pre-monsoon season respectively.

(iii) The lower valley section

In this section of the valley region, streams like the Balkhu, the Nakhu, the Bosan and the Chalti having different water qualities meet with the Bagmati river before it reaches Khokana a few kilometres downward from Chobhar. However none of the tributaries is as polluted as the Bagmati itself. There are also identified different tolerance level animals indicating varying quality of water in these streams. The type and abundance of animals is found increasing downward streams. For instance, in the Balkhu, the first tributary of this section of the Bagmati, are recorded 16 families from different groups, of which the most common families identified are Physidae, Baetidae, Caenidae, Leptophlebiidae, Hydropsychidae, Chironomidae, Corydalidae, Salifidae and Tubificidae. In the next downward tributary Nakhu are also identified 16 families from different groups but the common families are Tubificidae, Baetidae, Caenidae, Ephemerellidae, Leptophlebiidae, Perlidae, Hydropsychidae and Chironomidae. The sample sites along the Bosan, another downward stream have recorded largest number with 18 families from different groups and the common families identified are Baetidae, Caenidae, Heptageniidae, Leptophlebiidae, Perlidae, Tubificidae, Nemouridae, Glossosomatidae, Hydrobiosidae, Hydropsychidae and Potamidae. In the sample sites along the Chalti, the last tributary in the downstream of the Bagmati in the valley, are recorded with higher number of animal diversity of 17 families from different groups. The common families are Elmidae, Athericidae, Chironomidae, Baetidae, Caenidae, Nemouridae, Ephemeridae, Heptageniidae, Leptophlebiidae, Glossosomatidae and Philopotamidae.

In this region the diversity of taxa has been comparatively increased, the maximum and minimum diversity have been shown by the rivers Balkhu and Bagmati in post and pre-monsoon season respectively (Figure 8-1 a and b).

8.1.3 The Low region

There are identified altogether 10 families from different groups including three from Ephemeroptera, two from Diptera, two from Odonata, one each from Coleoptera, Megaloptera and Trichoptera.

It is evident from Table 8.1 information that the upper section of the headwater region has a relatively higher species diversity than other sections or regions in the study region which is also shown in (figure 8.2). The stream water quality of this section having these species richness is typified by water classes I and I-II. These species appear to occur in the streams which are least affected by anthropogenic factor. In other words, the section is still characterised by the overwhelming influence of natural factor.

Unlike in other two sections of the valley region, the total number of families has decreased abruptly in the middle section (Figure 8.2), the abundance of some of the genera which belong to very poor water condition has occurred in greater number (Figure 8-3).

In the low region, the type and abundance of the animals identified show that the Bagmati river has got better condition in terms of its saprobic quality (Figure 8-3).

It is clear from the above discussion that the animal richness varies greatly in different river profile regions; with greater diversity in the headwater region and with less diversity in the urban core middle valley section (Figure 8-3 a and b) but slightly increases in diversity and abundance in the lower sections of the Bagmati river (figure 8.2 and figure 8.3). It is also evident that as the stream flow downward in the valley, anthropogenic factor appears to be more effective and stronger causing the displacement and diminishing of the taxa. However, what is the degree of the anthropogenic effect on the stream biological condition is yet to investigate.

8.2 Saprobic Water Quality Classification of the River

Two indices measures have been employed to assess the river water quality in the study region. One is the *Bagmati Biotic Score-Average Score Per Taxon* (BBS-ASPT) index measure and the other *Biotic index* method. In the former method only tolerant score of the taxa is considered and an average score per taxon is obtained. In the latter measure, two factors such as tolerant score and abundance of each taxon are considered.

8.2.1 The Weight assigned to each water quality class (I-IV)

In this index measure, the weight ranging from a maximum of 10 score for water quality class (SWQC) I to a minimum of 1 for SWQC IV is obtained taking reference of the ASPT (Average score per taxon) method (After Modification Coring and Küchenhoff 1994). The weight score for other remaining classes is obtained from dividing the difference between those maximum and minimum scores by a total of seven water quality classes. Thus, this gives the ratio value of 1.3 (i.e. 9/7, where '9' is the difference between 10 and 1, and '7' is the total water quality classes). To begin with, 1 is already assigned to SWQC IV or class number 7, the lowest water quality class in this study. In order to assign weight to other classes, the ratio or weight value, i.e. 1.3 is added to each of the successive lower water quality classes to assign weight to each of its higher order classes. For example, for the next upper level class III-IV or class number 6, the ratio or weight value of 1.3 is added to the already given weight 1 to SWQC IV as stated above. So, a weight value of 2.3 (1 + 1.3) is assigned to SWQC III-IV. Similarly, for SWQC III or class number 5, the weight is assigned as 3.6 (1.3 + 2.3), and so on (Table 8.2). Thus, the scores fall within the given range of 1 to 10 of the ASPT (After Modification Coring and Küchenhoff 1994) and also see table2.2. This modified method is devised here to obtain a more objective as well as convenient basis for assigning score to a particular taxon.

Table 8.2: Weight assigned for saprobic water quality class based on (After Modification Coring and Küchenhoff 1994).

Class no.	SWQC	Assigned
1	I	10
2	I-II	7.5
3	II	6.2
4	II-III	4.9
5	III	3.6
6	III-IV	2.3
7	IV	1

8.2.2 The Tolerant Score Assigned to Taxon

Three steps for the tolerance score of the taxa are considered.

- To make score more objective, the derivation of score[12] for a particular taxon is obtained using Eq. 1/VIII.
- The score obtained from the calculation is compared with the score of NEPBIO (Sharma1996).
- Finalization of each score is made by the professional jugment of the expert.

[12] The example of taxa *Gruvelliuus sp.* is consided for the calculation of its tolerance score. As recorded in the appendix S, this animal occurred in total of 27 sites of which it is recored in 12, 6, 6 and 3 sites with WQC I, I-II, II, II-III. Weights for WQC I, I-II, II, II-III are 10, 7.5, 6.2, 4.9 (as given in Table 8.2).
According to the above equation:W = 4.5 + 1.6 + 1.3 + 0.5, W = 8 (tolerance score of the taxon)

$$W = \sum_{i=1}^{n} \frac{fiwi}{n} \quad \text{................ (Eq. 1/VIII)}$$

Where W = Score of a particular taxon; fi = number of occurrences of a particular taxon at the sample sites of given water quality class; wi = weight assigned to each of the seven saprobic water quality classes (SWQC); and n = total number of sample sites of given water quality classes which contain a particular taxon.

Now the question arises, at what taxonomic level scores are given to the animals? It is easier to choose family level for this. But some genera and species of the family have a wide range of distribution which makes difficult to decide the water quality. An attempt is made in this study to give scores to the collected animals which have been identified at different levels. For instance, *Baetidae* family has wide range of occurrence, so it is scored up to species level whereas other members of Ephemeroptera have been scored to genus or species or possible level identified.

In this study, out of 71 families identified 45 families are scored which are shown in Appendix S and some families are given scores in genus and species levels. The remaining families are not scored because the number of their occurrences at the sample sites were not enough. Gomphidae is not given score because this family has occurred in a wide range of water quality classes ranging from best to worst.

8.2.3 Biotic index for each site

Each site along a river may contain different numbers, as well as a variety of taxa and depending upon the riverine environments which are assumed to indicate different classes of saprobic water quality. On the basis of abundance of a taxon with respect to total number of individuals, the sample sites under consideration are evaluated for different SWQC. The following equation is employed to derive the biotic index for a particular site (Pantle and Buck 1955; Hilsenhoff 1982 ; Friendrich et al. 1992; Ghetti and Ravera 1994).

$$BI = \sum_{i=1}^{n} \frac{Wi \times hi}{H} \quad \text{..................... Eq. 2/VIII}$$

Where BI = Biotic index for a site, Wi = Score of ith taxon; hi = Number of ith taxon, and H = total number of taxa.

Thus obtained biotic index is compared with the weight assigned to SWQC to know the water quality of the site.

8.2.4 Comparison of the scores obtained by the three methods

Table 8.3: Average scores for water quality classes by the three index measures in BRS

SWQC	NEPBIOS-ASPT	BBS-ASPT	Biotic Index-BRB
I	7.6	7.8	7.9
I-II	6.9	7.0	6.9
II	6.4	5.9	6.2
II-III	5.5	5.5	5.3
III	4.9	4.7	4.5
III-IV	3.3	3.7	3.5
IV	1.9	2.2	2.1

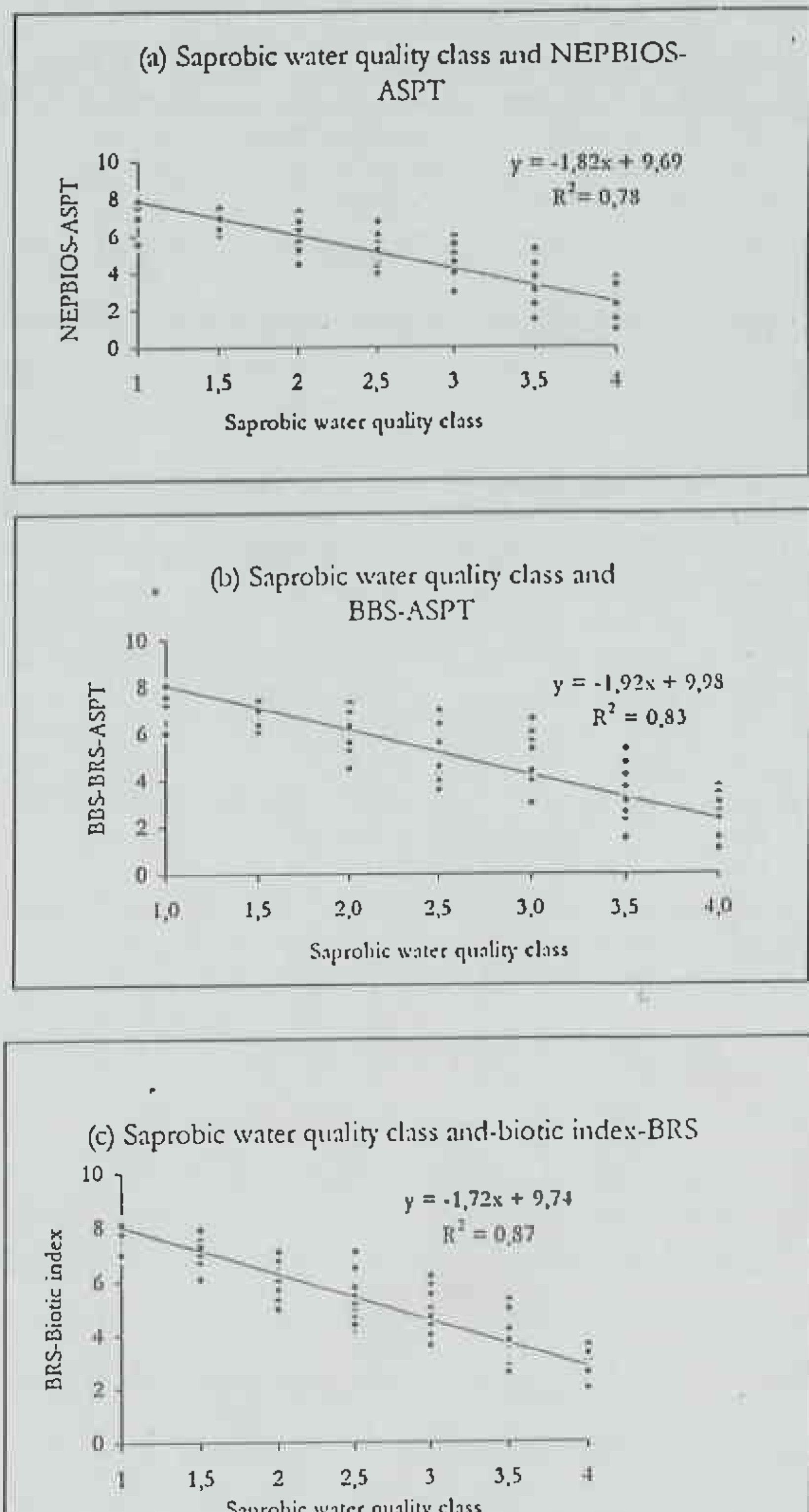
Source: *Field survey (1995-96).*

Note: BBS-ASPT = Bagmati biotic score-average score per taxon; NEPBIOS = Nepal biotic score; BRB = Bagmati river system

The score obtained for each sample site is computed and the mean value for each SWQC is depicted in Table 8.3. The table shows that the values obtained from all the three measures have decreased as the quality of water classes decreases. In other words, in the headwater region the computed values are increased. This means that in poor water quality classes the diversity of taxa is found to be decreased but the abundance of particular taxon which could adapt successfully to the changed environment has increased. Hence the maximum scores of the taxa are found in the headwater region, indicating the best water quality. For instance, Nepal biotic score- Average score per taxon(NEPBIOS -ASPT) , Bagmati biotic score -Average score per taxon (BBS-ASPT), and Biotic index gives scores of 7.6, 7.8, and 7.9 respectively to class I. The minimum scores obtained for the poorest water quality class, i.e. SWQC IV are 1.9, 2.2 and 2.1 by NEPBIOS-ASPT, BBS-ASPT and Biotic index respectively.

While comparing saprobic water quality class and the scores obtained by different indices like NEPBIOS-ASPT, BBS-ASPT and Biotic index of the Bagmati river system, the coefficient of determinant r^2 value obtained are 0.78, 0.83 and 0.87 respectively which are shown in fig. 8.4 a, b and c.

Figure 8-4: Relationship between indices score and Saprobic water quality class



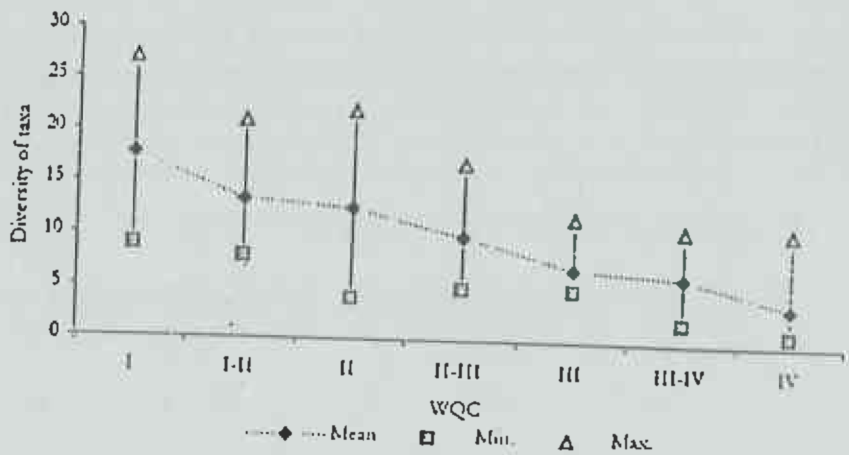
BBS = Bagmati biotic score; BRS = Bagmati river system; Nepbio-ASPT= Nepal biotic score- average score per

8.2.5 Diversity of taxa by saprobic water quality class (SWQC) and the River

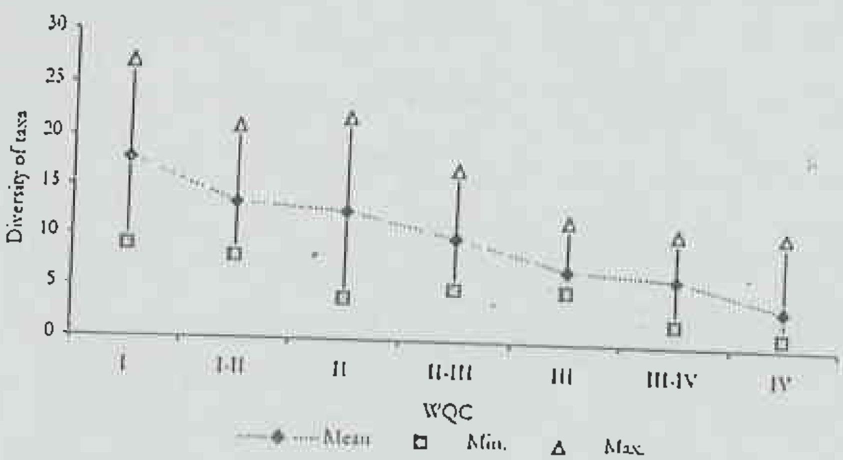
As shown in fig 8.5 the diversity of the taxa is found with a maximum of 28 in SWQC I in the headwater region whereas in other downstream regions, the diversity appears to be decreased but not with the same ratio where the river water quality classes deteriorates. However, the abundance of a particular taxa for certain water quality class (SWQC) has increased, for example the number of Chironomids and Tubificidae have been recorded as largest in SWQC III-IV and IV

Figure 8.6 and 8.7 show that the diversity of taxa vary from river to river respective to the quality and also with seasons. In the water quality class I, the Dhobikhola and the Manahara have the highest diversity record in post monsoon and in pre-monsoon season respectively (Figure. 8-6 and 8.7). The lowest diversity recorded in both seasons in the Tukucha indicating the poorest water quality class.

Figure 8-5: Diversity of taxa by water quality class



(a) Post-monsoon season



(b) Pre-monsoon season

Figure. 8.6 Diversity of taxa by rivers and water quality class (Post-monsoon)

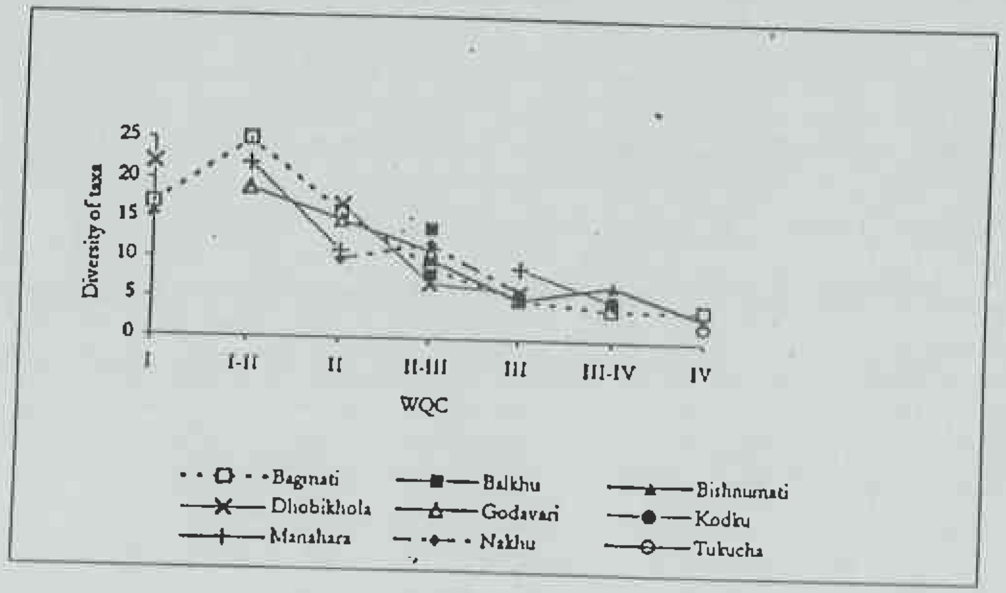
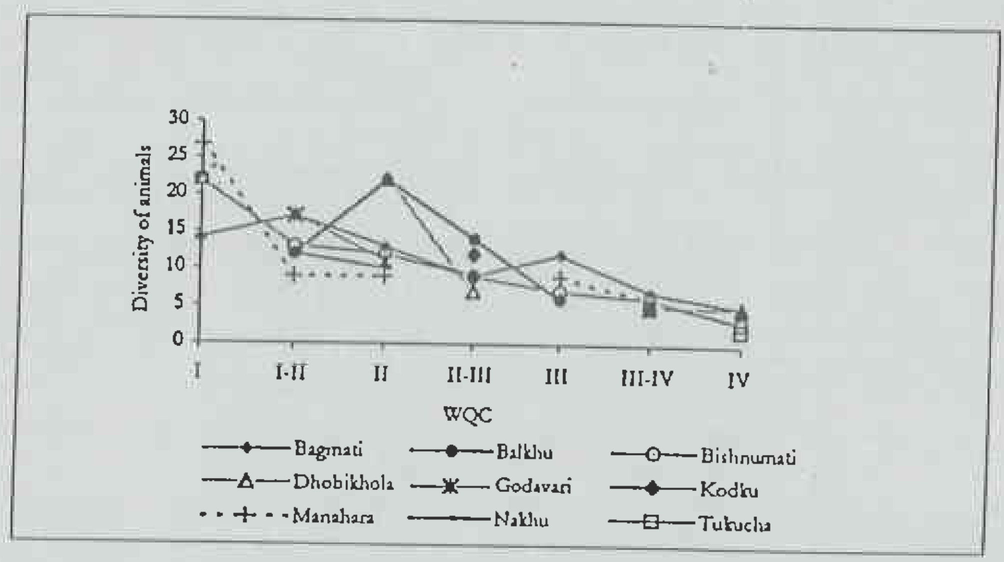


Figure 8.7: Diversity of taxa by rivers and water quality class (Pre-monsoon)



8.2.6 The Coefficient of Variation among the Water Quality Class and Percentage of Sensitive Taxa

The percentage of coefficient of variation (CV) among the Water quality classes (SWQC) and by two seasons post-monsoon (PO) and pre-monsoon (PR) by diversity, abundance and percentage of sensitive taxa of the groups Ephemeroptera, Plecoptera, and Trichoptera (EPT) have been depicted in table 8.4. From the table it is observed that there is less variation in diversity among the sample sites belonged to good water quality classes but it is higher in poor water quality classes. This could be that in some sites animals are drifted in poor water quality class by certain pollution stress. Regarding the taxa belonged to the groups Ephemeroptera, Plecoptera, and Trichoptera, they are considered as sensitive taxa to pollution. Normally as the water quality deteriorates their percentage of occurrence also decreases (Resh and Jaccson 1993). In the present case their percentage of occurrence have been computed by water quality class as shown in table 8.4. The percentage of EPT is seen higher in good water quality and it decreases with the deterioration of quality. The percentage of EPT seems higher in SWQC III than its preceding quality class II-III in both season. This increase in percentage is due to the occurrence of some comparatively pollution tolerant taxa of this group like Baetis sp.2 Baetis sp.3 of family Baetidae, Caenis sp. of family Caenidae, Euthraulus sp. of family Leptophlebiidae from the order Ephemeroptera and members of Hydropsychidae family from the order Trichoptera. EPT % would be more efficient in saprobic water quality assessment if pollution tolerant species of this group are excluded. The coefficient of variation among the water quality classes between two seasons are not significant statistically at $\alpha = 0.01$. However, the change has occured in the number of sites in saprobic water quality classes from existing quality to poorer quality class between post and pre-monsoon season which have already been discussed in chapter 4. This change in saprobic water quality class is mainly due to decrease of dilution capacity of the river.

Table 8-4: Coefficient of Variation (CV) of diversity and abundance and percentage of EPT

SWQC	SWQC[13]		PO			PR		
	PO	PR	CV %		EPT	CV %		EPT
			Diversity	Abundance	%	Diversity	Abundance	%
I	8	5	35	40	65	33	34	64
I-II	9	5	28	24	67	27	32	55
II	14	10	50	36	69	21	24	67
II-III	11	12	36	31	19	23	19	34
III	7	7	32	21	38	52	42	49
III-IV	12	11	72	33	18	40	29	10
IV	14	20	66	51	1	52	31	1

Source: *Field survey (1995-96);* . PO = Post-monsoon and PR = Pre-monsoon

[13] Please see in detail in chapter 4 for the change of the water quality classes between two seasons.

8.2.7 Comparison of Tolerance scores between BBS-ASPT and NEPBIOS-ASPT

An attempt is made in this study to give scores to the collected animals which have been identified at different levels on the basis of Eq. 1/VIII and final confirmation of score of each taxa is made by expert working in this field. The index development with reference to less precise taxonomic level to assess the quality of river of particular country may not be suitable to other country. With this regards there appeared several indices suitable to the places and countries which are discussed in chapter II. Sharma (1996) has developed a index for water quality assessment of Nepalese river and given the name Nepal Biotic Score (NEPBIOS). He has compared his result with several existing indices and NEPBIOS-ASPT separately. The coefficient of determination value (r^2) found more than 0.79 with NEPBIOS-ASPT but with other indices indecisive results he found. This index is found to be applicable to to Nepal, he has concluded. For the regional validity, this index needs to be cross-checked by several intensive studies in various river systems of Nepal. Regarding this view the present study has intended to compare its score to the scores of NEPBIOS. The scoring of the taxa will not be complete until all the taxa are identified to the species level.

In the present study altogether 71 families were listed and 54 families are given score in the family level and 12 families are given in genera and species levels (Appendix R and S). The remaining five families are not scored because the number of their occurrences of the taxa at the sample sites were not enough.

This study has also attempted to strengthen the NEPBIOS (1996), in this regard the score of taxa of present study the Bagmati biotic score (BBS) is compared with that of the NEPBIOS (Sharma 1996) which is shown in figure a to ac. In NEPBIOS (1996) altogether 103 families are listed and 82 families are scored. The scores are given basically on family level except for few genera and species of families such as Baetidae, Heptageniidae, Leptophlebiidae, Hydraenidae and Perlidae.

While comparing the scores between Bagmati biotic score (BBS) and Nepal biotic score (NEPBIOS), out of 45 scored families of NEPBIOS, 17 families got the same score while the rest of the families got different scores. Twelve families of BBS got one score less than NEPBIOS they are Athericidae, Corixidae, Euphaedae, Hydrophilidae, Limnephilidae, Limoniidae, Lymnaeidae, Nemouridae, Noteridae, Potamidae, Sphaeriidae and Tipulidae.

Figure 8-8a - ac illustrate the example of some of the families to describe the differences in the scores by two methods i.e. BBS and NEPBIOS. According to the occurrence of taxa to water quality class (SWQC) Athericidae received score 9 and 10 as shown in figures 8.7a and b by BBS and NEPBIOS respectively. From the figures, it is clear that the family Athericidae has occurred in many sites in SWQC I but it has also recorded in SWQC I-II and II. In this regards the score 10 given by NEPBIOS is higher. Similarly, figure 8.8 c and d depict the variation in the score of the family Corixidae. In case of BBS, it has occurred from SWQC II-III - IV and which is represented by only one genus *Sigara sp* of the family while in NEPBIOS the family has occurred from SWQC I to III-IV. This figure indicates the necessary to identify higher taxonomic level to give separate scores to the taxa occurring in separate quality classes.

Figure 8-8 e, f, g and h also compare the scores given by the two methods. Though the distribution of taxa belonged to the family Limoniidae is not uniform, it occurred from the SWQC I to III-IV in BBS and I to II-III in NEPBIOS (Fig. 8.8 e and f) due to this difference in occurrence to the water quality classes, one score has been less in the former case than the latter. In case of Nemouridae as shown in (figure 8.8 g and h, in both cases the occurrence of taxa are from SWQC I to II but in BBS the number of occurrence of taxa in SWQC I and I-II are same but large difference in NEPBIOS which brings the one score less in BBS than NEPBIOS.

The BBS has received one score higher than that of NEPBIOS to 8 families which are Corydalidae, Ephemeridae, Glossosomatidae, Gyrinidae, Leptophlebiidae, Physidae, Psephenidae, Psychomyiidae, and Tubificidae. The examples of some of these families have been shown in figure 8.8 i to o. The members of Ephemeridae and Psephenidae are distributed in SWQC I to II in BBS (figure 8.8 i and k) but in case of Psephenidae in NEPBIOS the taxa are distributed from SWQC I to III. The change of scores is noted according to the distribution of taxa to SWQC. But in case of Physidae (figure 8.8 m and n) the one score higher of BBS than NEPBIOS is that some taxa belonged to this family have occurred in better quality class also. In case of the family Glossosomatidae the frequency of occurrence of taxa to SWQC is different in both cases (figure 8.8 o and p). Figure 8.8 q and r indicate the Gyrinidae family, the occurrence of the taxa in BBS have been recorded from SWQC I to II-III but in NEPBIOS only in one SWQC II. Four families with two score less than the NEPBIOS are Hydrobiosidae and libellulidae and two families with two score higher are Polycentropodidae and Stenopsychidae.

Figure 8.8: (a-ac) Comparison of scores between Bagmati biotic score (BBS) and Nepal biotic score (NEPBIOS).

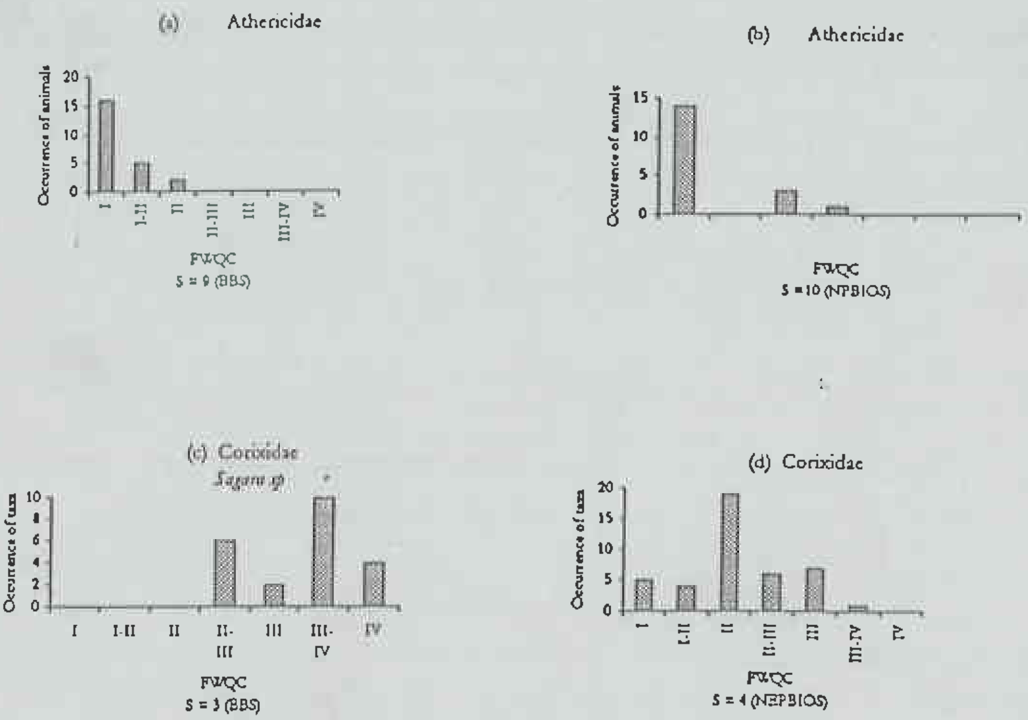
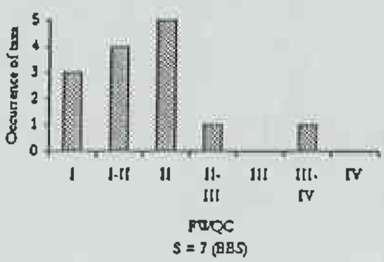
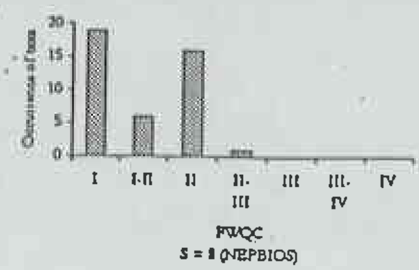


Figure 8-8:(a-ac) Comparison of scores between BBS and NEPBIOS

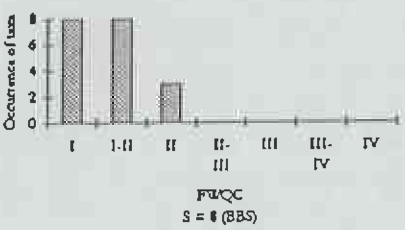
(e) Limoniidae



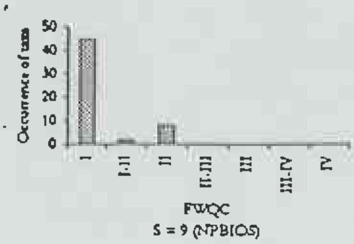
(f) Limoniidae



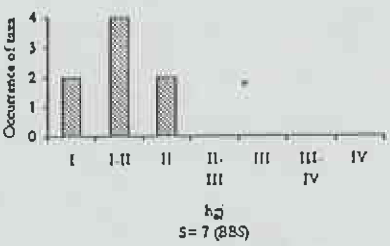
(g) Nemouridae



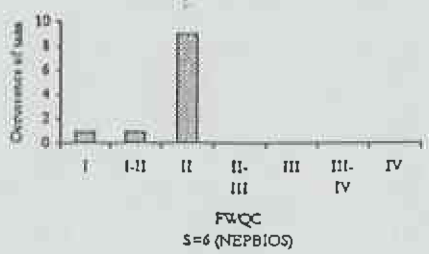
(h) Nemouridae



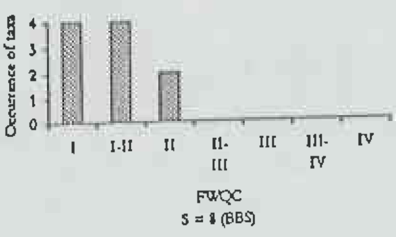
(i) Ephemeridae



(j) Ephemeridae



(k) Psephenidae



(l) Psephenidae

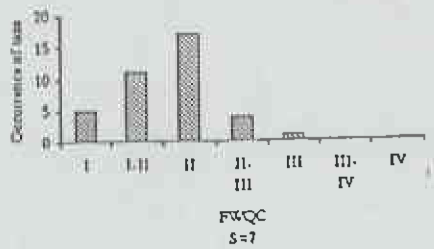


Figure 8.8: (a-ac) Comparison of scores between BBS and NEPBIOS

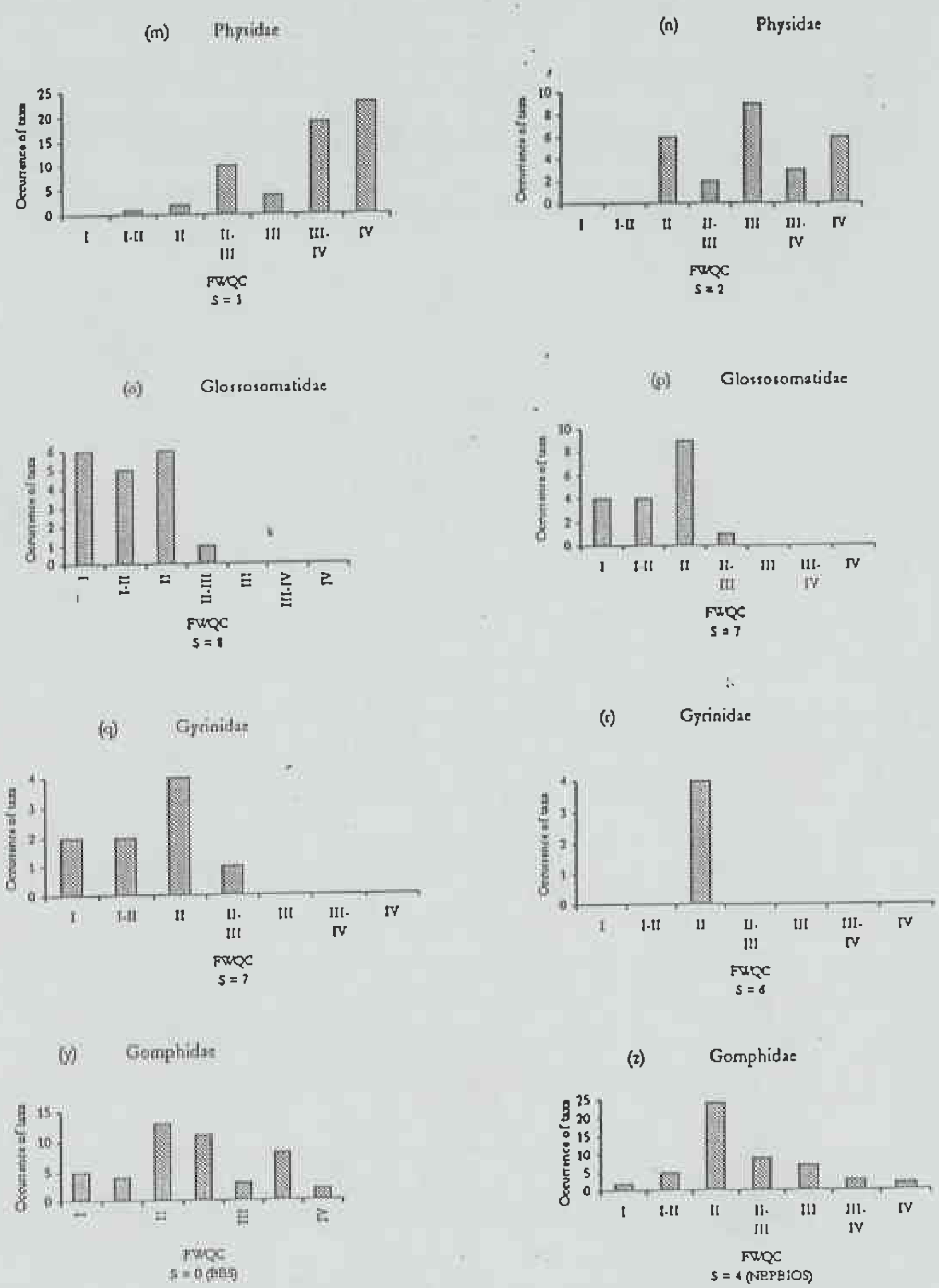


Figure 8.8: (a-ac) Comparison of scores between BBS and NEPBIOS

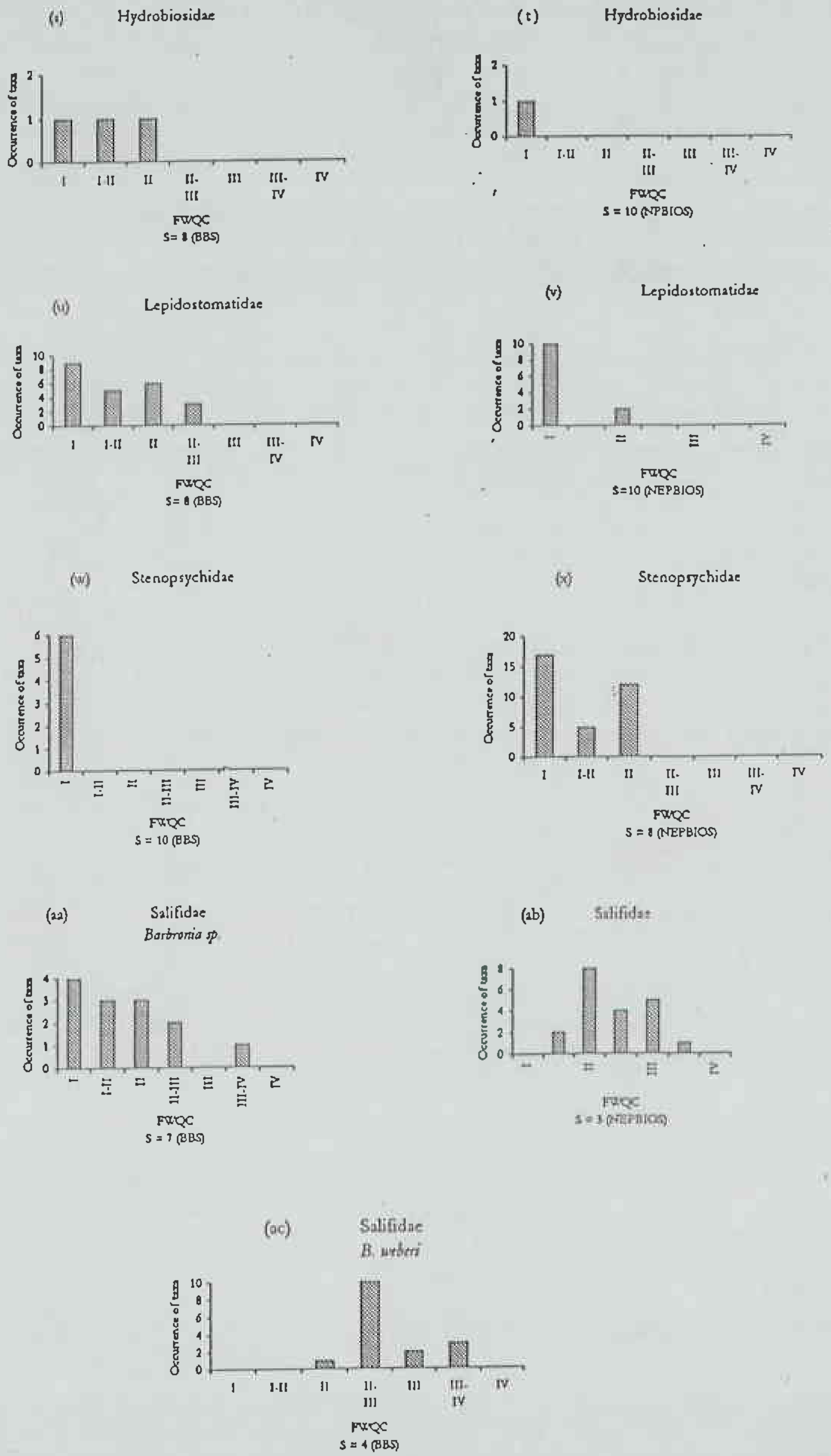


Figure 8-8 In the figure 8.8 s and t Hydrobiosidae family is illustrated. In this case NEPBIOS has been scored taking reference of only one site which shows inadequate site for scoring, while in BBS occurrence of taxa recorded from SWQC I to II. In case of the family Lepidostomatidae (fig.8.8 u and v) the occurrence of taxa are noted only in QWC I and II in NEPBIOS but in BBS the taxa are recorded from SWQC I to II-III.

In case of the family Stenopsychidae the taxa recorded only from SWQC I in BBS but in the latter case it is recorded from SWQC I to II (Figure 8.8 w and x)

The family Gomphidae has widest distribution from SWQC I to IV in both cases. This family has not been scored in BBS because of its wide distribution from SWQC I to IV and they are air breather but 4 score has been given in NEPBIOS reading the peak in the distribution (figure 8.8 y and z).

In contrast to the NEPBIOS (Figure 8.8 ab) the family Salifidae is not scored in BBS but the two species recorded from Kathmandu Valley have been scored separately (Figure 8.8 aa and ac). The distribution of these two species of genus *Barbronia* is quite contrast, *Barbonia sp.* is recorded from SWQC I to III-IV but the frequency of occurrence decreases from the upper reach to the lower reach (Figure 8.8 aa) but *B. weberi* occurred in lower reaches from SWQC II to III-IV (figure 8.8 ac).

Four families are added with score in NEPBIOS-BRS. The enlarged NEPBIOS-BRS is now with 86 scored families.

From the comparison of the scores in the two methods it is quite obvious that family level identification is not enough, for more precise water quality assessment deeper taxonomic level is needed. For example the genera of families like Baetidae, Ephemereliidae, Leptophlebiidae show quite variations in their occurrence. From the comparative study of NEPBIOS to BBS of Bagmati river system (BRS) some changes in the scores are made in order to strengthen NEPBIOS. After discussion with the water quality expert the strengthened and enlarged NEPBIOS is designated as NEPBIOS-BRS(1998). In this enlarged NEPBIOS the scores which have shown higher variation due to their specific occurrence to SWQC in between BBS and NEPBIOS such as in Polycetropodidae, Stenopsychidae etc. in these cases the new score for the family is calculated considering the occurrence of taxa in both score methods i.e. NEPBIOS and BBS. The family level score of NEPBIOS (1996) is kept as usual for those families whose genera and species identified and scored in BBS for example the family Salifidae. The families which are not found in Bagmati river system, have the same score as NEPBIOS. This process of cross-checking of scores of taxa and new score for the new animals should be continued until the identification of animals up to species level and the intensive study of most of the river systems from different regions of Nepal completed. The list of assigned score to the taxa in NEPBIOS and in NEPBIOS-BRS (1998) are given in Table 8.5.

Table 8-5: Scores assigned to the taxa by NEPBIOS and NEPBIOS-BRS

NEPBIOS (1996)	Taxa	NEPBIOS- BBS (1998)
6	**Aeshnidae**	6
	Ancylidae	x
7	**Aphelocheiridae**	7
10	**Athericidae**	9
x	**Atyidae**	x
	Baetidae	
7	*Baetiella sp.*	7
	Baetiella ausobskyi	7
7	*Baetis sp.*	7
	Baetis sp.1	7
	Baetis sp.2	5
	Baetis sp.3	5
	Baetis sp.4	6
	Baetis sp.5	6
	Centroptilum sp.	8
	Cloeodes sp.	7
5	**Bithyniidae**	5
7	**Brachycentridae**	8
6	**Caenidae**	6
4	**Calopterygidae**	4
10	**Capniidae**	10
x	**Ceratopogonidae**	6
x	**Chironomidae**	x
1	*Chironomus* group *riparius* and *plumosus*	1
	Microtendipes sp.	4
	Polypedilum sp.	4
	Diamesinae	8
5	**Chlorocyphidae**	5
9	**Chloroperlidae**	9
4	**Corbiculidae**	4
5	**Coenagrionidae**	5
	Cordulegastridae	8
5	**Corduliidae**	5
4	**Corixidae**	3
6	**Corydalidae**	7
2	**Culicidae**	2
x	**Dixidae**	x
x	**Dolichopodidae**	x
5	**Dryopidae**	5
4	**Dytiscidae**	4
6	**Ecnomidae**	x
8	**Elmidae**	8
	Empididae	x
7	**Ephemerellidae**	7
	Cincticostella sp.	7

NEPBIOS (1996)	Taxa	NEPBIOS- BBS (1998)
	Drunella sp.	10
6	*Torleya nepalica*	6
6	**Ephemeridae**	7
x	**Ephydridae**	
10	**Epiophlebiidae**	10
8	**Euphaeidae**	8
	Eulichadidae	
7	**Gammaridae**	7
4	**Gerridae**	4
4	**Glossiphoniidae**	4
7	**Glossosomatidae**	8
9	**Goeridae**	9
4	**Gomphidae**	0
6	**Gyrinidae**	7
	Hebridae	x
10	**Helicopsychidae**	10
10	**Helodidae (Scirtidae)**	10
7	**Heptageniidae**	7
	Cinygmina sp.	7
	Electrogena sp	6
	Epeorus bispinosus	8
10	*Epeorus rhithralis*	10
	Iron psi	8
	Notacanthurus cristatus	7
8	*Rhithrogena sp.*	8
10	*Rhithrogena nepalensis*	10
7	**Hydraenidae**	7
10	**Hydrobiosidae**	8
x	**Hydrometridae**	6
	Hydrobiidae	x
6	**Hydrophilidae**	5
6	**Hydropsychidae**	6
10	**Lepidostomatidae**	8
x	**Leptoceridae**	
7	**Leptophlebiidae**	7
5	*Euthraulus sp.*	5
	Habrophlebiodes sp.	9
10	**Leuctridae**	10
6	**Libellulidae**	3
9	**Limnephilidae**	8
x	**Limnichidae**	
9	**Limnocentropodidae**	9
8	**Limoniidae**	7
x	**Lumbricidae**	3
x	**Lumbriculidae**	x
6	**Lymnaeidae**	5
	Micronectidae	4

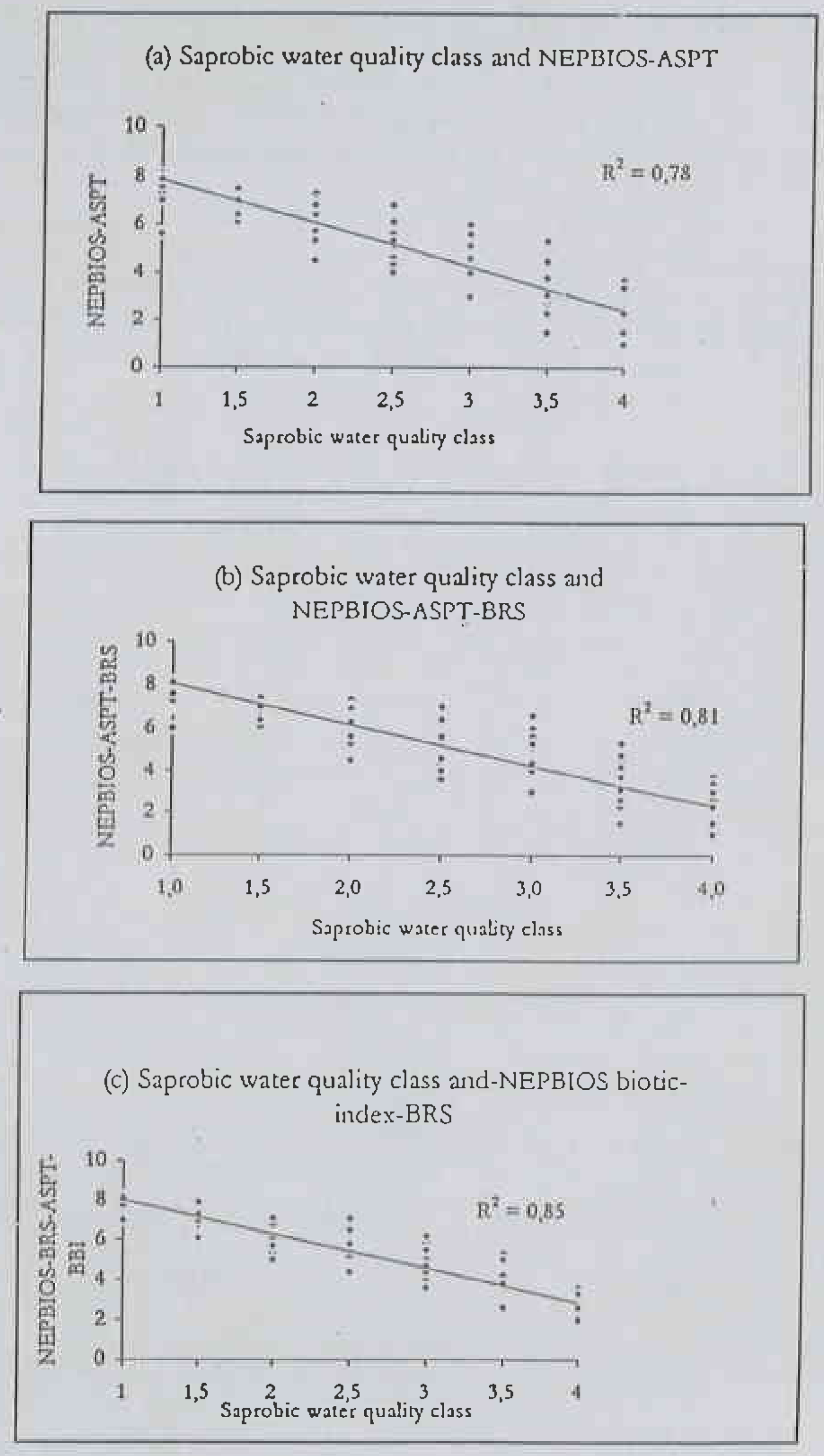
NEPBIOS (1996)	Taxa	NEPBIOS- BBS (1998)
x	Muscidae	x
4	Naucoridae	4
9	Nemouridae	8
9	Neoephemeridae	9
4	Nepidae	4
4	Noteridae	3
3	Notonectidae	3
5	Odontoceridae	5
4	Palaemonidae	4
10	Peltoperlidae	10
8	Perlidae	8
10	*Acroneuria sp.*	10
10	*Calineuria sp.*	10
9	Perlodidae	9
7	Philopotamidae	8
x	Phrygnaidae	x
2	Physidae	2
4	Planorbidae	4
4	Pleurocentridae	7
7	Polycentropodidae	9
7	Potamidae	6
5	Protoneuridae	5
7	Psephenidae	8
	Psychodidae	8
6	Psychomyiidae	7
4	Ranatridae	4
8	Rhyacophilidae	8
3	Salifidae	3
	Barbronia sp.	7
	Barbronia cf. weberi	4
10	Scirtidae (Helotidae)	6
7	Simuliidae	7
10	Siphlonuridae	10
5	Sphaeriidae	4
8	Stenopsychidae	9
x	Stratiomyidae	x
	Synlestidae	8
	Syrphidae	2
	Tabanidae	6
10	Taeniopterygidae	10
4	Thiaridae	4
8	Tipulidae	7
1	Tubificidae	2
10	Uenoidae	10
5	Unionidae	5
x	Veliidae	x
6	Viviparidae	6

8.2.8 Relationship between water quality classes and indices score

While comparing saprobic water quality class (SWQC) with Nepal biotic score - Average score per taxon (NEPBIOS-ASPT 1996), Nepal biotic score - Average score per taxon - Bagmati river system (NEPBIOS-ASPT-BRS 1998), and NEPBIOS index BRS (1998) separately by using the Coefficient of determination analysis, the r^2-score value obtained are 0.78 (Figure 8.9 a), 0.81(Figure 8.9 b) and 0.85 (Figure 8.9 c) respectively. The r^2 obtained in NEPBIOS-ASPT-BRS (1998) is higher than that of NEPBIOS-ASPT (1996) but it is less than the value of NEPBIOS-index-BRS (1998). This means that while both diversity and abundance of taxa considered together in the evaluation of quality, it gives better picture of SWQC rather than considering only tolerant score of the existing taxa as in NEPBIOS-ASPT (1996) and NEPBIOS-ASPT-BRS (1998). Although the r^2-scores of these measures are not so varied, a bit higher r^2-value of NEPBIOS-index-BRS (1998) indicates that the tolerance score and the abundance of the taxa combine together determine water quality class more decisively.

Figure 8-9: Relationship between indices score and saprobic water quality class

(a)



BRS = Bagmati river system; Nepbio-ASPT= Nepal biotic score- average score per taxon; BBI = Bagmati Biotic inde

8.2.9 Benthic and chemical parameters' relationships

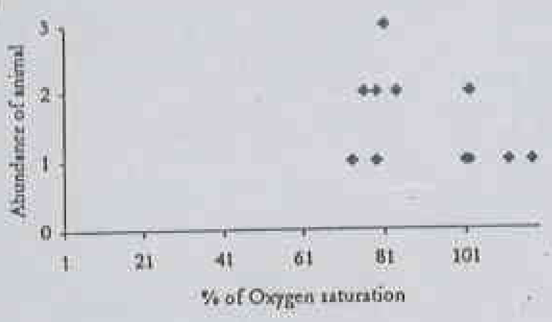
In river ecosystem, chemical component is one of the parameters to evaluate the tolerance level of benthic invertebrates. In other words, each benthic invertebrate has particular requirements with respect to the chemical condition of its habitat. So, animals respond to chemical components in different ways. Changes in chemical conditions may result in reduction in species number, change in species dominance or total loss of sensitive species by death or migration. Thus, the presence or dominance or absence of certain species can be an indicator of certain water quality condition(Welch 1992).

Though several chemical parameters do determine the tolerance level of animals, some chemical parameters such as dissolved oxygen, BOD5, ammonia nitrogen and total phosphate have been chosen to show the effect on the animals for the present purpose. To exemplify, only a few taxa are considered to show their different tolerance level to those chemical parameters through using graphs.

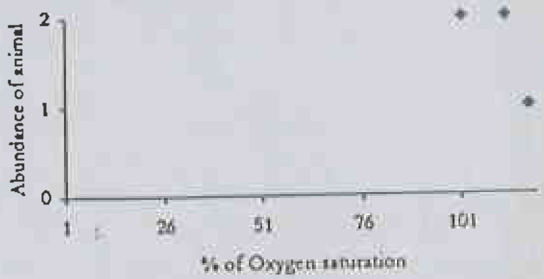
Figure 8-10 shows different tolerance levels of the taxa to oxygen saturation percent. It ranges from 5 to 70 percent for Tubificidae (Figure 8-10d), showing high tolerance to low oxygen saturation level in other word resistance to putricent substances , whereas Capniidae family is found showing its survival condition only in high oxygen saturation level with over 100 to 110 percent and sensitive to putrescent substance (Surbeck 1918: in James and Evison eds. 1979).

Figure 8-10: Oxygen tolerance level of taxa

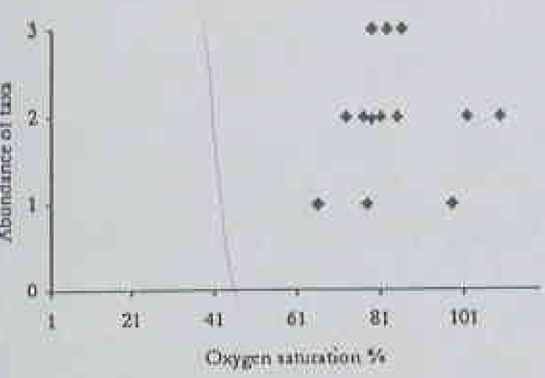
Nemouridae



(b) Capniidae



(c) Perlidae



d) Tubificidae

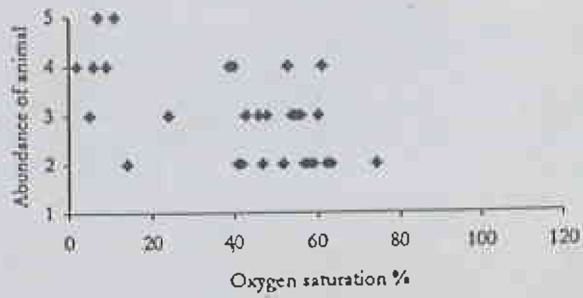
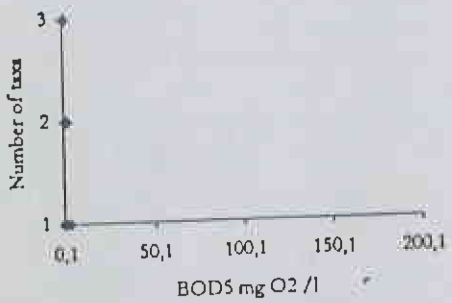
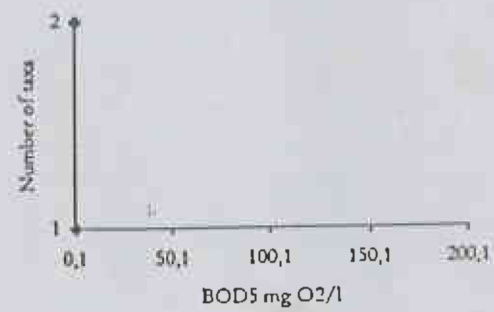


Figure 8-11: The relationship of the taxa with the amount of BOD5.

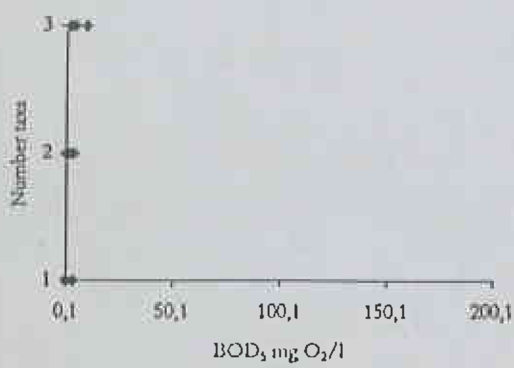
(a) Nemouridae



(b) Capniidae



(c) Perlidae



d) Tubificidae

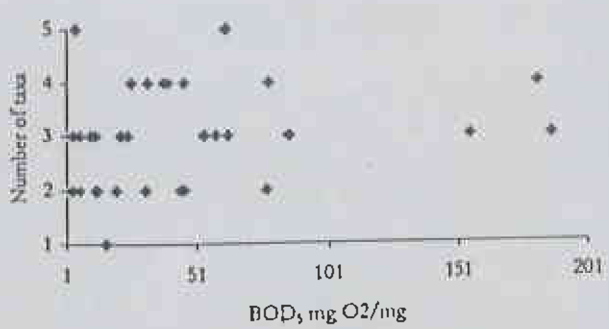
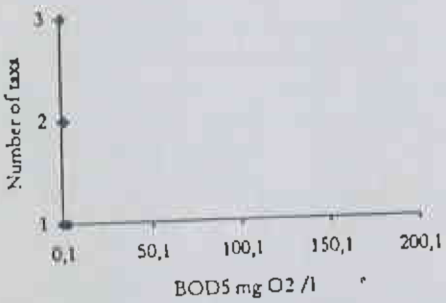
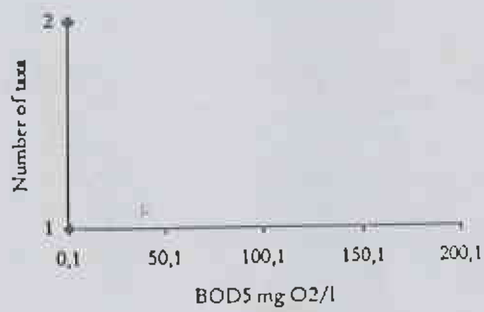


Figure 8-11: The relationship of the taxa with the amount of BOD5.

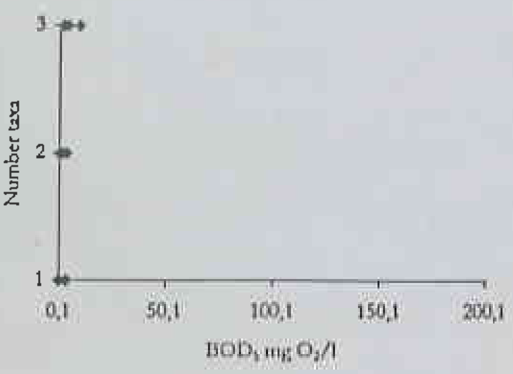
(a) Nemouridae



(b) Capniidae



(c) Perlidae



d) Tubificidae

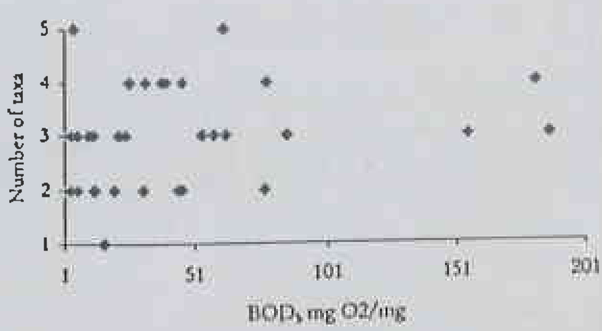


Figure 8-11: The relationship of the taxa with the amount of BOD5.

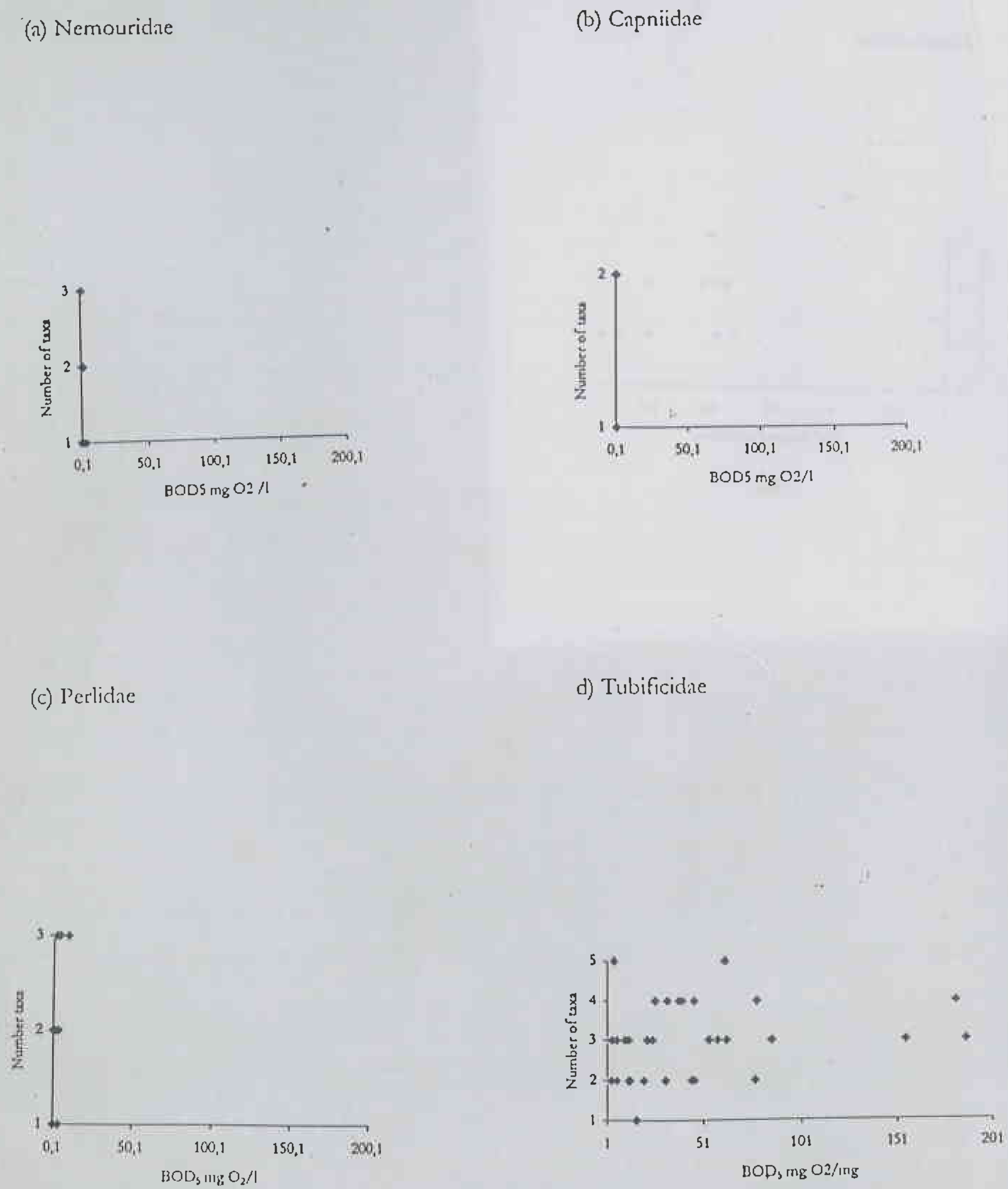
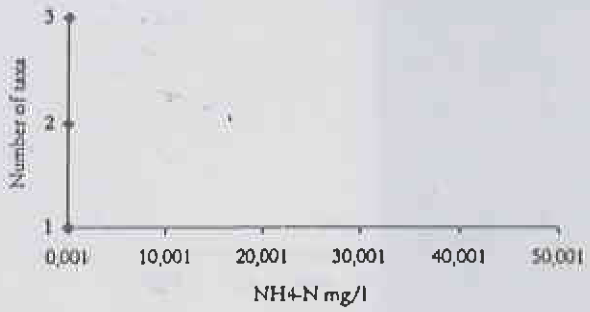
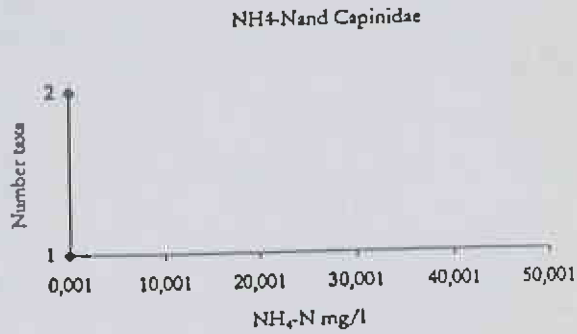


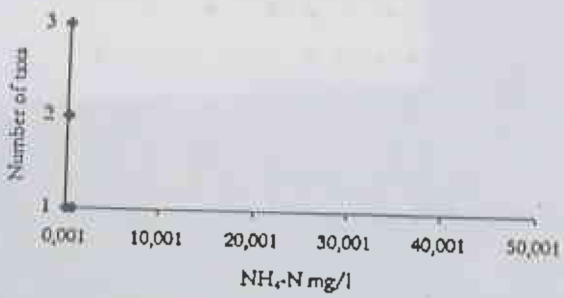
Figure 8-12: The relationship between the taxa and NH4-N



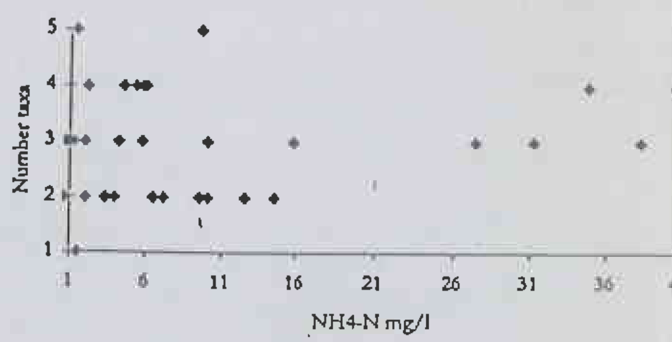
(a) Nemouridae



(b) Capniidae



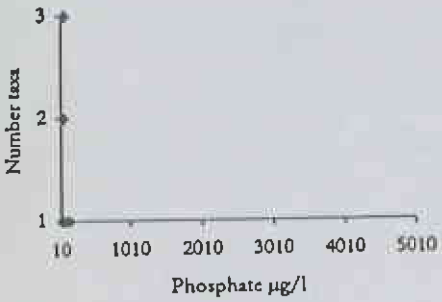
(c) Perlidae



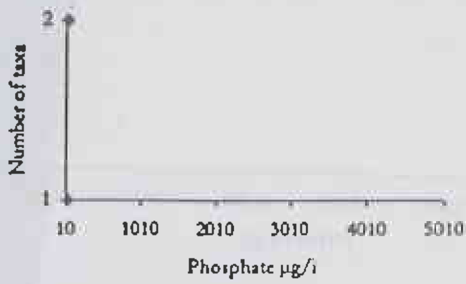
d) Tubificidae

Figure 8-13: The taxa and total phosphate relationship

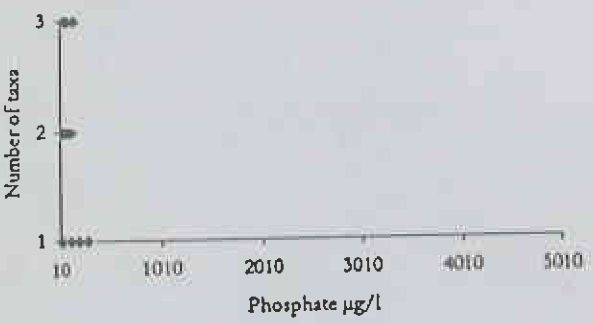
(a) Nemouridae



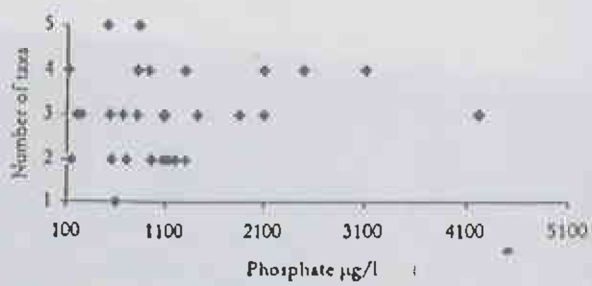
(b) Capniidae



(c) Perlidae



d) Tubificidae



From the Figure 8-11 a-d exhibits that among the three families of Ephemeroptera Capniidae has less tolerance to BOD_5 than others. This family has occurred at the BOD_5 range of 0.1 to 0.8 mg/l of O2 while other families Perlidae and Nemouridae have comparatively wider range of tolerance they are 0.1-9.5 mg/l O2 and 0.1-3.1 mg/l O2 respectively. However the taxa belonged to Oligochaeta have the widest tolerance and occurred at the range of BOD_5 3.4-187 mg/l O2.

8.12 a - d and Figure 8.13 a- d show the relation of the taxa belonged to these groups by NH4-N and PO4-P. With these chemical parameters also Capniidae has shown the lowest tolerance level at the range of 0.03-0.05 mg/l NH4-N and 0.03-0.040 mg/l PO4-P and other families Perlidae and Nemouridae have shown comparatively higher tolerance level of 0.03-0.9 mg/l NH4-N; 0.03-0.3 mg/l PO4-P and 0.03-0.2 mg/l NH4-N; 0.03-0.3 mg/l PO4-P respectively. Like as in other parameters, Oligochaeta shows highest tolerance level with these parameters too, the rang of NH4-N mg/l is 0.8-41 while PO4-P mg/l is 0.12-4.23.

From the above result, it is seen that the chemical parameters have significant role in determining the types of occurrence of animals, although the chemical parameters are changing with time. If the parameters are regularly monitored for a certain period of time, the real tolerance range of particular chemical by a particular taxa can be determined. With the help of this the real stress condition of a taxa for particular ecological situation can be studied (Welch 1992).

9 CHEMICAL WATER QUALITY ANALYSIS

9.1 Introduction

Chemical components are an indispensable element of water. They response to the change in state of quality of stream water. By examining the magnitude of different chemical components, it can be known the level of river water quality for use for different human activities. Quantitative measurements of physico-chemical parameters can describe the quality of river environment.

Surface water is contaminated by a variety of means which can be grouped into two broad types such as natural and human's activities. The natural contamination of surface water such as streams or rivers takes place due to erosion, leaching and weathering processes. The human activities such as domestic and industrial waste waters on the other hand can add contamination by disposing of in various ways into surface waters. They belong to the point source pollution. The runoffs from agricultural fields, cleared forest, construction sites, etc. which also add contamination into surface water are the non-point sources of pollution.

Many of the problems associated with water quality control are due to the presence of organic matter from natural sources or in the form of wastewater discharges or agriculture effluent with poisoning effect of pesticides and fungicides. This organic matter is normally stabilised biologically and the micro-organisms involved utilise either aerobic or anaerobic oxidation systems. Excess organic wastes upset the stream ecosystem by depleting the dissolved oxygen required by bacteria for aerobic decomposition of organic matter. High concentration of organic substances encourages the growth of decomposers such as bacteria and fungi which convert the biodegradable organic substances in the stream into their cells and into basic substances like carbon dioxide, nitrates, sulphates, and phosphates (Morn, Morgen and Wiesma 1986).

By virtue of dilution and self-purification effects, streams are capable of assimilating a certain amount of pollution without serious effects. However, streams will be unable to perform their natural purification process if additional pollution occurs. Each stream has individual pattern of physical and chemical characteristics depending on the climatic, geomorphologic and geochemical conditions prevailing in the area under study, and the underlying aquifer. Each has its own capacity for aerobic decomposition of organic matter without becoming anaerobic. The capacity is limited due to a limited amount of dissolved oxygen. If the organic load received is above its capacity, stream becomes unfit for normal aquatic life and unable to support organisms sensitive to oxygen depletion (Smith 1974). An understanding of the effects of various chemical factors and their magnitude in river is of considerable importance.

In this study, the assessment of river water quality is made taking consideration of the following variables: such as temperature, colour, odour, conductivity, pH, hardness and dissolved oxygen which represent the general variables; ammonia and phosphorus from the nutrient parameters while biochemical oxygen demand is selected from the organic matter variables and chloride is chosen from major ions. These parameters are generally associated with the rivers which receive urban sewage and wastewater, urban runoff, agricultural activities, waste disposal to land and industrial effluents (Welch 1992).

9.2 Results and Discussions

9.2.1 Results

The result data of each of the parameters by sample site are depicted in appendix O and P. The mean and minimum and maximum values are computed from the data results of the sites belonging to each saprobic water quality class (SWQC).

Analysis of the results is made both in terms of saprobic water quality class, spatial location, i.e. river profile region, season and river. This is sought in order to see the variation in the numerical values of the parameters by SWQC, region as well as by season. As already discussed in chapter-IV, SWQC I and I-II lies in the head water region and most of the saprobic water quality class IV lie in the middle valley section, while all other quality classes lie in upper and lower valley section. Of the parameters, colour and odour are not discussed here as they are already dealt earlier in the saprobic water quality analysis chapter. As no data were collected of the Tarai sites in pre-monsoon, the tables do not reveal the information on the lower-water region. The discussion on the results of the parameters for four *kunds* (spring) is made in separate unit.

Correlation coefficient between chemical parameters and SWQC

Before analysing the variation of chemical parameters with reference to SWQC, correlation coefficient between SWQC and the chemical parameter have been computed. The correlation coefficient value indicates that all the parameters have shown significant relation. The parameter Chloride, phosphate, DO and BOD_5 have shown high correlation (Table 9.1).

Table 9.1:Correlation coefficient between chemical parameters and SWQC

n[14] = 75+70

Chemical parameter	SWQC
Conductivity	0.7
Chloride	0.8
Total hadness	0.5
BOD5	0.5
PO_4-P	0.7
NH_4	0.6
DO	-0.7
% oxygen saturation	-0.8

All values are significant at $\alpha = 0.01$; df =143 in t-test statistic

[14] Sample sites from post and pre-monsoon

(i) The chemical parameters and saprobic water quality class

Table 9-2: Minimum and maximum range of Temp., DO and BOD5

SWQC	Temperature °C		DO mg/l		Oxygen saturation %	
	Min -Max	Mean	Min -Max	Mean	Min -Max	Mean
I	7-13	10	11.2-13.0	11.8	98 -108	105
I-II	12-21	15	7.7-10.2	9.0	68-104	83
II	9- 20	15	7.5-10.2	8.7	66-103	81
II-III	13-23	17	7.5-9.8	8.4	66-98	78
III	16-23	19	4.1-8.6	5.9	36-86	65
III-IV	13-22	17	1.2-6.5	4.1	11-71	47
IV	13-19	16	0.5-2.9	1.8	5.0-39	19

Source: *Field survey (1995-96);* n = 75+70

(a) Temperature

Temperature affects physical, chemical and biological processes in river water. As water temperature increases the rate of chemical reactions generally increases together with the evaporation and volatilisation of substances from the waste. Increased temperature also decreases the solubility of gases in water such as O_2, CO_2, N_2 and CH_4 and others. The metabolic rate of aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter.

Table 9.2 indicates that temperature is lowest in saprobic water quality class (SWQC) I, as all the sites of this class lie in head water region, due to this spatial variation temperature is lower in this class. There is not much change in mean temperature among saprobic water quality classes but the minimum maximum range for each saprobic water quality class is higher as shown in table 9.2. This shows that temperature does not increase or decrease with the change of saprobic water quality class unless there is hot water effluent from industries.

(b) Dissolved Oxygen (DO)

Oxygen content is a vital feature of water body. It is essential to all forms of aquatic life. Several factors account for the amount of oxygen in water temperature is one of them. The higher the water temperature, the lower the solubility of oxygen gas in water and vice versa. Biodegradable organic reduce the amount of dissolved oxygen in water due to biological oxygen demand. As oxygen is an essential ingredient for life, it becomes a very important limiting factor for aquatic life in water bodies receiving human wastes. The solubility of oxygen decreases as temperature and salinity increases. The amount of dissolved oxygen (DO) concentration in water measures the degree of organic pollution. A high waste discharge in organic matter and nutrients can lead to decrease in DO concentrations as a result of the increased microbial activity (respiration) occurring during the degradation of the organic matter (Chapman 1992). Hence determination of DO concentrations is a fundamental part of a water quality assessment since oxygen is involved in, or influences nearly all chemical and biological processes within water bodies.

As shown in table 9.2 DO is highest in SWQC I and I-II and lowest in SWQC IV. Percentage of DO saturation which is mainly related to temperature is also highest in these classes. The higher DO in these classes are mainly due to the slope of the region and high discharge which causes high aeration and low organic nutrient content. The DO concentration is also higher in SWQC II which is more that 100% saturation, is mainly due to the algal bloom. In successive lower saprobic water quality classes the DO mg/l and % of oxygen saturation also decreases with the increment of pollution load.

Table 9-3: Minimum and maximum range BOD5 , PO4-P and Chloride

SWQC	BOD5mg O_2 /l		PO4-P mg/l		Chloride mg/l	
	Min -Max	Mean	Min -Max	Mean	Min -Max	Mean
I	0.1-1.4	0.5	0.03-0.05	0.04	2.8- 3.9	3.2
I-II	0.2-1.5	1.1	0.05-0.20	0.09	3.1-7.8	4.9
II	1.1-4.1	2.6	0.04-0.51	0.10	4.2-20.2	8.9
II-III	1.3-5.2	3.3	0.07- 0.60	0.19	5.6-32.0	12.0
III	2.9-25	11	0.05-1.28	0.48	7.8-43.2	16.4
III-IV	4.6-78	29	0.51-1.30	0.91	12.7-49.2	33.3
IV	13-187	74	0.12-4.23	1.92	32.3-102.0	65.9

Source: *Field survey (1995-96).*; n = 75+70

(c) Biochemical oxygen demand (BOD5)

The biochemical oxygen demand measures the amount of biochemical degradable organic matter present in water sample. It is defined by the amount of oxygen required for the aerobic micro-organisms present in the sample to oxidise the organic matter to a stable inorganic form. It is estimated that unpolluted water typically have BOD values of 2 mg/l O_2 or less, whereas those receiving wastewater may have values up to 10 mg /l O_2 or more. Raw sewage has a BOD of about 600 mg /O_2 whereas treated sewage effluents have BOD values ranging from 20 to 100 mg O_2 /l depending on the level of treatment applied (Chapman 1992).

BOD value is very low in SWQC I which is within drinking water quality (WHO 1995), and it is increasing successively in poorer saprobic water quality class (Table 9.2). Up to SWQC II-III can be use as potable abstraction with A2 and A3 treatment. Water quality class III has shown abrupt increase in BOD5 and the deteriorate of SWQC which support pollution due to organic matter. Its concentration has increased successively in poorer saprobic water quality class and reached maximum in SWQC IV.

(d) Total Phosphate (PO4-P)

Phosphorus is an essential nutrient for living organisms and exists in water bodies as both dissolved and particulate form. It is generally the limiting nutrient for plant growth and therefore controls the primary productivity of a water body. In both natural and wastewater, phosphorus occurs mostly as dissolved orthophosphates and polyphosphates, and organically bound phosphates. Natural sources of phosphorus are mainly the weathering of phosphorus bearing rocks and the decomposition of organic matter. Domestic wastewater, particularly those containing detergents, industrial effluents and fertiliser run-off and domestic sewerage (as shown in table 9.4) contribute to elevated levels in surface waters.

Phosphate is increasing with the deterioration of saprobic water quality class as depicted in table 9.3, the change of ratio is not the same in each saprobic water quality class. The mean concentration of PO4-P is 0.04 mg/l in SWQC I which is within the rang of drinking water (WHO). Up to SWQC II its range is within the potable abstraction of raw water with different kinds of treatment i.e. A1-A3. Successive poorer saprobic water quality classes are showing very high phosphate concentration (Table 9.3) and SWQC IV showed the maximum.

Table 9-4: Average need of the chemicals per day per person

Chemical	Minimum	Average
Water (ml)	1200	2000-4000
Na(g)	0.4	2-7
K (g)	0.7	2-7
Mg(g)	0.2	0.3
Ca(g)		1
P(g)	0.8	1,5

Source Bässler *et al.* (1973)

(e) Chloride

Chloride, in the form of chloride (Cl^-) ion, is one of the major inorganic anions in water and wastewater. The main source of chloride in surface water is through natural sources like the weathering of some sedimentary rocks, mostly rock salt deposits, and also from the atmospheric deposition of oceanic aerosols. In potable water, the salty taste produced by chloride concentrations is variable and depended on the chemical composition of water. Some waters containing 250 mg Cl^-/l may have a detectable salty taste if the cation is sodium. On the other hand, the typical salty taste may be absent in waters containing as much as 1000 mg/l when the predominated cations are calcium and magnesium. The chloride concentration is higher in wastewater than in raw water because sodium chloride (NaCl) is a common article of diet (table 9.4) and passes unchanged through the digestive system.

In pristine freshwater chloride concentrations are usually lower than 10 mg/l and sometimes less than 2 mg/l (WHO 1995). As chloride is frequently associated with sewage, it is often incorporated into assessments as an indication of possible faecal contamination or as a measure of the extent of the dispersion of sewage discharges in water bodies.

In the present case chloride concentration is also increasing with the deterioration of saprobic water quality class. Minimum value is recorded in SWQC I (Table 9.4), the mean value of 3.2 mg/l chloride indicates that the SWQC I is not disturbed by human interference. The chloride concentration up to the SWQC II shows that the river is not much interfered by human activity. The concentration of chloride has gradually increased with the deterioration of saprobic water quality class and reached maximum value of 102 mg/l. This high variation from SWQC I to IV from head water region to the valley basin region strongly support the influence of domestic sewage into the river.

Table 9-5: Minimum and maximum range of Conductivity TH and NH4

SWQC	Conductivity µS/cm		Total hardness $CaCO_3$ mg/l		NH4-N mg/l	
	Min -Max	Mean	Min -Max	Mean	Min -Max	Mean
I	19-38	28	4.3-11.0	6.8	0.02-0.09	0.04
I-II	35-359	153	9.2-152.0	78.3	0.04-0.16	0.07
II	52-258	154	13.9-159.3	85.8	0.05-1.60	0.22
II-III	42-256	160	6.5-148.1	88.9	0.09-1.10	0.39
III	109-277	192	21.4-85.6	47.1	0.10-1.5	0.99
III-IV	150-534	291	36.7-417.3	144.1	1.0-12.6	4.9
IV	174-1025	513	71.2-301.6	148.6	4.6-40.6	18.0

Source: *Field survey (1995-96)*; n = 75+70

(f) Conductivity

The conductivity of water body depends on the quantity of dissolved salts present. It is expressed as microsiemens per centimetre (µS /cm). The conductivity of most freshwater ranges from 10 to 1,000 µS/cm but may exceed 1,000 µS /cm especially in polluted water or those receiving large quantities of land run-off (WHO 1996).

Table 9.5 indicates that conductivity is very low in SWQC I, This low conductivity indicates that river water is very soft and originating quartzites siltstones (HMG/ICIMOD/ CDG/UNEP 1994). Like other parameters it is also increased successively in poorer saprobic water quality class. But the rang of minimum to maximum per saprobic water quality class is high. It is mainly due to the increment of value depends on various factors like the origin of river, and type of water receiving from tributaries. So the variation is higher, some rivers are originating from the hill of calcium rock while other are not but with the same SWQC. In present case the value of conductivity is increasing successively along the river indicating increasing organic pollution towards the lower reach of the river. This parameter is very stable, it remains the same until the dilution effect from the tributary with less conductivity. As shown in figure 9.6 carpet industries are also situated along the river and the effluent coming into the river from washing carpets also contribute some chemical ions to increase conductivity. The maximum conductivity is recorded in SWQC IV is 1025 µS/cm and the mean value 513 µS/cm, the value indicates that the main pollution load is from organic waste not from industrial effluent of which is expected higher.

(g) The hardness

The hardness of natural waters depends mainly on the presence of dissolved calcium and magnesium salts. The total content of these salts is known as general hardness which can be further divided into carbonate hardness determined by concentrations of calcium and magnesium hydrocarbonates and non-carbonate hardness (determined by calcium and magnesium salts of strong acids).

Hardness may vary over a wide range. Calcium hardness is usually prevalent (up to 70 percent), although in some cases magnesium hardness can reach 50-60 percent. In present study total hardness has been measured in terms of $CaCO_3$ mg/l (table 9.5). Total hardness corresponds to conductivity. It is also very low in SWQC I indicating the softness of water. It is not directly related to the pollution but it also contribute to some extent to domestic sewage. The normal diet of a person contain certain amount of calcium as shown in table 9.4. In the study area, like other parameters it is also increasing with the deterioration of saprobic water quality class. But in SWQC III the value is recorded low. It is mainly because the rivers are originated from different sourses with different hardness ranges. It shows that hardness does not directly depend on SWQC.

(h) NH4-N

Ammonia occurs naturally in water bodies arising from the breakdown of nitrogenous organic and inorganic matter (NO_3^+, NO_3^+ and molecular N_2) in soil and water, excretion by biota, reduction of the nitrogen gas in water by micro-organisms and from gas exchange with the atmosphere. It is also discharged into water bodies by some industrial processes and also as a component of community waste. Ammonia is therefore a useful indicator of organic pollution (Welch 1992).

Unpolluted waters contain small amounts of ammonia and ammonia compounds, usually less than 0.1 mg/l as nitrogen. Total ammonia concentrations measured in surface waters are typically less than 0.2 mg/l N but may reach 2-3 mg/l N (WHO 1996). Higher concentrations could be an indication of organic pollution such as from domestic sewage, industrial waste and fertiliser run-off. Ammonia occurs in water as free ammonia or an ionised ammonium ion as shown in Figure 9-1. Free ammonia and ammonium ion exists in equilibrium in aqueous solution. Their percentage of occurrence in aquatic system is determined by pH and temperature. Figure 9-1. shows that at higher pH and temperature higher percentage of free ammonia occurs while vice versa to (NH_4^+). Free ammonia is comparatively more toxic in higher concentration than ammonium ion (WHO 1995).

Figure 9-1: The general relationship between the percentage of ionised and free ammonia with varying pH and temperature in freshwater (Source Chapman ed. 1992)

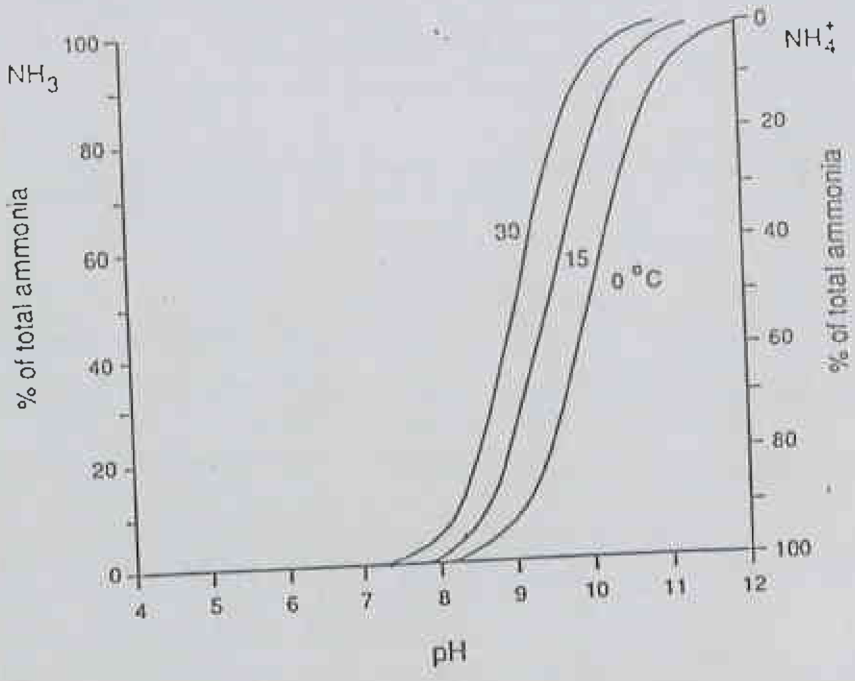


Table 9.5 shows that NH4-N is below 0.1 mg/l in saprobic water quality class I indicating unpolluted water. But in WQC I-II some sites are above this range indicating the beginning of pollution. The rang and the mean values are increasing with poorer saprobic water quality classes.

The change of ratio among the saprobic water quality class is not constant. Highest concentration is recorded in IV followed by SWQC III-IV indicating heavy organic pollution. Chemical fertilizer is used in field which also contribute NH4-N to the surface water.

While comparing pH, temperature and percentage of free ammonia and ionic NH4+, in SWQC I to II the concentration of ammonia is less and it is more than of 90 % in the form of NH4+, but in SWQC II-III to IV more than 10 percent of total ammonia has occurred as free ammonia. The percentage of free ammonia occurred in SWQC III-IV and IV is very toxic to aquatic life which should be less than 1mg/l (Pescod 1977).

From chemical parameter analysis it can be concluded that all SWQC I sites contain very low organic nutrient, high oxygen content and very low conductivity and showing not influenced by human interference. The SWQC I-II onwards indicates gradual increase in concentration of each chemical parameter. While comparing EC standard with SWQC, it shows that up to SWQC II the concentration of each parameter is within the potable abstraction for raw water with different treatments A1-A3. These quality classes are mainly from head water to the periphery of valley area where human interference is low.

(ii) River profile region

In the study area distinct river profile region and season is observed. In order to know their role in saprobic water quality class, each chemical parameter is analysed with reference to these variables. To make more distinct the analysis, in case of river profile region head water region, with two divisions such as upper head water (UHW) and lower head water region (LHW); and valley basin region with three divisions; they are upper valley region (UVR), middle valley region (MVR) and lower valley region (LVR) are made. Similarly, to see the seasonal change two seasons post-monsoon(PO) and pre-monsoon season(PR) are considered. The mean and standard deviation(SD) values are computed from the data results of the sites belonging to each river profile region and season. The minimum and maximum values are also computed.

(a) Temperature

The temperature ranges with mean 10°C in the upper headwater section to 18 °C in the upper valley section in post-monsoon. The minimum temperature of 7°C is recorded in the upper headwater section and the maximum has occurred in the lower valley section. While the variation in temperature recording is analysed by relating standard deviation (SD) to the mean, the great variation has occurred in the upper valley section and the lowest in the upper headwater section. The Tarai sites show mean temperature of 21°C.

Table 9.6:Temperature values (°C) by spatial location and season

Statistical parameters	River profile region									
	Upper HW		Lower HW		Upper VR		Middle VR		Lower VR	
	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Mean	10	17.1	14.2	21.1	17.7	22.9	16.8	23.5	16.0	22.7
SD	1.8	1.5	01.3	02.2	02.9	03.0	02.3	02.5	02.1	03.4
Minimum	7	15.0	12.0	18.0	09.0	17.0	13.0	20.0	12.0	18.0
Maximum	13	19.0	16.0	25.0	21.8	29.0	23.0	31.0	19.0	29.0

Source: *Field survey (1995-96)*. PO = Post-monsoon; PR = Pre-monsoon; HW = Headwater region; VR = Valley region.

There is pronounced seasonal variation in temperature by location. In pre-monsoon, the highest temperature of 31°C is found to be recorded from the site of the middle valley section. Compared to post-monsoon, the minimum temperature value has increased by 100 and 50 percent in all river profile regions in pre-monsoon. The maximum temperature values for all locations have increased by less than 50 percent in pre-monsoon than in post-monsoon. This one time temperature recording in different times of the day or different days of the month show much variation among the sample sites. This variation in temperature by different location and season has several implications for the explanation of the pattern of chemical constituents such as dissolved oxygen (DO), biochemical oxygen demand (BOD) and so on associated with it in the river water. The discussion on these is made later in this section.

(b) Dissolved oxygen (DO)

Table 9.7: Dissolved oxygen values (mg^{-1}) by location and season

n = 75+70

Statistical parameters	River profile region									
	Upper HW		Lower HW		Upper VR		Middle VR		Lower VR	
	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Mean	10.9	9.4	8.7	7.8	6.2	5.4	3.5	3.0	8.0	5.9
SD	1.3	0.5	0.7	1.0	2.3	2.2	2.5	2.3	2.0	2.0
Minimum	9.1	8.7	7.5	6.5	0.8	1.0	0.5	0.8	3.9	3.1
Maximum	13.0	10.2	10.2	9.2	8.9	9.0	9.6	9.2	9.8	8.6

Source: *Field survey (1995-96)*. PO = Post-monsoon; PR = Pre-monsoon; HW = Headwater region; VR = Valley region.

Table 9.8: Oxygen saturation percentage by location and season

n = 75+70

Statistical parameters	River profile region									
	Upper HW		Lower HW		Upper VR		Middle VR		Lower VR	
	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Mean	97	97	84	87	65	63	36	35	81	69
Minimum	75	87	70	69	7	10	4	9	18	33
Maximum	123	110	93	112	102	118	112	122	106	113

Source: *Field survey (1995-96)*. PO = Post-monsoon; PR = Pre-monsoon; HW = Headwater region; VR = Valley region.

Like temperature, the mean dissolved oxygen value is varied by location in post-monsoon with the highest variation in the middle valley section (mean 3.5 ± 2.5 mg/l) and the lowest mean variation of 8.7 ± 0.7 mg/l in the lower headwater section. The maximum of 13 mg/l DO has occurred in the upper headwater section and the minimum of 0.5 mg/l DO in the middle valley section(Table 9.7). DO has increased considerably in the Tarai sites by the mean value of 9 mg /l even though there is high temperature.

There has occurred a great change in DO mg/l between pre- and post-monsoon period. In all cases, the mean DO has decreased in pre-monsoon than in post-monsoon (Figure 9.7) which is simply due to increased mean value of organic amounts and low discharge in the stream in pre-monsoon. However, like in post- monsoon, the SD values in pre-monsoon show less variation in

DO among the sites within the region. While comparing the percentage saturation of dissolved oxygen among regions in post monsoon and pre-monsoon, there is not seen much differences, it is mainly because of the higher water temperature during pre-monsoon than post-monsoon (Table 9.8).

(c) Biochemical oxygen demand (BOD)

The mean results shown in Table 9.9 indicate increasing values of BOD_5 from headwater to downward, followed by decreasing trend in lower reach in post-monsoon. In the Tarai, it has decreased to 3.9 mg/l O_2. In this season, the lowest mean value of 0.5 mg/l O_2 has occurred in the upper headwater section while maximum mean value of 46. 4 mg/l O_2 in the valley section. There is high range value in the downward section of the valley with mean 46.4 ± 52.9 (SD). The values range from minimum of 1.1 mg /l O_2 to 187 mg /l O_2 in middle valley section.

Table 9.9: Biochemical oxygen demand values (mg l^{-1} O_2) by location and season

n = 75+70

Statistical parameters	River profile region									
	Upper HW		Lower HW		Upper VR		Middle VR		Lower VR	
	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Mean	0.5	1.0	1.3	3.1	16.7	23.7	46.4	55	18.3	38.2
SD	0.4	0.4	0.2	1.5	21.6	26	52.9	50	28.2	37.9
Minimum	0.1	0.3	5.2	1.1	1.4	2.3	1.1	3.5	1.3	2.1
Maximum	1.4	1.5	4.5	6.5	78.7	85	187	204	78.0	98.3

Source: *Field survey (1995-96).*

A similar trend is seen in the distribution of the values by location in pre-monsoon but with increased values. This is also mainly due to increased temperature and organic pollution. In headwater the values of BOD_5 show unpolluted condition whereas in the downward section the streams are said to receive wastewater and raw sewage since their values lie above 10 mg l^{-1} O_2.

(d) Ammonia

Table 9.10: Ammonia value (mg /l) by spatial location and season

n = 75+70

Statistical parameters	River profile region									
	Upper HW		Lower HW		Upper VR		Middle VR		Lower VR	
	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Mean	0.04	0.06	0.13	0.31	3.2	4.1	12.4	12.0	2.50	6.6
SD	0.02	0.04	0.15	0.31	7.8	8.4	12.1	10.5	3.48	9.16
Minimum	0.02	0.03	0.04	0.05	0.1	0.1	1.3	0.6	0.1	0.10
Maximum	0.09	0.16	0.50	0.80	34.8	37.5	40.6	39.4	10.1	26.3

Source: *Field survey (1995-96).*

There is a considerable variation in the distribution of mean values of ammonia by location. The mean values range from 0.1 mg/l N in the upper headwater section to 11.1 mg /l. N in the middle valley section in the post-monsoon (Table 9.10). Its maximum value is recorded at 40.6 mg/l N in the middle valley section. There is great variation in the ammonia values among the locations within the region, as evidenced by the corresponding SD values. For the Tarai site, the mean value is 0.8 mg /l NH_4-N.

Like in post-monsoon, the distribution of mean ammonia values in pre-monsoon rises gradually from the lowest value of 0.1 mg /l N in the upper headwater section, reaches peak in the middle valley section and declines in the lower valley section.

While comparing pH, temperature and percentage of free ammonia and ionic NH4+, in head water region the concentration of ammonia is less and it is more than of 90 % in the form of NH4+, but in all the three sections of the valley region i.e. in upper, middle and lower sections have more than 10 percent of ammonia as free ammonia. The percentage of free ammonia occurred in middle valley section is very toxic to aquatic life which should be less than 1mg/l (Pescod 1977).

With reference to EC standard for potable abstraction of water, head water upper and lower both could be used after A1[15] treatment (Guide limit A1 =1 mg/l), The water of upper valley section and lower valley section only in post monsoon season could be used for potable abstraction only after A3 treatment (Guide limit A3 = 4 mg/l).

There is a great fluctuation in the ammonia values between post- and pre-monsoon with increased values in the latter in most cases. The higher ammonia values in the downward sections indicate that there is organic pollution of domestic sewage or industrial waste or fertiliser run-off.

(e) Total Phosphorus

Table 9-11: Phosphorous value PO4 - P (mg /l) by spatial location and season

n = 75+70

Statistical parameters	River profile region									
	Upper HW		Lower HW		Upper VR		Middle VR		Lower VR	
	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Mean	0.04	0.05	0.08	0.22	0.26	0.6	1.3	1.4	0.50	0.70
SD	0.01	0.02	0.04	0.25	0.21	0.7	1.0	0.9	0.54	0.77
Minimum	0.03	0.04	0.04	0.05	0.05	0.1	0.1	0.1	0.05	0.10
Maximum	0.05	0.05	0.2	0.77	0.8	3.1	4.2	3.9	1.43	2.40

Source: *Field survey (1995-96).*

It is known from the information shown in Table 9-11 that the phosphate content is very low in the upper headwater section and minimum value in the lower headwater section in post-monsoon. The mean values are slightly elevated in the locations of the middle valley section and again declined in the lower reach to 0.9 mg /l P in the Tarai site.
With reference to the concentration of PO4-P mg /l the water from head water region could be used for potable abstraction with A1 (Guide line limit for PO4-P mg /l A1 = 0.4) while upper and lower section of valley region could be used either by A2 or A3.

The distribution pattern of the values in pre-monsoon is more or less similar with that in post-monsoon. The increasing values of phosphorous in the downward section of the valley indicate that the stream water has received domestic wastewater (Table 9.4) or industrial effluent or agricultural run-off.

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[15] EC standards for surface water used for potable abstractions (Directive 76/464/EC)
A1= Simple physical treatment and disinfection
A2= Normal full physical and chemical treatment with disinfection.
A3= Intensive physical and chemical treatment with disinfection

(f) Chloride

Table 9.12: Chloride value (mg /l) by spatial location and season

n = 75+70

Statistical parameters	River profile region: Upper HW PO	Upper HW PR	Lower HW PO	Lower HW PR	Upper VR PO	Upper VR PR	Middle VR PO	Middle VR PR	Lower VR PO	Lower VR PR
Mean	3.2	5.2	13.0	10.2	3.3	18.7	50.5	75	18.4	53.1
SD	-0.3	1.4	9.3	6.3	5.2	13.4	26.9	35.6	17.8	50.9
Minimum	2.8	3.1	5.6	3.6	0.1	6.7	7.8	10.0	3.8	6.8
Maximum	3.9	6.9	43.2	25.1	13.7	58.8	102.0	165.0	56.1	127.0

Source: *Field survey (1995-96).*

The mean values of chloride indicate the quality of headwater stream water is fresh and unpolluted (Table 9.12). The mean values also are risen sharply at the sites of the downward section the valley with great variation in post-monsoon. The mean chloride value for the Tarai site is 12.9 mg/l. There is not much varied between minimum and maximum values of chloride in the upper headwater section, but it does in the lower headwater section. In most cases, the chloride values have increased in pre-monsoon, and the pattern is more or less similar with that in post-monsoon.

The chloride values indicate that the rivers in the valley may be contaminated with domestic waste water or sewage. The concentration of chloride in all sites are within the guide line limit for potable abstraction (Guide limit = 200mg/l).

(g) Hardness

Table 9.13: Total hardness value (mg l^{-1} $CaCO_3$) by spatial location and season

n = 75+70

Statistical parameters	River profile region: Upper HW PO	Upper HW PR	Lower HW PO	Lower HW PR	Upper VR PO	Upper VR PR	Middle VR PO	Middle VR PR	Lower VR PO	Lower VR PR
Mean	6.8	9	75	97	88.3	106	137	164	100	121
SD	2.0	1.4	57.2	77.7	93.5	108.0	64	60.4	29.6	32
Minimum	4.3	7.3	13.9	16.1	6.5	8.1	22.8	45.6	62.0	54
Maximum	11.0	12.1	159	250	417	480	301	286	141	159

Source: *Field survey (1995-96).*

All the mean, and SD, and minimum and maximum values are found increasing at the locations of the valley basin and decreasing in lower reach in post-monsoon (Table 9.13). In the Tarai, it reaches up to 133 mg l^{-1} $CaCO_3$.

There is pronounced variation in total hardness of the streams. In all sections except the middle valley section, the total hardness values are higher in pre-monsoon than in post-monsoon. The highest variation has occurred in the upper valley section in both seasons.

Table 9.4 exhibits that one person consume 1 g in average calcium per day, in present study the direct sewerage disposal to the stream is the major problem. So the increase in the amount of total hardness to the middle valley section shows that it could be from the domestic sewerage.

(h) Conductivity

Table 9-14: Conductivity value (µS /cm) by spatial location and season

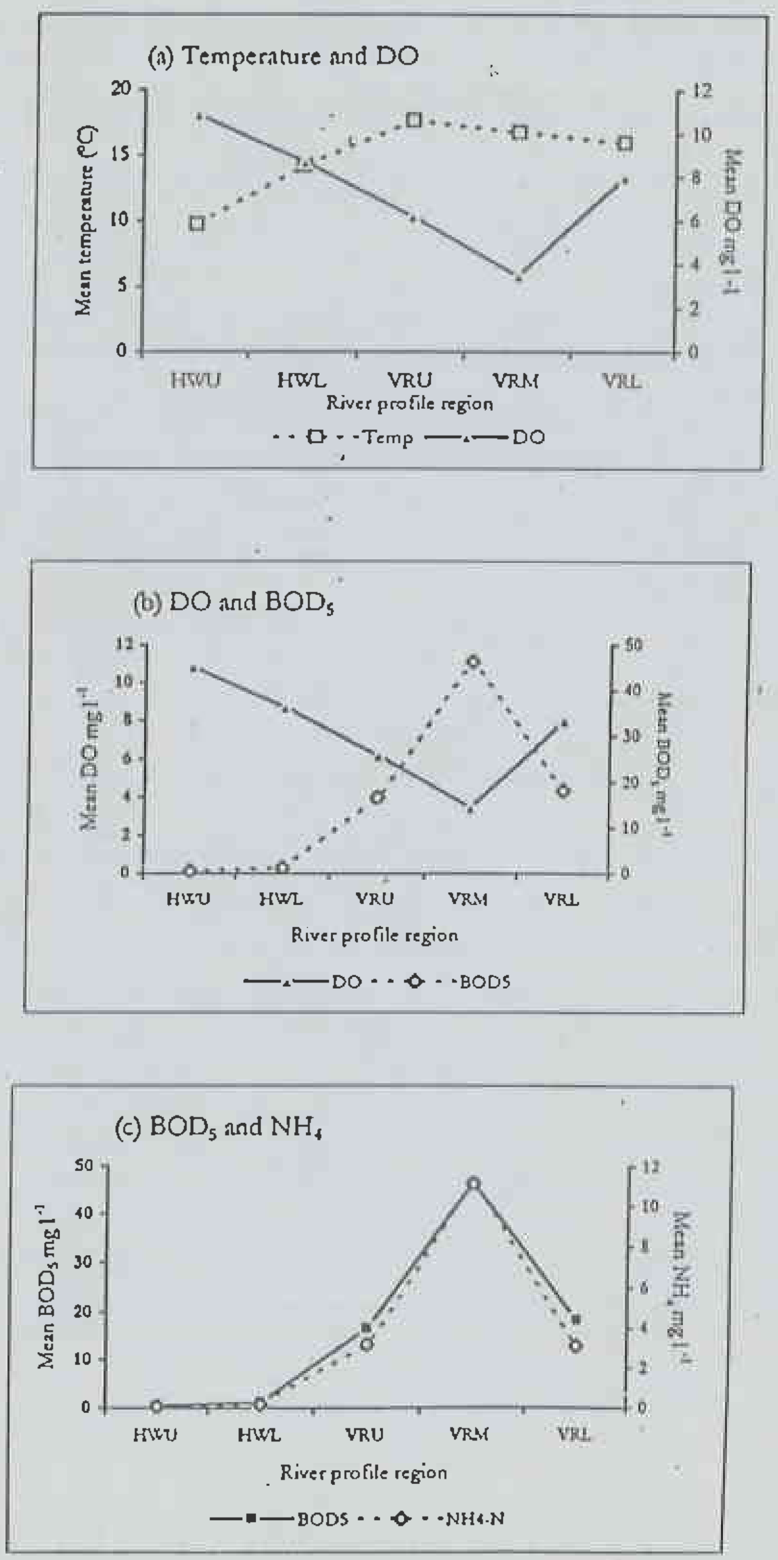
n = 75+70

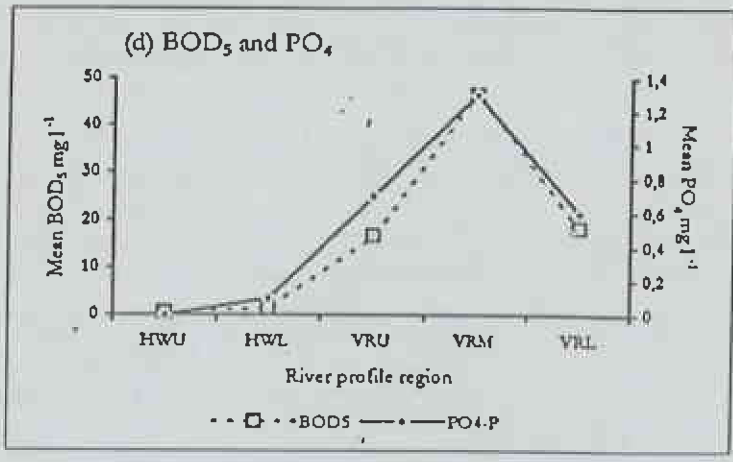
Statistical parameters	River profile region: Upper HW PO	PR	Lower HW PO	PR	Upper VR PO	PR	Middle VR PO	PR	Lower VR PO	PR
Mean	28.3	34.4	128.3	158	150.8	206.0	409.6	549	282.1	461
SD	4.9	4.8	127.3	82	81.7	110.0	251.4	268	108.3	294
Minimum	19.0	24.0	35.0.	64	35.0	49.0	150.0	210	137	146.
Maximum	38	42	307	314	307	428	1025	1140	534	905

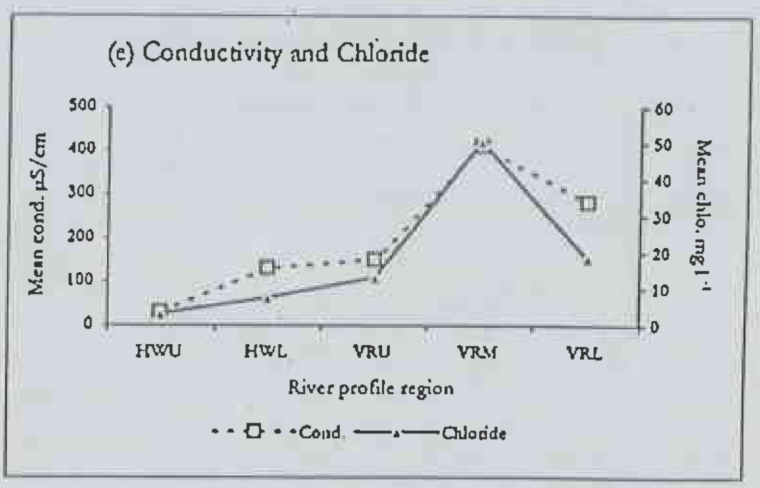
Source: *Field survey (1995-96).*

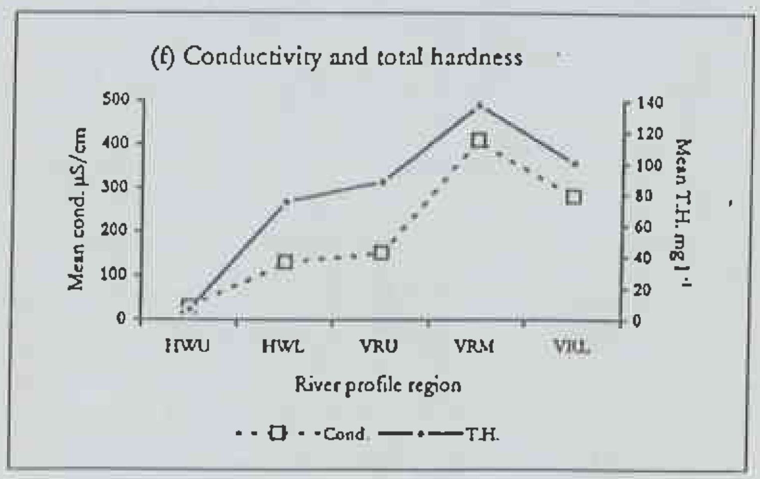
Like other elements mentioned above, the conductivity values are also increased progressively towards valley sections (Table 9-14) and declined sharply in the lower reach to 255 µS /cm in the Tarai site in post-monsoon, and the values are risen sharply in pre-monsoon in all cases. A great fluctuation has occurred in the values of conductivity in the middle valley section.

Figure 9-2: Mean values of the chemical parameters by location




(d) BOD5 and PO4
Mean BOD5 mg l-1
Mean PO4 mg l-1
50
40
30
20
10
0
1,4
1,2
1
0,8
0,6
0,4
0,2
0
HWU
HWL
VRU
VRM
VRL
River profile region
BOD5
PO4-P


(e) Conductivity and Chloride
Mean cond. µS/cm
Mean chlo. mg l-1
500
400
300
200
100
0
60
50
40
30
20
10
0
HWU
HWL
VRU
VRM
VRL
River profile region
Cond.
Chloride


(f) Conductivity and total hardness
Mean cond. µS/cm
Mean T.H. mg l-1
500
400
300
200
100
0
140
120
100
80
60
40
20
0
HWU
HWL
VRU
VRM
VRL
River profile region
Cond.
T.H.

9.2.2 Discussions

(i) Co-relationships among the chemical parameters

The relationships among the variables have been obtained and they are shown in table 9.16. The degree of the relationship is computed through using the Pearson's Product-Moment Coefficient of correlation. The t-test for the pairs of variables is also performed. The formulas for these statistics are as follows (Williams 1984):

(i) *Product-Moment Coefficient of Correlation formula:*

$$r = \frac{n\Sigma XY - \Sigma X \Sigma Y}{\sqrt{[n\Sigma X^2 - (\Sigma X)^2]}\sqrt{[n\Sigma Y^2 - (\Sigma Y)^2]}}$$

(ii) *t-test formula:*

$$t = \frac{r\sqrt{(n-2)}}{\sqrt{[1-(r)^2]}}$$

The correlation coefficient value of r = -0.32 between temperature and dissolved oxygen is so much so weak (Table 9.15). Stated otherwise, DO has fallen sharply with respect to the rising temperature in downward section. The fact that there is not much differentiated mean temperature between headwater and valley regions (10° to 18°C). In other words, the mean value of DO mg/l is too low in the middle valley section compared to that in the upstream. It is evident from the DO results that there is heavy concentration of organic pollution in the rivers that are flowing through the urban core area. Downward of the urban core area, the mean DO mg/l has risen but the temperature has not much declined. The t-test result shows a significant inverse relationship between temperature and DO at $\alpha = 0.01$.

Table 9.15: Results of correlation coefficient of the chemical parameters

Parameters	Temp.	DO	OS %	BOD5	Ammonia	Phosphate	Conduct..	Chloride	Hardness
Temperature		-0.34	-0.26	0.10	-0.05	0.19	0.22	0.14	0.12
DO			0.77	-0.71	-0.61	-0.65	-0.60	0.72	-0.32
OS %				-0.64	-0.72	-0.75	-0.73	-0.82	-0.53
BOD5					0.80	0.81	0.76	0.76	0.31
Ammonia						0.84	0.87	0.88	0.48
Phosphate							0.80	0.89	0.46
Conductivity								0.82	0.63
Chloride									0.50
Hardness									

DO = dissolved oxygen; OS = Oxygen saturation

The relationship between DO and BOD5 as shown by in figure 9.2 b is strong negative for which coefficient value is r = -0.71. The figure 9.2 b shows that there is sharp declining of DO towards the middle valley section where BOD5 is rising sharply from the headwater. It is due to the fact that biodegradable organic reduces the amount of dissolved oxygen in water due to biological oxygen demand for their composition (Spellman 1974). So, the lowest DO mg/l in the middle valley section is due to highest BOD5 mg/l However, in the lower section of the valley, BOD5 is found declining sharply with respect to rising DO, which may be due to dilution effect or high aeration.

Ammonia, as one of the important constituents of organic wastes derived chiefly from sewage, increase BOD5. The figure 9.2 c shows that both mean values of NH4-N and BOD5 are risen sharply towards the middle valley section more or less in parallel way. This means that the two components are closely and straightway related. The coefficient of correlation for these two parameters is r = 0.80. There is found significant correlation between them at $\alpha = 0.01$.

The river water may receive phosphate from various sources such as agriculture run-off, domestic sewage, industrial effluent and rocks. The mean value result of PO4-P is plotted together with BOD5 in figure 9.2 d. As phosphate is one of the constituents of organic wastes, the value of BOD5 in river water is squarely dependent on it. The correlation coefficient value between them is r = 0.81 indicating strong relationship. The relationship is found significant at $\alpha = 0.01$.
The conductivity shown in figure 9.2 e which has risen gradually up to the upper valley section and sharply risen to the middle valley section and declined afterwards in the downstream. More or less paralleling with this graph line are those of chloride and total hardness (figure 9.2 e and f). Conductivity has increased along with increased chloride. Chloride is one of the important ions derived from nature and human sewage. It is estimated that one person's metabolism releases on average ≈ 6 g of chloride each day (Tebbutt 1992). The rising mean value of chloride towards the middle valley section indicates a high organic sewage in the river. The sharp decline of mean chloride value in the lower section may be due to dilution effect of the relatively freshwater streams. There is very low chloride concentration in the upstream.

It can be concluded from the above discussions that there is great variation of the chemical parameters among the sample sites. DO is high in the upstream and is sharply declined in the downstream of the valley area. All other variables such as temperature, conductivity, BOD5, NH4 -N, PO4-P, pH, chloride, and total hardness show low values in the upstream and their values are rising progressively in the downstream section of the valley region and then fallen sharply in the lower section. These results indicate that the rivers in the urban core of the valley region where SWQC III-IV and IV are heavily polluted with organic wastes of human origin. The high value of DO together with the low values of all other parameters in the SWQC I in headwater indicates very low level of organic pollution. The rising trend of DO and declining trend of the rest other parameters in the lower section of the valley region exhibit that the organic pollution has not much added but rather declined which may be due to dilution effect of the mixing of relatively fresh stream waters into the Bagmati or aeration.

(ii) Distribution pattern of the chemical parameters by individual river

The above discussion indicates the pattern of pollution level in different locations of the study region. Attempt here is made to show the pattern and intensity of pollution level in terms of those chemical components by individual river. By this method which rivers or streams are most polluted by the chemical parameters compared to others in the study region.

The mean value results of temperature shown in Figure 9-3a exhibit that for all streams, the highest temperature has occurred in the upper valley section, followed it by the middle valley section. Taking consideration of the values of DO, BOD5, ammonia, total phosphate, and chloride, the Tukucha is found the most polluted stream in the middle valley section (.Figure 9-3 b; c; d; e; and f). It is followed by the Dhobikhola in most cases. The Bagmati and the Bishnumati are also found equally polluted in the middle valley section. The highest value of total hardness and conductivity is found at the sites along the Tukucha in the middle valley section (Figure 9-3g; h).

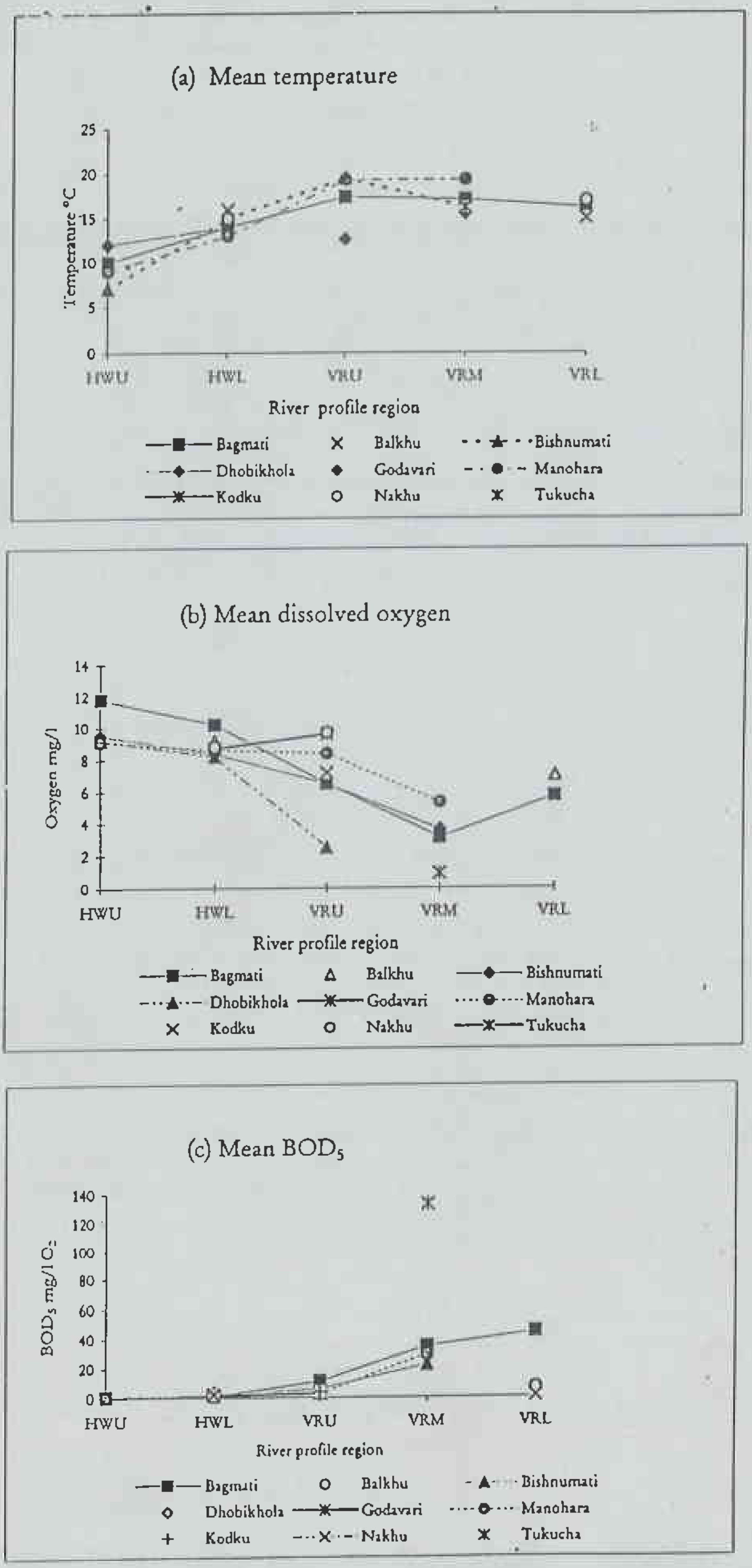
(iii) Diel change pattern of the chemical parameters

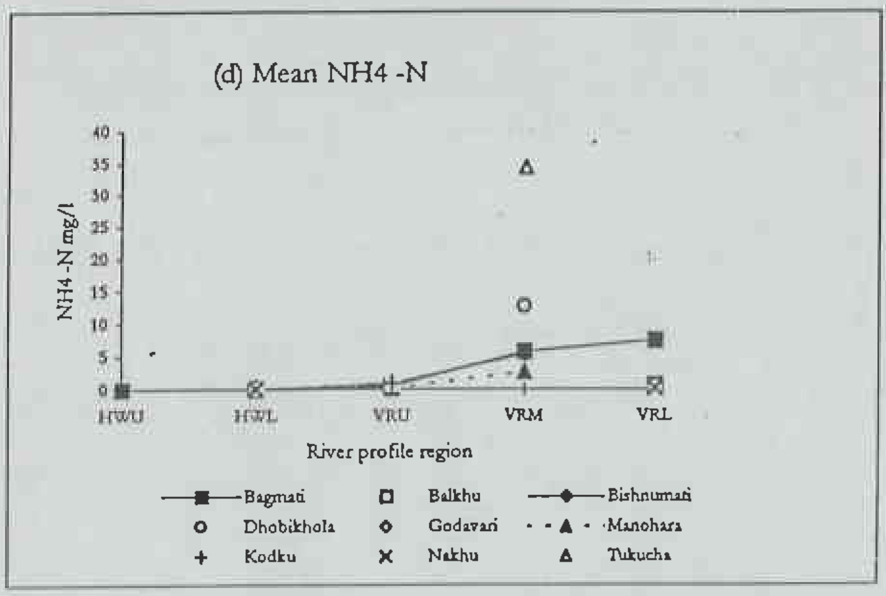
The diel change of the chemical parameters has been observed at the sample site 13 of the Pashupati temple located on the bank of the Bagmati. The results shown in Figure 9-4. indicate that while the temperature is falling gradually towards evening and night and reaching minimum (10°C) in the early morning at 4:00 AM and then rising again, dissolved oxygen (DO) value with 4 mg l^{-1} is the least at 4:00 PM and risen maximum with 7.7 mg l^{-1} at 7:00 PM and then falling. There is not exact matching between downward sloping of temperature and upward sloping of DO. However, the coefficient of correlation value with $r = -0.81$ indicates strong inverse relationship between the two parameters. The diel trend pattern of BOD5 has established strong inverse relationship with DO ($r = -0.92$). There is very strong straight relationship ($r=0.95$) between BOD5 and ammonia.

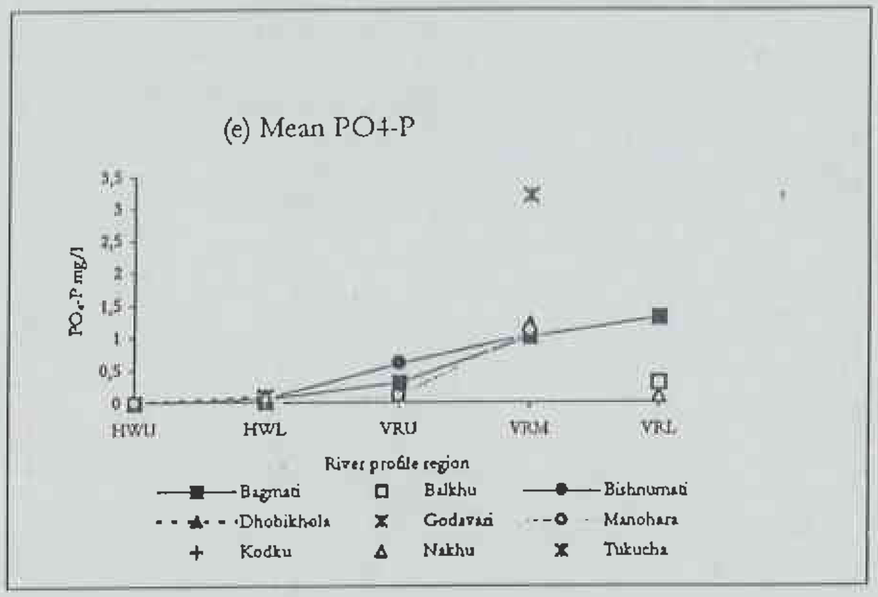
In Figure 9-4b, the highest value of ammonia with 2.94 mg /l taken place at 1:00 PM and the lowest with 0.71 mg l^{-1} at 1:00 AM. The diel pattern of orthophosphate shows more or less similar pattern with that of ammonia. The three parameters including chloride, total hardness and conductivity are falling towards evening and night from 1:00 PM, reaching minimum values more or less in the early morning and then rising. BOD indicating total pollution also shows the same diel pattern.

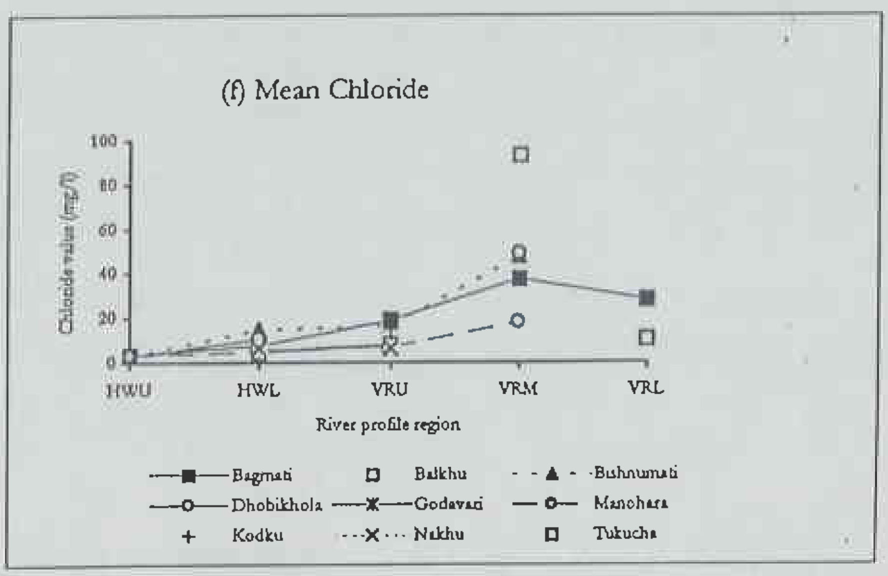
There is not much variation in the distribution of the values in 24 hours as measured in terms of mean and standard deviation. Relatively higher variation has occurred in BOD5 and chloride than in other parameters. The mean values of DO, BOD5, NH_4-N and chloride with 5.6, 9.1, 1.6, and 10.2 mg/l respectively show that there is organic pollution.

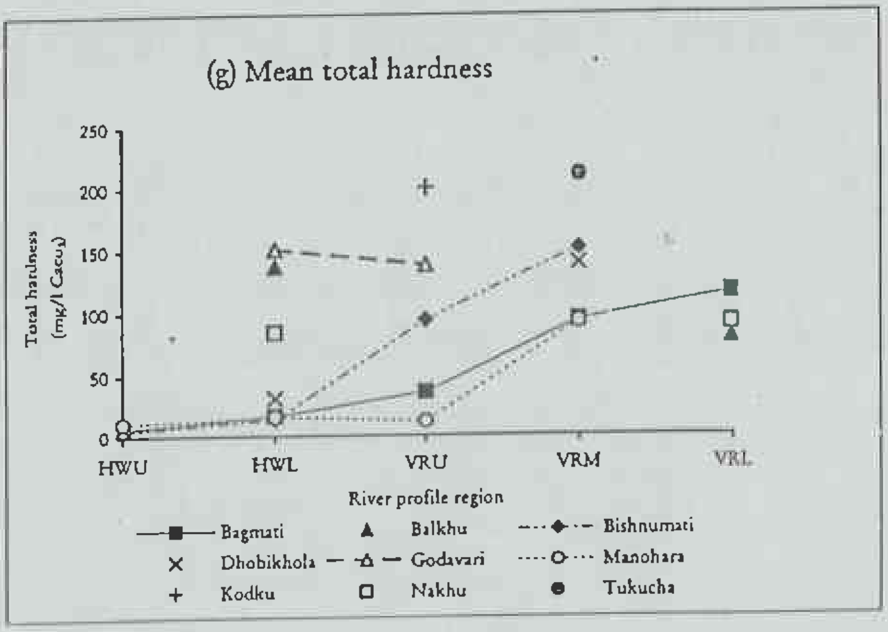
Figure 9-3: Mean values of the chemical parameters by river




(d) Mean NH4 -N
NH4 -N mg/l
0
5
10
15
20
25
30
35
40
HWU
HWL
VRU
VRM
VRL
River profile region
Bagmati
Balkhu
Bishnumati
Dhobikhola
Godavari
Manohara
Kodku
Nakhu
Tukucha


(e) Mean PO4-P
PO4-P mg/l
0
0,5
1
1,5
2
2,5
3
3,5
HWU
HWL
VRU
VRM
VRL
River profile region
Bagmati
Balkhu
Bishnumati
Dhobikhola
Godavari
Manohara
Kodku
Nakhu
Tukucha


(f) Mean Chloride
Chloride value (mg/l)
0
20
40
60
80
100
HWU
HWL
VRU
VRM
VRL
River profile region
Bagmati
Balkhu
Bishnumati
Dhobikhola
Godavari
Manohara
Kodku
Nakhu
Tukucha


(g) Mean total hardness
Total hardness (mg/l CaCO3)
250
200
150
100
50
0
HWU
HWL
VRU
VRM
VRL
River profile region
Bagmati
Balkhu
Bishnumati
Dhobikhola
Godavari
Manohara
Kodku
Nakhu
Tukucha

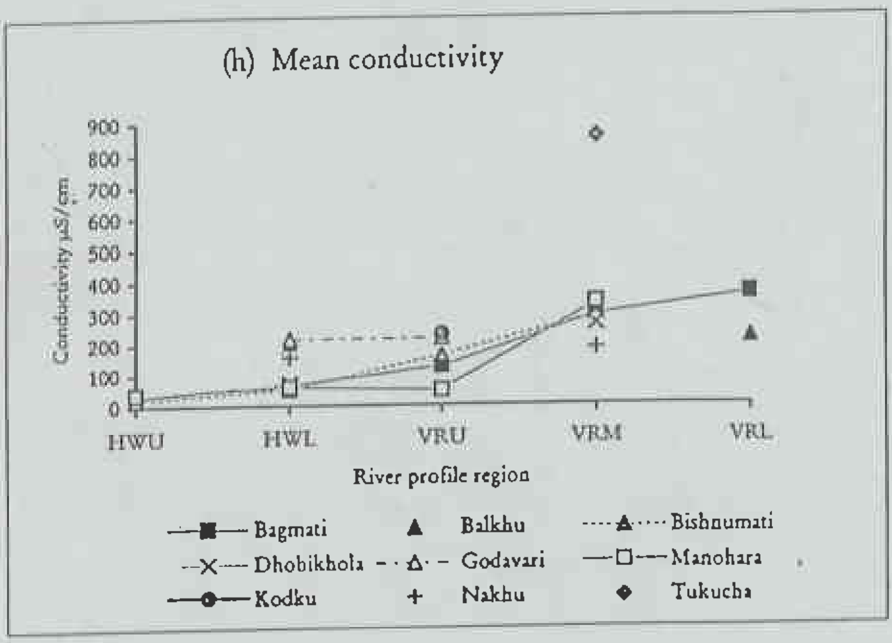
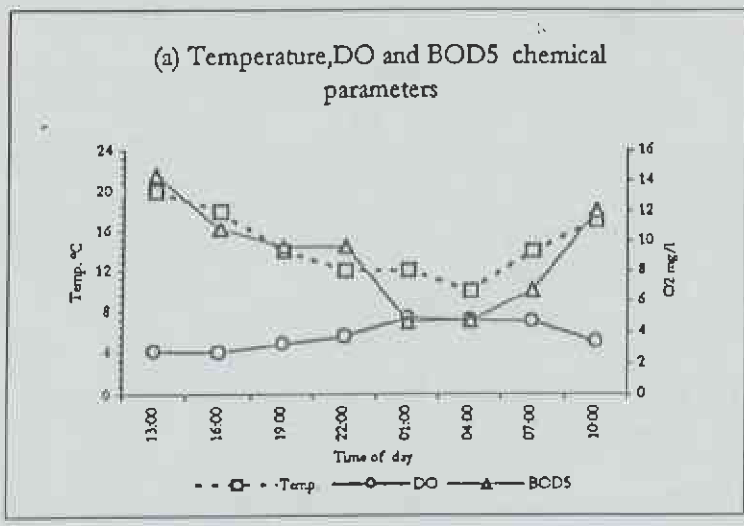
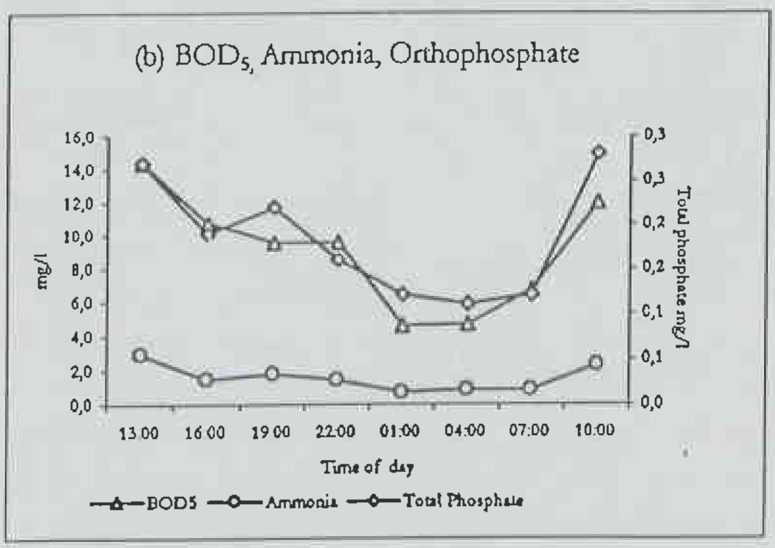

(h) Mean conductivity
Conductivity µS/cm
900
800
700
600
500
400
300
200
100
0
HWU
HWL
VRU
VRM
VRL
River profile region
Bagmati
Balkhu
Bishnumati
Dhobikhola
Godavari
Manohara
Kodku
Nakhu
Tukucha

Figure 9-4: Diel change of the chemical parameters at the Pashupati temple site





(iv) Kunds

Table 9.16 a and b show that there is not much variation in all the chemical parameters among the four *kunds* as well as between post- and pre-monsoon. The values of DO, BOD5, phosphorous, chloride and ammonia indicate no manmade organic pollution. The values of ammonia, chloride, hardness and pH of the *kunds* lie within the desirable level set by WHO standard. The set values are 0.5 mg l/lfor NH4-N, 250 mg /l for chloride, 500 mg /l for CaCO3 and 6.5 - 8.5 for pH (WHO 1996).

Table 9.16: Results of the chemical parameters of *kunds*

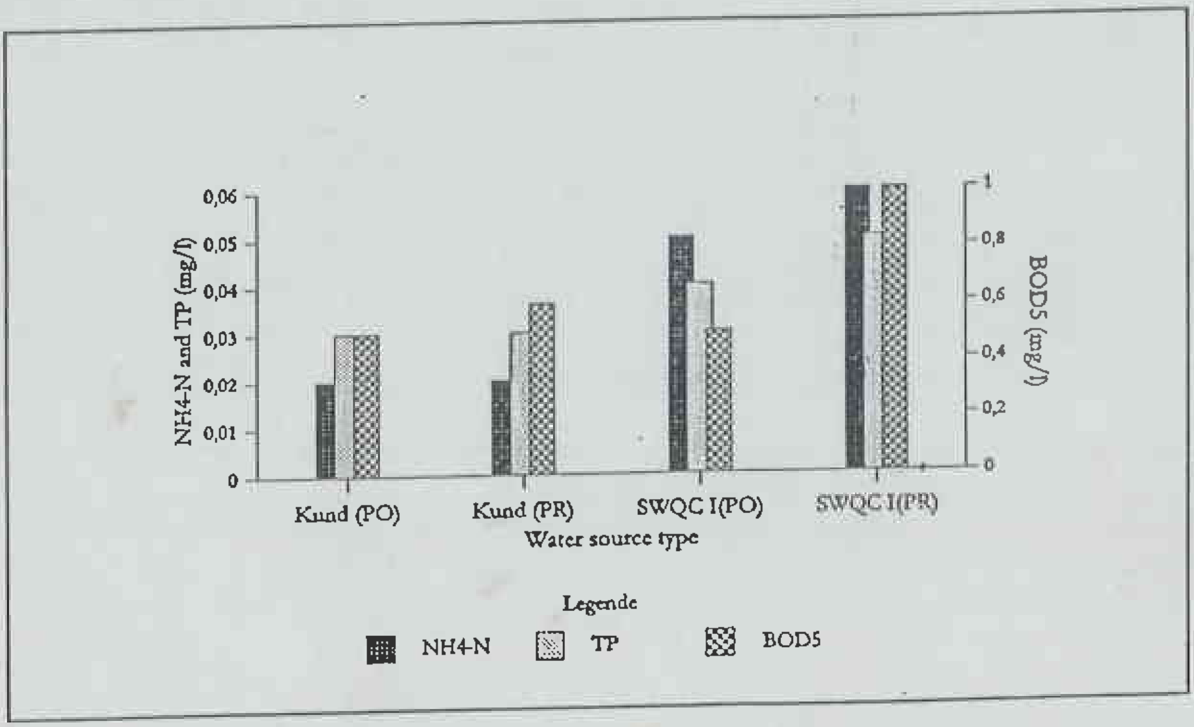
(a) Post-monsoon

Kunds	Temp° C	pH	Cond. μS cm/l	T. hard. (CaCO3) mg /	Chloride mg /l	N-NH4 mg /l	TP mg /l	DO mg /l	DO %	BOD5 mg /l O_2
Godavari	15	8	264	147	3	0.02	0.02	8	80	0.4
Gaurikund	16	7	301	152	3	0.03	0.03	7.5	76	0.5
Naudhara	15	7	195	135	2	0.02	0.03	8.1	81	0.5
Matatirth	16	8	271	158	4	0.03	0.03	7.8	79	0.5

(b) Pre-monsoon

Kunds	Temp° C	pH	Cond. μS cm $^{-1}$	T. hard. mg/l	Chloride mg /l	N-NH4 mg /l	TP mg /l	DO mg /l	DO %	BOD5 mg /l O_2
Godavari	17	9	285	152	3	0.04	0.03	7.5	78	0.6
Gaurikund	17	8	305	163	3	0.03	0.04	6.8	70	0.5
Naudhara	16	8	179	142	2	0.03	0.03	7.8	79	0.4
Matatirth	15	8	273	146	5	0.03	0.04	7.4	74	0.6

Figure 9-5: Comparison of chemical parameter results between *kunds* and stream SWQC I



The chemical parameters like ammonia, chloride and total hardness in drinking-water are not of immediate health relevance, and therefore no health-based guideline value is proposed.(WHO 1996). The numerical values of the chemical parameters between *kunds* and streams with SWQC I are compared and the values of the given chemical parameters of the *kunds* lie within the set values of WHO drinking water standard.

According to figures 9.5 a and b there are seen variations in the concentration of the parameters between Kund and stream head water region of SWQC I but both of the sources can be used for drinking water with treatment A1 (WHO 1995). As, all the kunds are coming from the carbonate rocks and they are less aerated than stream head water region. From the figure 9.5 b it is seen that total hardness and conductivity are higher while dissolved oxygen is lower in the kund as compared to stream head water. There is very less temperature fluctuation in case of Kunds through out the year but in stream head water there is marked fluctuation between post and pre monsoon which is 10°C (mean temperature) during post-monsoon and of 17°C (mean temperature) in pre-monsoon. Oxygen saturation percentage has been recorded to 75-80 % in the kunds while about 97% in stream SWQC I.

(v) Comparison of frequencies of water quality classes by chemical indices and saprobic water quality classes

It has also been discussed in chapter 2 that there are many types of chemical indices used in different studies. The type of parameters and the weight given to the parameters vary from study to study. They are mainly based on the prevailing their study areas. Some of the chemical indices which have common parameters as with the present study have been taken for the comparison. Chemical index developed by Bach (1980) considering eight chemical parameters are used to compare here as a multiple parameter index and indices of Perchlaner (1985), Doetsch (1987),and Hamm (1969), are used as a single Parameter.

From the equation given by Bach(1980) . the chemical parameter has been computed qi^{wi} for each parameter is given in Appendix Q.

$$CI = \prod_{i=1}^{n} qi^{wi}$$

Where CI = Chemical index,
qi = Transformed value of each parameter
wi = relative weight of *n th* parameter
qi^{wi} value for each parameter is given in the appendix Q

After computing CI value for each sample site, it is grouped into saprobic water quality classes as given the ranges in Table 9.17. The frequencies of these saprobic water quality classes are compared with the frequencies of the saprobic water quality classes. From this index saprobic water quality class I is overestimated, and it shows good correlation with poor water quality. Water quality class II-III is underestimated. This comparison shows that this index is not applicable to the study area.

Table 9.17: Comparison of Frequencies of SWQC by Chemical Index (Bach 1980) and Saprobic water quality class

WQC	Range of Chemical Index (CI)	Freq. of SS based on CI (Bach 1980)	Freq. of SS SWQC (PO)
I	>83	17	8
I-II	73-82	8	9
II	56-72	15	14
II-III	44-55	2	11
III	27-43	7	7
III-IV	17-26	10	12
IV	<17	16	14
Total		75	75

SS = Sample site; PO = Post-monsoon; PR = Pre-moonsoon

Table 9.18: Comparative results of number of sample sites by selected chemical parameters

a) Total phosphate

WQ	Perchlaner 1985		Freq. of SS
Class	Range (μg/l)	Freq. of SS	SWQC
I	< 0.035	2	8
I-II	-	-	9
II	0.036 - 081	6	14
II-III	0.082 - 0.196	18	11
III	0.196 - 0.261	13	7
III-IV	0.262 - 0.327	3	12
IV	>0.327	33	14
Total		75	75

(b) Ammonia nitrogen

WQ	Perchlaner 1985		Freq. of SS
Class	Range (μg/l)	Freq. of SS	SWQC
I	< 0.080	21	8
I-II	-	-	9
II	0.081 - 0.190	13	14
II-III	0.191 - 0.470	3	11
III	0.471 - 0.620	0	7
III-IV.	0.621 - 0.780	2	12
IV	>780	36	14
Total		75	75

(c) BOD5

WQ Class	Doetsch 1987 *Range (mg/l)	Doetsch 1987 Freq. of SS	Freq. of SS SWQC
I	1	11	8
I-II	1-2	11	9
II	2-6	16	14
II-III	5-10	8	11
III	7-13	1	7
III-IV	10-20	5	12
IV	>15	23	14
Total		75	75

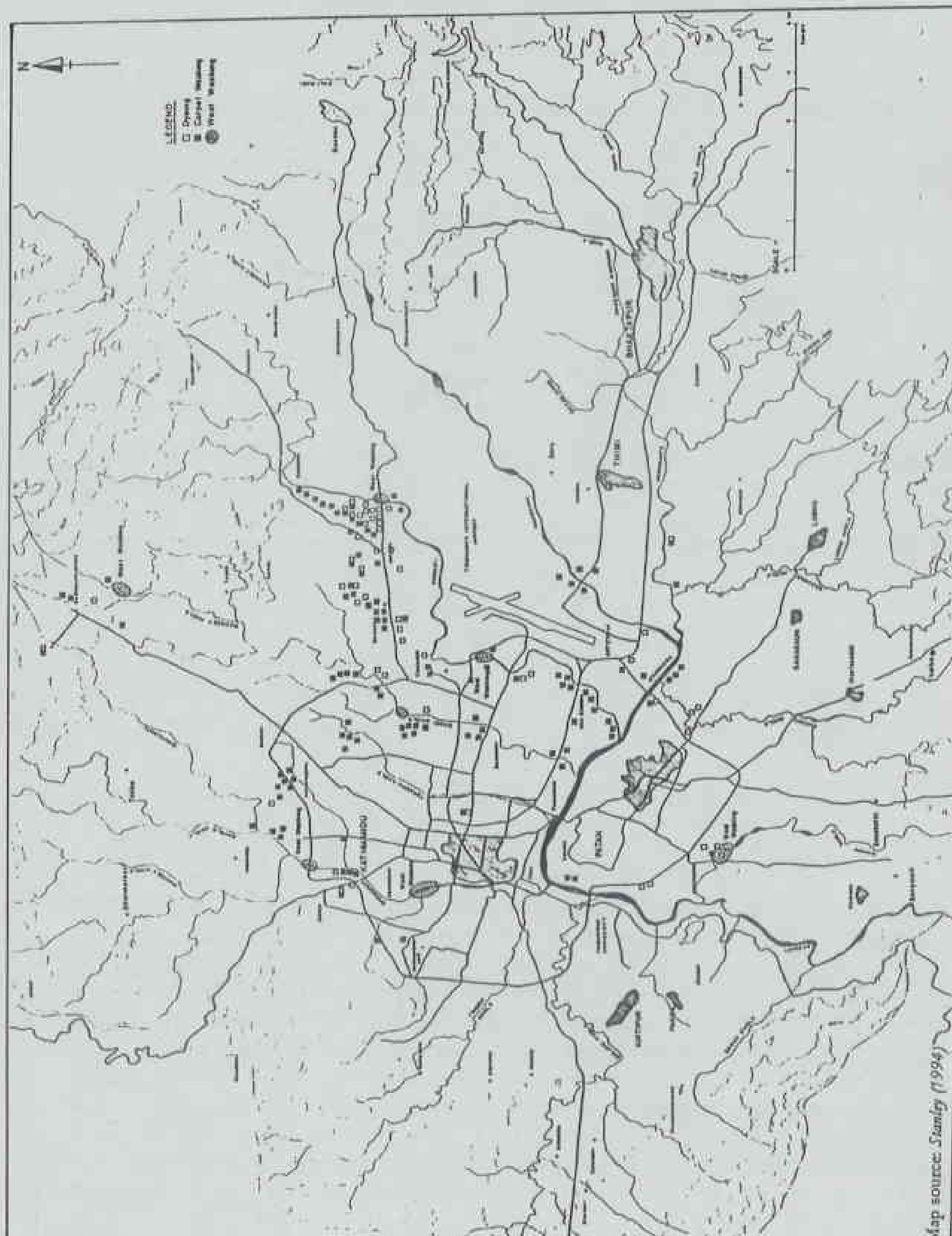
** The range given here is overlapping in some cases hence the mean of the range has been used.*

(d) Oxygen saturation percentage

WQ Class	Hamm (1969) Range % O2 saturation	Hamm (1969) Freq. of SS	Freq. of SS SWQC
I	95 - 100	12	8
I-II	85 - 95	3	9
II	70 - 85	26	14
II-III	50 - 70	10	11
III	25 - 50	10	7
III-IV	10 - 25	10	12
IV	< 10	4	14
Total		75	75

Table 9.18 indicates the frequency of SWQC and frequency of comparison of chemical parameters with reference to different ranges given by different authors. In Table 9.19 a indicates that total phosphate range for SWQC I, I-II and II are underestimated while WQC IV is over estimated. Table 9.19 b shows the chemical parameter NH4-N overestimated the SWQC I and the distribution of frequencies are not uniform. It is less in SWQC II-III and there is no frequency in WQC III and again highest number in WQC IV. Table 9.19 c and d shows the frequencies with BOD5 and Oxygen saturation %.they are also quite different to the same saprobic water quality class. Different chemical parameter gave different frequencies to the same SWQC. According to the given range values of those chemical parameters by different authors, the frequencies in three parameters like Total phosphate , Ammonia and BOD5, all showed high frequency in QWC IV indicating that the river has all the three chemicals are in high amount. On the other hand Oxygen saturation showed over estimate of WQC I and underestimated saprobic water quality class IV. This comparison between chemical parameter and SWQC is very controversial, each chemical is giving different result. This result shows that saprobic water quality class estimated with the help of chemical parameter may not reflect the same what is existing saprobic quality.

Figure 9-6: Location of carpet industries in Kathmandu valley



Map source: *Stanley (1994)*

10 SUMMARY, CONCLUSIONS AND RECOMMENDATION

10.1 Summary and Conclusions

- The river water in Nepal is used for various domestic uses and it is socially and culturally attached with the people for their day to day activities and from birth to death. The rivers are holy and people use river water as a holy water despite the poor quality. The ADB's study (1985) showed that more than 50 percent of the hospital patients in Nepal were suffering from gastrointestinal disorders normally caused by water borne pathogens, and about one third of child deaths under four years of age in rural Nepal are due to such waterborne diseases as cholera, typhoid, dysentery and gastro-enteritis. The water quality assessment is felt essential to know the overall situation of rivers.

- The present study focuses on water quality assessment of Bagmati river and its tributaries. Three monitoring aspects such as bacterial, benthic macroinvertebrate and chemical parameters have been considered for the study. The methodological background of water quality assessment is based on saprobic water quality classes (SWQC). The method for saprobic water quality class assessment follows Moog (1991), ÖNORM 6232 (1995), Nepal biotic score (NEPBIOS). With the increasing pollution level four main and three transitional water quality classes have been adapted such as WQC I non to very slightly polluted (oligosaprobic), SWQC I-II slightly polluted (oligosaprobic to beta-mesosaprobic), SWQC II moderately polluted (beta-mesosaprobic), SWQC II-III critically polluted (beta-mesosaprobic to alpha -mesosaprobic), SWQC III heavily polluted (alpha-mesosaprobic), SWQC III-IV very heavily polluted (alph-mesosaprobic to polysaprobic) and SWQC IV extremely polluted (polysaprobic).

- The sampling design for each monitoring aspect is based on grouping sampling sites due to (a) river profile region (b) river system and (c) season

- The result for each monitoring aspect is referred to the saprobic water quality classes.

River profile region:

- The Kathmandu valley region is distinctively made up of mountain slope and valley basin. To make analysis of river profile region more clear, three spatial divisions such as headwater, valley region and low region are made considering the factors of relief (slope), streams system (stream order) and socio-economic (population density and road). The sub-divisions for the former two regions have also been identified. The headwater region has been classified into upper and lower sections simply on the ground of terrain and stream order system while the three sub-divisions of the valley region such as upper, middle and lower have been identified mainly in terms of social and drainage system. In terms of drainage system, in the upper section, streams join the Bagmati river in the upper part of the valley basin and flow through the city core, while in the lower section streams meet the Bagmati after it passes the city core in downward section. The Tarai section of the Bagmati is distinctive from the rest other regions simply because it lies completely in the plain terrain.

River System

- For the precise comparison of the rivers, the Bagmati river system has been categorized into different sub-river systems such as (1) the Bagmati sub-system including the upper Bagmati itself, Nagmati, Syalmati, Bosan, and Chalti; (2) the Bishnumati sub-system including the Bishnumati itself, Mahadev, Manamati, Sangla and Samakhusi; (3) the Balkhu comprising the Balkhu itself, Dharapani and Indrawati; (4) the Dhobikhola composing of Phedi and Mahadev; (5) the Manohara consisting of Bhagerikhola, Hanumante, Indrayani, Manamati, and Salinadi; (6) the Godavari; (7) the Kodku; (8) the Nakhu making up of Lele and Nallu; and (9) the Tukucha. Four *kunds* such as Gauri, Godavari, Matatirth and Naudhara are separated from the river system analysis.

Season

- Of the total 75+4[16] sample sites in post monsoon season, the number of sample sites in each of the river profile regions are as follows: headwater - 24 (12/12), valley segment - 53 (19/24/10), and low region - 2. While the sample sites have been divided according to the saprobic water quality classes (SWQC), 8 of the total sites excluding four *kunds* are found in saprobic water quality Class I; 9 and 14 sites in SWQC I-II and II respectively; while II-III and III possess 11 and 7 sites respectively. Of the remaining 26 sites, 12 and 14 in SWQC III-IV and IV respectively in post-monsoon season. In pre-monsoon season only 74 (70+4) samples have been analysed because three sites dried and two cites of lower region (Tarai) have not been considered.

Bacterial Aspect

- Three bacterial parameters they are heterotrophic bacteria, *E.coli* number (EC) and Faecal streptococcus (FS) are considered for the present study. The enumeration of bacteria is made in terms of colony forming unit (cfu). The heterotrophic plate count (HPC) is made as cfu/ml at 22°C, and *Escherichia coli* and faecal streptococcus numbers are recorded as cfu/100 ml at 37°C and 44°C respectively. The saprobic water quality classification made in field provides main basis for bacterial water quality assessment mainly for estimating dilution.

- In addition to these bacterial parameters, total bacterial count through epifluorescence microscope and Salmonella tests are also considered to compare their result with SWQC.

- The bacterial range for each saprobic water quality class has been computed from the three replicate samples each from post-monsoon and pre-monsoon seasons from 75 and 70 samples sites respectively representing of seven saprobic water quality classes. Total bacterial counts are made from 35 sample sites, five from each saprobic water quality class. Salmonella test is performed in 30 sample sites from the sites where people use water for domestic work.

- In the study area SWQC has shown strong correlation with heterotrophic plate count (HPC) *E.coli* (EC) and faecal streptococcus (FS) counts separately showing that the water quality deterioration is due to organic pollution mainly from domestic raw sewage.

- The comparison of cfu/ml of HPC with the range given for saprobic water quality class with reference to European rivers (Jung's range cited in Popp 1994), 75% sample sites of saprobic water quality class lie within the range. Each quality class compare to its next quality class shows in average 50% overlapping in the range. This is mainly because of the bacterial

[16] Sample from rivers and four spring (kund).

numbers of two extreme seasons, post and pre-monsoon seasons are considered. For each SWQC the minimum and maximum range as well as the mean bacterial number is lower in post-monsoon season than in pre-monsoon season. This variation in HPC may be due to higher temperature in pre-monsoon season than in post-monsoon which facilitates faster multiplication of bacterial growth (Rheinheimer1992) and for *E.coli* and streptococcus numbers are mainly due to the comparatively higher human interference to the river which is observed. The variation in range in the number of bacteria is seen in each saprobic water quality class which is higher in poorer water quality classes.

- In the Bagmati river system, *E.coli* number is found to be higher in each SWQC compare to the range provided by Kohl (1975) with reference to the central European river.

- In headwater region for all three bacterial parameters' numbers have been recorded low and their numbers have been increased tremendously in the valley section. It is observed that it is due to the pollution caused by discharging of solid wastes and untreated sewage directly into the streams. The mean colony forming unit (cfu) of each bacterial parameters have been decreased significantly downstream of the urban area and further decreased drastically beyond the valley region in the Tarai plain. It is seen that in the section downward of the middle valley, the Bagmati has improved its water quality in terms bacterial number which may be because of self purification process as well as mixing of additional hilly fresh streams into the main river system.

- The headwater region, where saprobic water quality class I, I-II and II (only 50 % sites) have been recorded, the range of the bacterial number is within the standard values set by EC for the potable raw water abstraction with preliminary treatments A1[17], A2 and A3 respectively. The sites where above saprobic water quality II are not recommended to use any domestic purpose (WHO 1995; PESCOD 1977). The water of *Kunds* shows safe drinking water quality, which sometime needs A1 treatment.

- There is a high variation in the ratio of total bacterial number (TC) and heterotrophic plate number (HPC) for each saprobic water quality class. However, the ratio is highest in saprobic water quality class I and decreases with the deterioration of the quality indicating lower number of allochthonous bacteria in saprobic water quality class I. The percentage of heterotrophic number with reference to direct number (TC) is increased along with poorer water quality classes. The mean bacterial number increases with the deterioration of water quality classes. Biomass of the bacteria also increases with the deterioration of water quality class indicates that the river has sewage effluents in which the proportion of biodegradable organic carbon (BDOC) is highest and which is used by the bacteria to increase its biomass (Servais 1985).

- It is found out that most of the positive *Salmonella* test sites are in the valley basin region. Despite the contamination of river water with faecal and household refuse, people use the river water for various domestic purposes. This has often resulted into several types of water borne disease, it is observed UNICEF (1987).

[17] EC standard for surface water used for potable abstractions (Directive 80/778/ EEC).
A1= Simple physical treatment and disinfection
A2= Normal full physical and chemical treatment with disinfection.
A3= Intensive physical and chemical treatment with disinfection

Benthic macroinvertebrates

- In this study, a total of 71 families, 136 genera, and 157 species of benthic invertebrates have been identified. Incidence of occurrence of these animals is found varied markedly by the river profile region in which the physiographic variation and the socio-economic factors appear to be significant. On the whole, two orders Trichoptera and Diptera are the most common for each of the saprobic water quality class. Each has possessed the largest number of families, and accounted for 17 percent in the total. These are followed by Coleoptera, Odonata and other orders.

- It is observed that there is less coefficient of variation (CV) in diversity of taxa among the sample sites belonged to good water quality classes but it is higher in poor water quality classes.

- The EPT concept, which considers the taxa belonging to the groups Ephemeroptera, Plecoptera, and Trichoptera (EPT) are as sensitive taxa to pollution could not be verified in the study area. The percentage of EPT is recorded highest in SWQC II. The percentage of EPT seems higher in WQC III than its preceding quality class II-III in both season. This increase in percentage is due to the occurrence of some comparatively pollution tolerant taxa of this group like *Baetis sp.2, Baetis sp.3*, of family Baetidae, *Caenis sp.* of family Caenidae, *Euthraulus sp.* of family Leptophlebiidae from the order Ephemeroptera and members of Hydropsychidae family from the order Trichoptera.

- The coefficient of variation in benthic invertebrate among the saprobic water quality classes between two seasons are not significant statistically at $\alpha = 0.01$. The change has occurred in the number of sites in water quality classes from existing quality to poorer quality class between post and pre-monsoon season. This change in water quality class is mainly due to the decrease of dilution capacity of the river in pre-monsoon season.

- The most sensitive taxa to pollution are recorded from some of the genera of family Perlidae, Nemouridae, Heptageniidae, Leptophlebiidae, Ephemerellidae, and most of the families from the order Trichoptera except Hydropsychidae and some genera from Diptera. Some taxa from the families Chironomidae, Tubificidae and Physidae are found pollution tolerant.

- To make saprobic water quality class more precise 45 families from total of 71 families are given score in the family level and 12 families are given in genera and species levels.

- Considering the taxonomic limitation of Nepalese fauna, a suitable score system for Nepal, Nepal biotic score (NEPBIOS Sharma1996) has been developed. For the strengthening of NEPBIOS, it is cross-checked with the scores of the Bagmati river system (BRS) and minor changes in the scores are made and 4 families, 10 genera and 10 species are added to enlarge NEPBIOS as NEPBIOS-BRS.

- The study confirms that for the better precision of water quality classification higher taxonomic level is necessary which is shown by the genera identified from the families such as Baetidae, Heptageniidae and Salifidae etc. have different scores according to their occurrence with saprobic water quality class.

Chemical Aspect

- For chemical parameter analysis, pH, Conductivity, DO, Chloride, Total hardness, Temperature, BOD5 PO_4-P and NH_4 have been considered. The SWQC has shown significant correlation with the chemical parameters such as Conductivity, DO, Chloride, Total hardness, BOD5, PO_4-P and NH_4-N considered for the study.

- Chloride, NH_4-N, PO4-P and BOD5, are increasing with the poor water quality class and *E.coli* showing strong correlation with NH_4, chloride and phosphate supporting raw sewage effluent into the river.

- While comparing pH, temperature and percentage of free ammonia and ionic $NH4^+$, in SWQC I to II the concentration of ammonia is less and it is more than 90 % in the form of $NH4^+$, but in SWQC II-III to IV more than 10 percent of total ammonia has occurred as free ammonia. The percentage of free ammonia occurred in SWQC III-IV and IV is very toxic to aquatic life.

- Taking consideration of chemical and bacterial parameters the Tukucha is found the most polluted stream with SWQC IV. It is followed by the Dhobikhola with same SWQC IV in most of the chemical parameters in the middle valley region. The Bagmati and the Bishnumati are also found equally polluted in the middle valley section.

- From chemical parameter analysis it can be concluded that all SWQC I of head water region sites contain very low organic nutrient, high oxygen content and very low conductivity indicating not influenced by human interference. The SWQC I-II onwards indicates gradual increase in concentration of each chemical parameter. While comparing EC standard, Pescod (1977), standard for developing country (Lohani et al.1993) with SWQC, it shows that up to SWQC II the concentration of each parameter is within the potable abstraction for raw water with different treatments A1-A3. These quality classes are mainly from head water to the periphery of valley area where human interference is low.

10.2 Recommendations:

- The following recommendations have been derived from the findings of this study:

- Water quality assessment is one of the important steps for the planning and policy making as well as for the preservation and improvement of the river water quality. To fulfill this goal regular water quality monitoring through saprobic water quality class followed by Nepal biotic score (NEPBIOS) is suitable because it is cheaper, reliable and applicable to the Nepalese river system. For the regional validity of Nepal biotic score (NEPBIOS) it needs to be cross-checked by several intensive studies in various river systems of Nepal.

- River water is one of the important water resources of Nepal. As mentioned earlier, people use river water for various domestic purposes on one hand and water borne disease is the main disease of Nepal on the other hand. It is the quality of water that people using measures the health status of the people directly or indirectly. So, it is essential to know the hygienic quality of water to improve the health status of the people. Hence, Bacteriological water quality monitoring is essential for it. For bacteriological water quality monitoring, faecal parameter such as, faecal indicator bacteria like *E.coli* and faecal streptococcus and to know the level of organic pollution heterotrophic bacteria are recommended.

- Chemical parameters are also equally important for water quality assessment. For the chemical water quality assessment where domestic sewage is the main cause of pollution, the following minimum chemical parameters are recommended: from organic matter BOD5; from nutrients NH_4-N and PO_4-P; from general variable pH, conductivity, dissolved oxygen and total hardness; and from the major ions chloride.

- For the monitoring of river system, region, season, length of a river, and tributaries to the river should be considered.

- Diel and daily changes are observed, for the maximum number of bacterial count Saturday and noon time should be considered specially for saprobic water quality class III-IV and IV.

- For the validity of present bacterial range for each saprorbic water quality class, it should be cross-checked from different river systems and different ecological regions.

- Mixed sample is recommended to be taken for bacteriological and chemical samples along the cross-section of the river.

- The tolerance range of the taxa to the chemicals can be determined by regular monitoring of the basic chemical parameters as mentioned above for a certain period of time. With the help of tolerance range the real stress condition of a taxon for particular ecological situation can be studied.

- On basis of bacteriological and chemical parameters, the study found out that up to SWQC II, water can be used for various domestic purposes with different kinds of treatments (A1-A3). In the study area only the head water region and a few sites in the upper valley region and in the lower valley region are within SWQC II. Hence, there appears an urgent need to formulate a goal to achieve SWQC II in all the regions of Bagmati river system within certain time limit.

- The river ecosystem of the Bagmati river has been influenced tremendously by anthropogenic activities. Much of the stream water in headwater regions has been tapped for drinking purpose through the construction of impoundment or reservoirs. The river seems very weak from the very beginning to perform its self-purification activity. On the other hand the river is receiving solid waste and domestic sewage directly into it, once it reaches the valley basin region where SWQC III-IV and IV is detected. From the study it is found out that most of the positive *Salmonella* test sites and high *E. coli* number and faecal streptococcus number are recorded in the region. Despite the contamination of river water with faecal and household refuse, people use the river water for various domestic purposes. This has often resulted into several types of waterborne diseases. In Nepal a majority of people are ignorant to the situation. In this regard, community awareness program regarding water quality and water borne disease is one of the important steps to minimise waterborne diseases in Nepal.

- Stream sources in the headwater region need to be protected at larger extent. The Shivapuri and the Bagmati watershed projects are already implemented for the conservation of the Bagmati river system and the activities towards improving and monitoring the watershed under these projects seem to be commendable until now. However one step to be taken immediately is to provide pipe drinking water supply to the people living in the upper headwater region. By doing so, a direct interference of the local communities into the headwater streams can be controlled. Another consideration needs to be made is the controlling over the picnic activities around the streams in the headwater region. Picnic spots need to be defined and confined at particular places and restriction should be made regarding the direct influence of the communities into the stream water

- As water quality and health of people are two inseparable components, to get safe drinking water, the protection of source water including *Kunds* is quite essential.

- To maintain the self-purification capacity of a river residual water level of the river should be maintained.

- In addition to tapping headwater of river, the construction of dams and weirs against the river flow, sand quarrying and pebble collection, vehicle washing and squatting the river bank for housing and direct waste disposals have caused to change in disruption of biota and deterioration of river water quality. To maintain the water quality and to get rid of the waterborne diseases, a law against these activities is required to be made.

- As the on going practice of direct discharge of domestic sewage and industrial waste into the river is one of the main causes of pollution, to solve this problem a practical, reliable and cheaper method of treating effluent before being passed into the river should be sought. For this, biological wastewater treatment would be one of the best alternatives to treat the wastewater in Nepal. Regarding wastewater treatment, recently very positive work has been done as an example in Nepal to treat hospital waste of Dhulikhel through biological wastewater treatment by using reed bed treatment system which has been installed with the technical experts from IWGA-SIG BOKU university Vienna and ENPHO Nepal. There should be planned such treatment plants to treat industrial and domestic waste in larger extent.

- Proper place for dumping solid wastes should be identified.

BIBLIOGRAPHY

ABEL, P. D. (1989) *Water Pollution Biology*. England: Ellis Horwood.

ADB (1985), *Nepal Water Supply and Sanitation Sector Profile*. Manila: Asian Development Bank.

ADHIKARI, R., S. K. Rai, B. M. Pokharel and J. B. Khadka (1986), Bacterial study of drinking water of Kathmandu Valley. *Journal of Institute of Medicine*, 8 (3):313-316.

ALEXANDER, C.P. (1956) Undescribed species of Crane flies from the Himalayan mountains (Tipulidae ,Diptera). I. Jour. N. Y. Ent. Soc. 64: 137-147.

APHA-AWWA-WEF (1995), *Standard methods for the examination of water and wastewater*. 19 th edition Washington, DC

AZAM, F., T. Fenchel, J. G. Field, J. S. Gray, L. A. Meyer-Reil and F. Thingstad (1983), The Ecological Role of Water-Column Microbes in the Sea. *Mar. Ecol. Prog. Ser.* 10: 257-263.

BACH, E. (1980) in Doetsch, P. (1987), Entwicklung und exemplarische Anwendung eines Verfahrens zur nutzungsadäquaten Quantifizierung von Gewässergüte. *Hochschulreihe Aachen, Gewässerschutz-Wasser-Abwasser*, 91

BAJRACHARYA, Keshari (1994), *Water Quality Study for Bishnumati Khola in Shivpuri Watershed*, Kathmandu: HMG of Nepal/FAO-United Nation.

BARTRAM, Jamie and Richard Ballance, eds. (1996), *Water Quality Monitoring* [A practical guide to the design and implementation of freshwater quality studies and monitoring programmes]. London: E and FN Spon.

BÄSSLER K.H. and W. Fekl K. Lang (1973), Grundbegriffe der Ernährungslehre. Springer- Verlag. Berlin, Heidelberg, New York.

BAUER, J. J., T. M. Maskey, and G. Rast (1994), River systems, hydro development and species crisis in the Tarai. In: Bishnu Bhandari, T. B. Shrestha and J. McEachern (eds.), *Safeguarding Welands in Nepal*. Proceedings of the National Workshop on Welands Management in Nepal [3-5 March 1993]. Kathmandu: IUCH Nepal: 136-144.

BAYLEY, Peter B. (1991), The flood pulse advantage and the restoration of river-floodplain systems. *Regulated River: Research and Management*. 6: 75 - 86.

BRATBAK Gunnar (1993), Microscope Methods for Measuring Bacterial Biovolume: In Paul et al. ed. Handbook of Methods in Aquatic Microbiology Ecology. Lewis publishers: 309-307.

BROWN, R.M , McClelland, N,I.; Deiniger, R.A., Tozer, R.G.(1970), A water quality index - do we dare ? *Water and sewage works*, 117: 339-343

BRUNKE, M. and Gonser, T. (1997), The ecological significance of exchange processes between rivers and groundwater. *Freshwat. Biol.*, 37, 1: 1-33

CAIRNCROSS, Sandy and Richard G. Feachem (1983), Environmental Health Engineering in the Tropics: An introductory Text. John Willey and Sons.

CAIRNS, John and James R. Pratt (1993), A history of biological monitoring using benthic macroinvertebrtes. In:

CANTER, Larry W. (1985), *River Water Quality Monitoring*. Michigan: Lewis Publisher, Inc.

CBS (1995), *Statistical Yearbook of Nepal*. Kathmandu: Central Bureau of Statistics.

CEDA (1989), *A Study on the Environmental Problems Due to Urbanisation in Some Selected Nagar Panchayats of Nepal*. Report Submitted to UNDP/Kathmandu: Centre for Economic Development and Administration (CEDA), T.U.

CHADWICK, E. (1842), *On an Inquiry into the Sanitary Condition of the Labouring Population of Great Britain, London*. London: W. Clowesand Sons, Stamford Street for Her Majesty's Stationery Office.

CHAPMAN, Deborah, ed. (1992), *Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring*. London: Chapman and Hall Ltd.

COHN, F. (1853), Über lebendige Organismen im Trinkwasser. *Zeitschrift für klinische Medizin von Dr. Günsberg*. 4:229-237.

CORING, E. and Küchenhoff, B.. (1994), Vergleich verschiedener europaischer Untersuchungs und Bewertungsmethoden fur Fließgewässer. Landesumwltant Nordrhem - westfalen Nr. 18.

CULP, J.M. and R..W. Davies (1982), Analysis of Longitudinal Zonation and the river continuum concept Oldman-South Saskatchewan River System. *Can. J. Fish. Aquat. Sci.* 39: 1258-1266.

DARSIE, Richard F., Gregory W. Courtney and Shreedhar P. Pradhan (1994), Proc. Entmol. Soc. Wash. 92, 2: 230-235.

DAVID M. Rosenberg and Vincent H. Resh (eds.), *Freshwater Biomonitoring and Benthic Macroinvertebrates.* London: Chapman & Hall: 10-27.

DAVIS S. Wayne (1995), Biological Assessment and Criteria Building on the Past. In: Davis S. Wayne and Thomas P. Simon (eds.) , *Biological assessment and Criteria Tools for Water Resource Planning and Decision making.* 7-14, Lewis Publisher

DE PAUW, Niels and Dirk Roels (1988), Relationship between biological and chemical indicators of surface water quality. *Verh. Internat. Verein. Limnol.* 23: 1553-1558.

DINUS, S.H. (1972), Social accounting system for evaluating water resources. *Water resources research* . 8, 4: 1159-1177.

DISVI (1989), *Water Quality Monitoring of Kathmandu City Water Supply.* Final Report. Kathmandu: Health Education and Service Project.

DISVI (1990), *Water Quality Assessment in Terai Tubewell Project.* Kathmandu: Health Education and Service Project.

DISVI (1990), *Water Quality Testing in Ilam*, Kathmandu: DISVI.

DOETSCH, P. (1987), Entwicklung und exemplarische Anwendung eines Verfahrens zur nutzungsadäquaten Quantifizierung von Gewässergüte. *Hochschulreihe Aachen, Gewässerschutz-Wasser-Abwasser,* 91.

DOUDOROFF, P. and E. E. Warren (1957), Biological indices of water pollution with particular reference to fish populations. In: C. M. Tarzwell (ed.), *Biological Problems in Water Pollution, Transactions of the 1956 Seminar.* Cincinnati, Ohio: U.S. Public Health Service: 144-163.

EC Standard (1975) Richtlinie 75/440/ EWG Über die Qualitätsanforderungen an Oberflächenwasser für die Trinkwassergewinnung in den Mitgliedstaaten, ABI. Nr. L 194 vom 25. Juni 1975, S. 34.

EC Standard Richtlinie 80/778/EWG (1980), Über die Qualität von Wasser für den menschlichen Gebrauch, ABI, Nr. L 229 vom 30. August 1980, S 11.

EDINGTON, J. M. and A. G. Hildrew (1981), Fresh water Biological Association Scientific Publication. No. 43.

EISP (1987), An Environmental Impact Assessment of Leather and Tanning Industries, Environmental Impact Study Project. Kathmandu: Department of Soil Convervation and Watershed Management.

ELLIOTT J. M. (1977), A key to British freshwater Megaloptera and Neuroptera. Fresh water Biological association scientific publication no. 35, 1977.

ELLIS K.V. (1989), Surface Water Pollution and its Control. Macmillian.

ENPHO (1996), Report on the Water Source Monitoring Program for the Shivapuri Watershed by Assessing Water Quality (First Phase), Kathmandu: Environment and Public Health Organisation (ENPHO).

ENPHO/DISVI (1990), Water Quality of Stone Taps (Kathmandu City). Kathmandu: Environment and Public Health Organisation and DISVI.

FAUSCH, K. D, J. Lyons, J. R. Karr, and P. L. Angermeier (1990), Fish communities as indicators of environmental degradation. In: S. M. Admas (ed.), Biological Indicators of Stress in Fish. American Fisheries Society Symposium, 8. Bethesda, Maryland: 123-144.

FERESU, S. B. and J. Van Sickle, (1990), Coliforms as a measure of sewage contamination of the River Zambezi. *Journal of Applied Bacteriology.* 68: 397-403.

FERRO, W. (1978), *Limnology of the Pokhara valley Lakes (Himalayan Region of Nepal) and Its Implications for Fishery and Fish Culture.* A report prepared for integrated fishery and fish culture development project. Rome: FAO.

FERRO, W. (1978/79), Some limnological and biological data from Rara, a deep Himalayan lake in Nepal. *J. Nepal Research Center.* 2/3: 241-261.

FIDALGO, M.L.(1990), About the relationship between some bacteriological parameters and other ecological factor s in crestuma/Lever reservoir . *Publicacoes do instituto de zoologia dr augusto nobre faciödade de coemcoas dp porto* 0, 217: 1-26.

FINDLAY, S., M. L. Pace, D. Lints, J. J. Cole, N. F. Carco, and B. Peierls (1991), Weak coupling of bacterial and algal production in a heterotrophic ecosystem: the Hudson river estuary. *Limnol. Oceanogr.* 36: 268-278.

FORMAN, Richard T. T. (1995), Land Mosaics, The ecology of Landscapes and Regions.Cambridge university press.

Friendrich, G., D. Chapman, and A. Beim. (1992), The use of biological material, : 171-238 In D. Chapman(ed.), *Water quality Assessments*: A guide to the Use of Biota, Sediments and Water in environmental Monitoring, Chapmann and Hall, London.

FRISSELL, C. A. et.al. (1986), A hierarchucal frame-work for stream habitat classification: viewing streams in a watershed contex. Environmental management 10: 199-214.

GANJIN, S., M. Gantar, M. Matavulj and O. Petrovic (1990), The long term investigation of the river Danube water quality in the Yugoslav section according to microbiological parameters. *Wat.Sci. Tech.* Vol. 22. No.5: 39-44.

GARNIER J , PIERRE Servais and Gilles Billen (1992) Bacteriplanton in the Seine River (France): impact of the Parisian urban effluent. *Can. J. Microbiol.* 38: 56-64.

GELDREICH, E. E. and B. A. Kenner (1969) Concepts of fecal *Streptococci* in stream pollution. *J of Water Pollution Control Federation* 4, 336-352

GLEESON Cara and Nick Gray, E, (1997) *The coliform Index and Waterborne Disease.* FN. Spon. London

GHETTI, P. F. and O. Ravera (1994), European perspective on biological monitoring. Pages 31-46 in S.L. Loeb and A. Spacie (ed.). Biological Monitoring of Aquatic systems. Lewis Publishers, Boca Raton, Florida.

GORDON, Nancy D.; Thomas A. McMahon and Brian L. Finlayson (1992), *Stream Hydrology An Introduction for Ecologists.* John Wiley and sons

GOUDIE, Andrew, B. W. Atkinson, K. J. Gregory, I. G. Simmons, D. R. Stoddart, and David Sugden, eds. (1994), *The Encyclopedic Dictionary of Physical Geography.* Backwell.

Graf Wolfram, Subodh Sharma (1996), Contribution to the Knowledge of genus Hmalopsyche (Trochoptera: Rhyacophilidae) from Nepal.Internatioal Conference on Ecohydrology of High Mountain Area. Kathmandu, Nepal ICIMOD.

GRAY, J. S. (1989), Effects of environmental stress on species rich assemblages. *Biological Journal of the Linnean Society. 37:19-32.*

GUHL, W. (1987), Aquatic ecosystem characterisations by biotic indices. *Internationale Revue der Gesamten Hydrobiologie.* 72:431-55.

HAPPER, P.P. (1974), New protonemura from Nepal. Psyche, 81, 367-376.

HAPPER, P.P. (1976), Plecoptera collected by the Hokkaido University Expedition to the Himalaya, 1968. Mushi, 49, 25-33.

Happer, P.P. (1977), Capniidae, Leucritidae and Perlidae (Plecoptera) from Nepal. Oriental Insects, 11 (1), 53-62.

HAMM A. (1969), Erläuterungen zur Gewässergütekartierung bayerischer Voralpenseen –in: Der Wassergüteatlas, Münchner Beiträge zur Abwasser-, Fischerei- und Flussbiologie 15: 49 – 66.

HASSALL, A. H. (1850), *A Microscopic Examination of the Water Supplied to the Inhabitants of London and the Suburban Districts* [Cited in W.M. Ingram, K.M Mackenthun and A.F. Bartsch 1966, *Biological Field Investigative Data for Water Pollution Surveys.* Washington, D.C.: Federal Water Pollution Control Administration.

HAWKES, H. A. (1977), Biological classification of rivers: conceptual basis and ecological validity. In: J.S. Alabaster (ed.), *Biological Monitoring of Inland Fisheries*, London: Applied Science Publishers Ltd: 55-67.

HAWKINS, Charles P. and James R. Sedell (1981), Longitudinal and Seasonal Changes in Functioal Organization of Macroinvertebrate communities in four Oregon Streams. Ecology, 62, 2: 387 - 397.

HEGEDUS M, Fodre, Z. and Dobler E. (1990), Bacteriological quality of the fresh water in the region of the lower Tisza (Hungary) in the period 1977-1986. *Tiscia (Szeged)*, 25 (0): 21 - 30.

HEIKKINEN K.and Visuri A. Effect of water quality on bacterioplankton densities in river, brook and peatmining water in the basin of the humic river. Kiiminkijoki. *Archiv fuer Hydrobiologie* 119, 2: 215 - 230.

HELLAWELL, J. M. (1986) *Biological Indicators of Freshwater Pollution and Environmental Management.* London: Elsevier.

HENDERSON-SELLERS, A. and P. J. Robinson (1984), *Contemporary Climatology.* New York: Longman Scientific & Technical.

HERAUSGEGEBEN VON DER BAYERISCHEN LANDESANSTALT FÜR WASSERFORSCHUNG, München (1986) Bewertung der Gewässerqualität und Gewässergüteanforderungen. R. Oldenbourg Verlag München Wien.

HICKEL, B. (1973), Limnological investigations in lakes of the Pokhara valley, Nepal. *Int. Revue ges. Hydrobiol.* 58 (5): 659-672.

HICKEL, B. (1973), Phytoplankton in two ponds in Kathmandu valley (Nepal). *Int. Revue ges. Hydrobiol.* 58: 835-842.

HILSENFHOFF, W. (1982), *Using a Biotic Index to Evaluate Water Quality in Streams.* Technical Bulletin No. 132. Madison, WI: Wisconsin Department of Natural Resources.

HILSENHOFF, W. F.(1977), Use of Arthropods to Evaluate Water Quality of Streams. *Technical Bulletin* No. 100, Wisconsin Department of Natural Resources , Madison, Wisconsin.

HILSENHOFF, W.L. (1988), Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society*, 7: 65-68.

HMG (1969), *The Physical Development Plan for the Kathmandu Valley.* Kathmandu: Department of Housing and Physical Planning, HMG.

HMG/ICIMOD/CDG/UNEP (1994), *Geological Map of Nepal.* Kathmandu: Department of Mines and Geology., HMG.

HMG/UNDP (1992), *Greater Kathmandu Water Supply Project: Summary Volume.* Kathmandu: HMG/UNDP.

HORMONNAY, A. (1979), Gewässergüteerfassung in Ungarn und Kriterien der Erfassung, in: Wasser und Abwasser, Bd. 22, 1979, S. 127-141.

HORNE, Alexander J. and Charles R. Goldman (1994), *Limnology.* McGraw-Hill, Inc.

HORTON, R.. K. (1965), Water quality criteria - stream vs. Effluent standards/ An Index- number System for rating water quality, in: *Journal WCPF.* 37, 3.

HUGHES, R. M. and D. P. Larsen (1987), Ecoregions: an approach to surface water protection. *Journal of the Water Pollution Control Federation.* 60: 486-93.

HYDROLOGY DIVISION/HMG (1996), *Water Quality Data of Rivers of Kathmandu Valley.* Kathmandu: Department of Hydrology and Meteorology/HMG.

HYNES N. B. N.(1984), Adults and Nymphs of British Stoneflies (Plecoptera). Freshwater Biological association Scientific Publication no. 17. Third edition.

IAWR (1982), Der aktuelle Stand der Durchführung des Rhein-Chemievertrages, in: *gwf-wasser/ abwasser.* H. 3, 123.

INGRAM, W. M.,K.M Mackernthun and A.F. Bartsch (1966), *Biological Field Investigative Data for Water Pollution Surveys.* Washington, D.C. Federal Water Pollution Control Administration.

ISC (1984), *A Study of Pollution Discharge of Bhrikuti Paper Mill and Saraswati Paper Mill, and Environmental Impact on Narayani River.* Kathmandu: Economic Services Centre.

IUCN Nepal (1991), *Environmental Pollution in Nepal: A Review of Studies.* Kathmandu: IUCN Nepal.

JAMES and Evanson, ed., (1979), Biological indicator of water quality. Wiley

JÄCH M and Sharma Subodh (1996), A checklist of water beetles of Nepal with distribution pattern in relation to altitude.Internatioal conference on Ecohydrology of high Mountain Area. ICIMID.

JÄCH M. and L. Ji eds. (1995), Water beetles of China. Vol. 1 Zoologisch-Botanische Gesellschaft der Wiener Coleopterologen.

JOCV (1986), *Survey Report of Gandaki River System: Marsyangdi and Budhigandaki rivers* [Part 2, 3, 4]. Kathmandu: Department of Agriculture.

JONES, J. g. (1974), Some observations on direct counts of freshwater bacteria obtained with a fluorescence microscope. Limnol. Oceanogr. 19: 540 - 545.

JONES, J. R, M. F. Knowlton, and D. B. Swar (1989), Limnological reconnaissance of water bodies in central and southern Nepal. *Hydrobiologia*. 184: 171-189.

JOSETTE, Garnier; Pierre Servais and Gilles Billen (1991), Bacterioplankton in the Seine River (France): impact of the Parisian urban effluent. Can. J. Microbiol. 38: 56 - 64.

JUNK, J. Wolfgang ; P.B. Bayey and R. E. Sparks (1989), The flood pulse concept in river-floodplain systems:110 - 127. In D.P. Dodge (ed.) Proceedings of th <internatioal Large river Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

JUNK, Wolfgang J.; Bayley P.B. and Richards E. Sparks (1989), The Flood Pluse Concept In River Floodplain Systems: 110 - 127, In. D. P: Dodge (ed.) Proceedings of the Internatioal Large River Symposium. Can Spec. Publ. Fish. Aquat. Sci. 106.

KARMACHARYA, A. P. (1990), *Water Pollution Assessment in the Bagmati River and Its Tributaries in Kathmandu Town Section*. M.S. Thesis. Kathmandu: Central Department of Botany, T.U.

KARR, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser (1986), *Assessing Biological Integrity in Running Waters: a Method and Its Rationale*. Champaign, IL:Illinois Natural History Survey Special Publication 5.

Kasimir, G. and Kavka, G. (1988), Untersuchung der zählbaren und züchtbaren Bakterien in einem Laufstauökosystem (Donaustau Alteenwörth). Wasser und Abwasser 32: 57-88.

KAVKA, Gehard G. (1994) Erfassung und Bewertung der bakteriologischen Beschaffenheit der Donau im Jahre 1993. Vergleich der Grenzprofile Deutschland- Österreich und Österreich - Slowakei. 30 Arbeitstagung der IAD, Zuoz- Schweiz 1 Wissenschaftliche Kurzreferate.

KAVKA, Gerhard G., et al (1996), Assessment of microbiological water quality in the Austrian section of the River Danube. Arch. Hydrobiol. Suppl. 113, Large river 10, 1-4: 79-86

KEPNER, Raymond L. JR and James R. Pratt. (1994), Use of Fluorochromes for Direct Enumeration of total Bacteria in environmental samples Past and Present. Microbiological Reviews , 58, 4, 603 - 615.

KHADKA, M. S. (1983), Study of major ions in Bagmati river near Pashupatinath temple on the day of Mahashivratri. *J. Nep. Chem. Soc.*, 3: 53-56.

KHADKA, R. B., J. Shrestha, and A. S. Tamrakar (1981), *The Effluent Impact of Bansbari Tannery on the Local Fresh Water Ecology (A Micro-Level Study on Water Pollution and Its Consequences - Phase 1)*. Kathmandu: National Council for Science and Technology.

KIHARA, H ed. (1955), Fauna and Flora of Nepal Himalaya Scientific Results of the Japanese Expeditions to Nepal Himalaya 1952 – 1953. *Fauna and Flora Research Society Kyoto University Kyoto Japan, Ueno Park, Tokyo Japan*. Vol. 1.

KIMMINS, D. E. (1964), On the Trichoptera of Nepal. *Bulletin of The British Museum Entomology*. (Natural History). Vol. 15: No. 2: 33 – 55.

KLOVE, B.; Kettunen, J.; Varis, O.; Vakkilainen, P. and Sirvio, H. (1993), A real time monitoring system for Kerava river quality. *Environmental Monitoring and Assessment*. 24, 2: 167 - 180.

KOHL, W (1975), cited in Kavka, Gehard G. (1994) Erfassung und Bewertung der bakteriologischen Beschaffenheit der Donau im Jahre 1993. Vergleich der Grenzprofile Deutschland- Österreich und Österreich - Slowakei. 30 Arbeitstagung der IAD, Zuoz-Schweiz 1 Wissenschaftliche Kurzreferate.

KOLKWITZ, R. (1950), Ökologie der Saprobien. *Schriftenreihe des Vereins für Wasserhygience*. No.4. Stuttgart: Piscutor-Verlag.

KOLKWITZ, R. and M. Marsson (1902), Grundsätze für die biologische Beurteilung des Wassers nach seiner Flora und Fauna. Mitteilungen der kgl. *Prüfungsanstalt für Wasserversorgung und Abwässerbeseitgung Berlin-Dahlem*. 1:33-72.

KOLLER-KREIMEL, V., O. Moog, A. Schernhammer and I. Stubauer, (1997), Quantifizierung der Unschärfe familienbenzogener Gewässergütebeurteilungsmethoden. 32. Konferenz der IAD, Wissenschaftliche Referate (Posterpräsentation), Wien - Österreich

KUNWAR, U.K. (1985), *Field Report on Pollution Aspects (Effluents of Leather, Textile, Paper, Kattha and Sugar Factories in Birganj.* Kathmandu: Nepal Bureau of Standards and Meteorology.

Lager, J. A and W. G. Smith (1975) Urban stormwater management and technology. An Assessment EPA-670/2-74-040, Washington, DC.

LAUTERBORN, R. (1901), Die sapropelische Lebewelt. *Zoologischer Anzeiger* 24: 50-55.

LAWA (Länderarbeitsgemeinschaft Wasser), (1980), Die Gewässergütekarte der Bundesrepuplik Deutschland.

LEE, S. and J.A. Fuhrman (1987), Relationship between biovolume and Biomass of natural rerived marine bacterioplanktin. *Appl. Environ. Microbiol.* , 53, 1298,

LEE, Sanghoon (1993), Measurement of Carbon and Nitrogen Biomass and Biovolume from Naturally derived Marine Bacterioplankton. In: Paul et al. (ed.), *Handbook of Methods in Aquatic Microbiology.* Lewis publishers: 319-325.

LEE, W. L. and C. P. Chen (1991), Bacteriological quality and E. coli resistance from downwardstream water source of Kao-Ping River 8Taiwan) in the period September 1990- January 1991. Kaohsing Journal of medicine sciences. 7(3): 98 - 106.

LESSARD, E. J. and J. M. Sieburth (1983), Survival of natural sewage populations of enteric bacteria in diffusion and batch chambers in the marine environment. *Applied and Environmental Microbiology.* 45: 950-959.

LIEBMANN, H. (1962), *Handbuch der Frischwasser- und Abwasserbiologie,* Band I. 2. Auflage München R. Oldenbourg Verlag

Lohani, Bindu N., J. Warren Evans (1993), Appropriate Environmental Standards for developing countries. Environmental system Reviews, 35.AIT.

LÖFFLER, H. (1969), High altitude lakes in Mt. Everest region. *Verh. Int. Ver. Limnol.* 17: 373-385.

LUDWIG Ch., H. Ranner, G. Kavka, W. Kohl and U. Humpesch (1990), Long term and Seasonal Aspects of the Water Quality of the River Danube within the region of Vienna (Austria). *Wat. Sci. Tech.* Vol. 22, No. 5, : 51-58.

MACAN, T. T. (1977), A key to the British Fresh and Brackish-water Gastropods. Freshwater Biological association scientific publication No. 13, 4th edition.

MANAFI, M. (1991), A new plate medium for rapid presumtive identification and differentiation of Enterobactriaceae. Int. J. Food Microbiol. 14: 127-134.

MANAFI, M (1996), Fluorogenic and Chromogenic enzyme substrates in culture media and identification tests. International Journal of Food Microbiology 31: 45 - 58.

MALICKY, H (1993a), Neue asiatische Köcherfliegen . Entomologische Berichte Luzern, 29, 77-88.

MALICKY, H (1993b), Neue Köcherfligen. Linzer. Biol, Beitr. 25 (2), 1099-1136.

MANAFI, M. and W. Kneifel (1991), Fluorogenic and Chromogenic substrates A Promising Tool in Microbiology. Acta Microbiologica Hungarica 38, 3-4: 293 - 304.

MANANDHAR, M. S., N. G. Ranjitkar, P. K. Pradhan, and N. R. Khanal (1987*), Study on Health Hazard in Kathmandu City.* A Project Report. Kathmandu: Nepal National Committee for Man and the Biosphere (MAB).

MARA, D.D. and J. I. Oragui (1981), Occurance of Rhodococcus coprophilus and associated Actinomycetes in feces, sewage, and freshwater. *Applied and Environmental Microbiology,* 42: 1037-1042

MASON, W. T., Jr. P. A. Lewis and C.I. Webber (1985), An evaluation of benthic macroinvertebrate biomass methodology, *Environmental Monitoring and Assessment.* 5: 399-422.

MASON, W. t., Lewis, P.A. and Weber C. I. (1985), An evaluation of benthic macroinvertebrate biomass methodology. Environmental monitoring and assessment , 5: 399 - 422.

MASSA, S; Grandi, M; Poda, G.; Cesaroni, D. and Cangamella, F. and Trovatelli, L. D. (1989), Coliform detection from river waters : comparison between MPN and MF techniques. Air and Soil Pollution 43, 1-2: 135 - 146.

MAYOSHI, Y. (1987), *Study Report on Industrial Pollution Control.* Kathmandu: Economic Services Centre.

McEACHERN, Preston (1994), Limnology and the national wetlands survey. In: Bishnu Bhandari, T.B. Shrestha and J. McEachern (eds.), *Safeguarding Welands in Nepal.* Proceedings of the National Workshop on Welands Management in nepal [3-5 March 1993]. Kathmandu: IUCH Nepal: 89-103.

McKENZIE, D. H., D. E. Hyatt and V. J. McDonald (eds.) (1992), *Ecological Indicators.* Proceedings of the International Symposium on Ecological Indicators, October 16-19, 1990, Ft. Lauderdale, England: FL. Elsevier Science Publishers Ltd.

MERRITT R.W., K. W. Cumminis (eds.) (1996), An introduction to the Aquatic Insects of North America. Third edition, Kendall / Hunt.

MESSA, S.; Trovatelli, L. D.; Cangamella, F.; Cesaroni, d. and Poda , G. (1989), Salmonellae recovery from surface water anfd statistical relationship with usual indicator bacteria. *Igiene Moderna* 91,2: 169 - 178.

METCALFE, J. L. (1989), Biological water quality assessment of running waters based on macroinvertebrate communities: history and present status in Europe. *Environmental Pollution.* 60:101-39.

MILLER, C. (1985), Correlates of habitat favourability for benthic macroinvertebrates at five stream sites in an Appalachian Mountain drainage basin, U.S.A. *Freshwater Biology.* 15:709-733.

MINSHALL, G. W., K. W. Cummins, R. C. Petersen, C. E. Cushing, D. A. Bruns, R. R. Seddell, and R. L. Vannote (1985), Developments in stream ecosystem theory. *Can. J. Fish. Aquat. Sci.* 42: 1045-1055.

MIYOSHI, Y. (1987), *Study Report on Indsutrial Pollution Control.* Kathmandu: Economic Service Centre (ESC).

MOOG, Otto (ed.) (1995), Fauna Aquatica Austria. Wasserwirtschaftskataster, Bundesministerium für Land-und Forstwirtschaft, Wien.

MOOG, Otto (1996), Biological river Water Quality assessment in Austria. Proc. Internat. Workshop on Assessment and Classification of Rivers; Düsseldorf (in print).

MOOG, Otto and S. Sharma (1996), Biological assessment of the water quality in the river Bagmati and its tributaries, Kathmandu valley, Nepal. In: S. R. Chalise and N. R. Khanal (eds.), *Extended Abstracts,* International Conference on Ecohydrology of High Mountain Mountain Areas. Kathmandu: ICIMOD: 23-24.

MOOG, Otto (1993), Makrozoobenthos als Indikator bei ökologischen Fragestellungen. Landschaftwasserbau 15, 104-143, TU. Wien.

MOOG, Otto (1991), Biologische Parameter zum Bewerten der Gewässergüte von Fliessgewässern. Landschaftswasserbau 11, 235-266. TU Wien.

MOOG, Otto (1990), Makrobenthologischer Aspekt bei der Wiederherstellung naturnaher Flussabschnitte-Wiener Mitt. 88: 55-103.

MORAN, J. M., Morgan, M.D. and Wiessma, J.H. (1986), Introduction to Environmental Science. New York: W.H Freeman and Company.

MORSE, John C.; Yang Lianfang, Tian Lixin (eds.) (1996), Aquatic Insects of China useful for monitoring water quality (part II). Honoi University Press.

MÜLLER, P. (1980), Biogeographie, in: UTB uni Taschenbücher 731, Ulmerverlag.

NAKANISHI, A. M. (1986), Limnological study in Phewa, Begnas and Rupa lakes. In: Y. Ishida (ed.), *Studies on distribution, adaptation and evolution of microorganisms in Nepal Himalayas* (second report). Kyoto (Japan): 3-13.

NATIONAL WATER COUNCIL, (1981), River Quality the 1980 Survey and future Outlook, National Water Council, London.

NESEMANN, Hasko, Subodh Sharma (1996). Distribution and species composition of Leeches in the Aquatic habitat of Nepal.

NIEMI, R.M. and Niemi J. S. (1990) Monitoring of fecal indicators in rivers on the basis of random sampling and percentiles. *Water Air and Soil Pollution.* 50, (3 - 4): 331 - 342.

NIEVES, A. E. (1989), Study of some ecological aspects of the Santa Marta Bay (Colombian Caribbean) and ist bacterial contamination. Anales Del Instituto De Investigaciones <marinalas De Punta De Betin 0, 18: 39 - 58.

NORRIS, R. H. and A. Georges (1993), Analysis and interpretation of benthic macroinvertebrate surveys. In: D.M. Rosenberg and V.H. Resh (eds.), *Freshwater Biomonitoring and Benthic Macroinvertebrates.* New York: Chapman and Hall:234-285.

NWSC (1995), Management Information Report (April-March 1995), Kathmandu: Nepal Water Supply Corporation (NWSC). *Oikos.* 41:372-77.

OMERNIK, J. M. (1987), Ecoregions of the conterminous United States. *Annals of the Association of American Geographers.* 77: 118-25.

ÖNORM M 6232 (1995), Guidelines for the ecological study and assessment of rivers. Fachnormenausschuß 140 Wassergüte und -aufbereitung: 2-82.

OSSMER, Dr. Rolf and E. Merck (1993), Simultaneous Detection of total Coliforms and E. coli Fluorocult LMX Broth. 15th Internatioal Symposium/ Food Micro.

PADCO, (1987), Immediate Action Programme for Planning Control in the Kathmandu Valley.

PADCO Inc, (1990): Nepal Urban Development Policy Study Management Support for Urban Development Project. HMG, UNDP World Bank, USAID.

PANTLE, R. and H. Buck (1955), Die biologische Überwachung der Gewässer und die Darstellung der Ergebnisse. *Gas- und Wasserfach.* 96:604.

PERCHLANER, R. et.al. (1985), Gutachten über die limnologischen Verhältnisse in der mittleren Traun (Stand Winterhalbjahr 1984/85) und über die limnologischen Auswirkungen einer Aufstauung der Traun fur das KW Ehrenfeld – GA i. A. der OKA: 1 – 139.

PESCOD, M. B. (1977), Surface water quality criteria for developing countries , in water'Waste and Health in Hot Climates, Feachem, R. McGarry, M. and Mara, D. (eds).: 52-72. John Wiley London

PETERJOHN, W. T. and Correll, D. L. (1984), Nutrient dynamics in an agricultural watershed: Observations on the roll of a riparian forest. Ecology 65: 1466-75.

PETERSEN, C. E.; Klopp, J.; Gane , M. and Brogan R.,(1992), Water quality study of the west branch of the DuPage river system located in northeastern Illinois. Transactions of the Illinois state academy of science . 85, 3-5: 211 - 219.

PETTO H., Fleckseder H. and Humpesch U. H. (1991), The water quality of the river Danube in the backwater area above the altenworth power station (Austria). *Oesterreichische Wasserwirtschaft.* 43 (3-4): 71 - 81.

POUCHER, A. M.; Devriese, L. A., Hernandez, J. F. and Delattre, J.M. (1991), Enumeration by a miniaturised method of E. coli, Streptococci bovis and Enterococcus as indicators of the origin of faecal pollution of waters. Journal of Applied Bacteriology, 70: 525-30.

POPP, W. (1994), Mikrobiologische Kenngrößen und ihre Bedeutung für die ökologische Bewertung von Gewässern. Entwicklung von Zielvorstellungen des Gewässerschutzes aus der Sicht der aquatischen Ökologie. Band 48, Münchener Beiträge zur Fischerei- und Flußbiologie.R. Oldenbourg Verlag Munchen Wien.

PRADHAN, Bandana (1995), Limnological study of three ponds in Kathmandu Valley, Nepal. In: K.H. Timotius and F. Göltenboth (eds.), *Tropical Limnology. Volume II: Tropical Lakes and Reserviors.* Salatiga (Indonesia): Satya Wacana Christian University.

PRADHANANG, T. M., B. Singha, and S. N. Khanal (1988), *Water Quality of the Bagmati River in the Pashupati Area.* Proceeding of Seminar on Environmental Issues of Pashupati Area: Identification and Control Measures. Nov 7-9. Kathmandu: Royal Nepal Academy of Science and Technology (RONAST): 99-124.

PRADHANANG, T. M., P. Shrestha, R. Adhikari, N. P. Upadhaya, and R. B. Khadka (1988), The effluent impact of Bhrikuti and Everest Paper Mills on the local biotic systems. *J. Nep. Chem. Soc.* 8: 31-41.

PRINGLE, Catherine M., Robert J. N., Gernot B., James R. K., Mark W. O., Jackson R. W., Robin L. W. and Michael J. W. (1988), Patch dynamics in lotic systems: the stream as a mosaic. *J.N. Am. Benthol Soc.*, 7 (4): 503-524.

RAHIM, Z., Suthienkul, O., Aziz, K. M. S. and Echeverria, P.(1989) Aeromonas and other indicator bacteria in aquatic sources in Thailand. *Bangladesh Journal of Botany*. 18, 2: 197 - 204.

RANA, K. (1990), *Water Pollution Assessment of Phewa Lake, Pokhara, Nepal.* M.Eng Thesis. Bangkok: Asian Institute of Technology (AIT).

REICHERT, J.K. (1975), Spezielle Inhaltsstoffe des Oberflächenwassers und ihre Bedeutung für die Trinkwasserversorgung, Ref. 26; *DVGW- Fortbildungskurs Wasserversorgungstechnik, Essen.* 1 :20-24.

REILLY, William J. (1931), *The Law of Retail Gravitation.* New York: Reilly.

RHEINHEIMER G. (1992), Aquatic Microbiology. 4 th edition. John Wiley and sons.

RICHARDON, R.E. (1928), The bottom fauna of the Middle Illinois River, 1913-1925: its distribution, abundance, valuation, and index value in the study of stream pollution. *Illinois Natural History Survey Bulletin.* 17: 387-472.

RIVILLA, R and C. C. Gonzalez (1989), Seasonal variations of pollution indicators in a wildfowl reserve (Donana National Park, Spain). *Journal of Applied Bacteriology.* 67: 219-223.

ROBACK, S. S. (1974), Insects (Arthropoda:Insecta). In: C. W. Hart, Jr. and S. L. H. Fuller (eds.), *Pollution Ecology of Freshwater Invertebrates.* New York: Academic Press: 313-76.

RONAST (1987), *A Preliminary Study on the Effluent Impact of Bhrikuti and Everest Paper Mills on the Local Biotic System.* Kathmandu: Royal Nepal Academy of Science and Technology.

RONAST(1988), *Water Quality of Bagmati River in the Pashupati Area.* Kathmandu: Royal Nepal Academy of Science and Technology.

RUNDLE, S. D., A. Jenkins, and S. J. Ormerod (1993), Macroinvertebrate communities in streams in the Himalayan, Nepal. *Freshwater Biology.* 30: 169-180.

RYDER, G. I. and D. Scott (1988), The applicability of the river continuum concept to New Zealand streams, *Verh. Internat. Verein. Limnol.* 23 (Oktober): 1441-1445.

SCHAEFFER, D. J., E. E. Herricks and H. W. Kerster (1988), Ecosystem health I: measuring ecosystem health. *Environmental Management.* 12: 445-55.

SCHINDLER, D.W. (1987), Detecting ecosystem responses to anthropogenic stress. Canadian *Journal of Fisheries and Aquatic Sciences.* 44 (Supplement 1): 6-25.

SCHIMITZ, W. (1971) Biologische und chemische Kriterien zur Beurteilung des Gütezustandes von Fliessgewässern, in: Wasserwirtschaft in Baden-Wüttemberg, Verwaltungsverlag GmbH.

SCHNEIDER, E. (1989), *Kathmandu Valley* [1:50,000], Munich: Arbeitsgemeinschaft für vergleichende Hochgebirgsforschung.

SCHOENER, T. (1983), Rate of species turnover decreases from lower to higher organisms: a review of the data.

SERVAIS, Pierre; Gilles Billen and Jose Vives Rego. (1985). Rate of Bacterial Monitoring in Aquatic Environments. Applied and Environmental microbiology. 49, 6:1448 - 1454.

SERVAIS, Pierre; Gilles Billen andMarie Claude Hascoet (1987), Determination of the Biodegradable fraction of dissolved organic matter in waters. *Wat. Res.* 21, 4: 445 - 450.

SEWELL R. b. S. (ed.), (1936), The fauna of British India, Ceylon and Burma. Odonata Vol. III, Taylor and Francies LTD.

SHARMA, A. P. (1978), The quality of drinking water in Kathmandu. *Journal of Institute of Science.* Vol.11:15-22.

SHARMA, A. P. and A. Rijal (1988), *Impact of Industrial Effluent on Pollution of River and Adjoining Land.* A Project Report. Kathmandu: Nepal National Committee for Man and the Biosphere.

SHARMA, A. P.(1986), *Kathmandu Drinking Water Monitoring.* A Project Report. Kathmandu: Nepal National Committee for Man and the Biosphere.

SHARMA, Chandra K. (1977), *River Systems of Nepal.* Kathmandu: Sangeeta Sharma.

SHARMA, S. (1996), *Biological Assessment of Water Quality in the Rivers of Nepal.* Ph.D. Dissertation, Vienna: University of Agriculture, Forestry and Renewable Natural Resources.

SHARMA Subodh and Otto Moog (1996), Using several indices in water quality assessment of higher mountain streams of Nepal. Internatioal Conference on Ecohydrology of high Mountain Area. ICIMOD.

SHERR, BF., EB. Sherr (1984), Current perspectives in Microbial Ecology. In: Klug MJ, Reddy CA, eds.,: American Society for Microbiology. Washington DC: 412-423.

SHRESTHA, R. R. (1990), *Biological and Physico-Chemical Investigation of the Bagmati River* (with special reference to water pollution). M.Sc. Thesis. Kathmandu: Central Department of Botany, T.U.

SHRESTHA, R. R. (1995), A review of limnological studies and research, Nepal 1994. In: K.H. Timotius and F. Göltenboth (eds.), *Tropical Limnology. Volume III: Tropical Rivers, Wetlands and Special Topics.* Salatiga (Indonesia): Satya Wacana Christian University: 221-234.

SHRESTHA, S. B., T. K. Shrestha and B. Pradhan (1979), *Report on Aquatic Ecology and Potential Fishery Development in Bagmati River.* Kathmandu: GTZ.

SHRESTHA, T.K. (1979-81), Studies on the resource biology and fresh waters of Kathmandu valley with particular reference to fish production. *Management, Marketing and Conservation*: 296.

SHRESTHA, T.K. (1980), Bio-indicators of pollution in the river Bagmati., *Journal of T.U.* 11(1): 114-135.

SHRESTHA, T.K.(1990), Rare fishes of Himalayan waters of Nepal. *Journal of Fish Biology.* Supplement Academic Press. 37:213-216.

SIEVEC, I. (1981), Contribution to the knowledge of Nepal stoneflies (Plecoptera). Aquatic Insects, 3,4: 247-245

SLADECEK (1977), Zum Verhältnis Saprobität : *Trophic Arch. Hydrobiol. Beih. Ergebn. Limnol.* 9: 79 – 93.

SMEC, (1989), *Greater Kathmandu Drainage Water Master Plan Studies.* Kathmandu: Department of Drinking Water.

SMEC, Stanley International Ltd. (1994), *The Bagmati Basin Water Management Strategy and Investment Program.* A Project Report submitted to His Majesty's Government of Nepal.

SMITH, R.L. (1974), *Ecology and Field Biology.* New York. Haper and Row Publishers.

SONTHEIMER, H., R.. Gimbel and W. Weindel (1979), Die Rheinwasserqualität, IAWR, 7. Arbeitstagung : 60-81.

STANDFORD, J. A. and Ward, J. V. (1993), An Ecosystem Perspective of Alluvial Rivers: Connectivity And Hyporheic Corridor. Journal of the North american Benthological Society JNASEC, 12, 1: 48-60.

STANLEY/ EAST CONSULTANT. (1990), Environmental/ Socio- Economic Assessment /Review. Kathmandu Water supply Project Draft-final reports. HMGN/ WSSC.

STEHR Frederick W.(ed.) (1987), Imature Insects. Kendall Hunt Dubuque, Iowa.

STEHR Frederick W.(ed.) (1991), Imature Insects Volume 2. Kendall/Hunt.

STRAHLER, Arthur N. (1957), Quantitative analysis of watershed geomorphology, *American Geophysical Union Transactions.* 38: 913-920.

STRAHLER, Arthur N. and Alan H. Strahler (1978), *Modern Physical Geography.* John Wiley & Sons.

SWAR, D. B. (1980), *Present Status of Limnological Studies and Research in Nepal.* Proceedings of the First Workshop for the Promotion of Limnology in Developing Countries.

TEBBUTT, T.H.Y. (1992), *Principles of Water quality Control.* Pergamen Press, Oxford.

THAYIB, S. S., Ruyitno, Kunarso, D. H., Razak,H. (1989), Water quality indicator bacteria in Bengawan Solo and Porong rivers and their esturies. *Marine Research in Indonesia 0, 27: 1 - 18.*

TILLYARD, R.J. (1917), The Biology of dranflies. Cambridge university Press.

TITTIZER, Thomas and Peter Kothe (.1979.), Possibilities and limitations of biological methods of water analysis. In: A. James and Lilian Evison (eds.), Biological Indicators of Water Quality. John Wiley & Sons: 4.1-4.21.

TOWNSEND, C.R. (1989), Patch dynamic concept of stream community ecology. J. N. AM. Benthol. Soc. 8, 1: 36 - 50.

TRIPATHI, C. K.M. (1988), Bacteriological quality of Ganga river (India). Biological Memoirs ,14, 2: 109 - 116.

UENO,M. (1955), Mayfly nymphs. In: Kihara (eds.) Fauna and flora Res. Soc. Kyoto Univ:303 - 316.

UNEP (1981), *The Resources of Development.* UNEP Asia-Pacific Report 1981. Bangkok: UNEP Regional Office for Asia and the Pacific.

UNICEF (1987), *Children and Women of Nepal: A Situation Analysis.* Kathmandu: UNICEF:

UPADHYAYA, M. P. and N. N. Roy (1982), Studies in river pollution in Kathmandu valley. *Indian Journal Environmental Health.* 24 (2).

VAIDYA, Kamini (1990), *Macrozoobenthos (invertebrates) of Bishnumati Khola, Water Quality and Surrounding Ecology.* Kathmandu: Ministry of Forests and Soil Conservation, HMG/FAO.

VANNOTE, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing (1980), The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences.* 37:130-137.

VOLLENWEIDER; R.A: (1968), Scientific Fundamentals of the Eutrophication of lakes and flowing waters, with particular reference to nitrogen as factors in Eutrofication OECD, Paris, Techn. Report DA 5, SCI: 68. 27

VOLLENWEIDER; R.A: Kerekes, J. (1980), The Loading Concept as basis for Controlling Eutrphication Phylosophy and Preliminary Results of OECD Program on Eutrophication Proj. *Wat. Tech.* Vol. 12: 5 - 18

WALLANCE, I. D.; B. Wallance and G.N. Philipson (1990), Fresh water Biological association Scientific Publication no. 51

WARD, J. V. and J. A. Stanford (1995), The serial discontinuity concept: extending the model to floodplain rivers *Regulated Rivers: Research and Management.* Vol 10: 159-168.

WARD, J.V. (1989), Riverine -wetland Interactions. Freshwater wetland and wildlife, Conf-8603101, DOE Symposium Series 61, R.r. Shritz and J.W. Gibbons (eds.), USDOE Office of Scientific and Technical Information, Oak Ridge, Tennessee.

WASHINGTON, H. G. (1984), Diversity, biotic and similarity indices. A review with special relevance to aquatic ecosystems. *Water Research.* 18:653-94.

WELCH E.B. (1992), *Ecological Effects of Wastewater Applied limnology and Pollutant effects.* Chapman and Hall

WHEATER, E. W. F. ; Mara, D. d. and J. I. Oragui (1979). Indicator systems to distinguish sewage from strom water runoff and Human from animal fecal material. In. James, A. and L. Evison.(Eds). *Biological indicators of water quality.* Johns Wiley and sons. New York.

WHO (1996), *Guildline for drinking-water quality.* Volume 2 Health Criteria and other supporting information. World health organization Geneva

WILLIAMS, R. B. G. (1984), *Introduction to Statistics for Geographers and Earth Scientists.* London: Macmillan Publishers Ltd.

WIMMER Reinhard and Otto Moog (1994), Flussordnungszahlen Österreichischer Fliessgewässer Monographien Bd. 51, Bundesministerium für Umwelt.

WRIGHT, S. and W. M. Tidd (1930), Summary of limnological investigations in western Lake Erie in 1929 and 1930 *Transactions of the American Fisheries Society.* 63: 271-285.

ZELINKA, M. and P. Marvan (1961), Zur Präzisierung der biologischen Klassifikation der Reinheit fliessender Gewässer. *Archiv für Hydrobiologie.* 57:389-407.

ZWEIFEL, Li Ull and Ake Hagsttom (1995), Total counts of marine bacteria include a large fraction of non-nucleiod-containing bacteria (Ghosts). Applied and Environmental Microbiology 61, 6: 2180 - 2185.

ZWICK, P. and Sivec, I. (1980), Beiträge zum Kenntnis der Plecoptera des Himalaya Ent. Basiliensia 5, 59-138.

Appendix A: FIELD PROTOCOL FORM

(Moog 1991. ÖNORM 6232 and Gordan 1992)
[Description of the Sample Sites]

1. General Information

ite	1.2 River's Name:	1.3 Locality's Name:	1.4 Latitude: Longitude:	1.5 Date:	1.6 Time (hour):	1.13 Effluents:
ude er):	1.8 Weather condition: a. Sunny b. Cloudy c. Rainy d. Foggy e. Others(specify)	1.9 Air Temperature (°C):	1.10 River Type: a. Straight (St) b. Meandering (Md) c. Braidded (Br) d. Others (specify)	1.11 Water Level a. Bankful b. Medium c. Low d. dry e. Others. if any	1.12 Water Use a. Agriculture(Ag) b. Domestic(Do) c. Cleaning(Cl) d. Construction(Co) e. Others. if any	a. Domestic(Do) b. Sewage(Se) c. Solid waste(Sw) d. Industry(In) e. agriculture(Ag) f. Other. if any

2. Substrate Composition *(in percent)*

Boul er cm):	2.2 Cobble (20-40 cm):	2.3 Large Pebble (6.3-20 cm):	2.4 Small Pebble (2.-6.3 cm):	2.5 Gravel (0.2-2.0 cm)	2.6 Sand (0.063-0.2 cm):	2.7 Silt (< 0.063 cm):

3. Physical Components

) : :	3.2 Depth (meter) a. Max : b. Min :	3.3 Bank type a. Natural (N) b. Artificial (A)	3.4 Bank Vegetation (Left/Right) a. Tree (Tr) b. Shrub (Sh) c. Herb (Hr) d. Grass (Gr)	3.5 Bank Structure (Left/Right) a. Stable (Hd) b. Erodable(Er) c. Stony (Sn) d. Semihard (Se)	3.6 Channel type a. V- shaped (V) b. Rectangular (Rec) c. Trapezoidal (Tra) d. Terraced Ter)	3.7 Flow type a. Turbulent(Tb) b. Medium (Me) c. Slow (Sl)	3.8 Velocity (m/s) a. High (H) b. Medium (M) c. Low (L)	3.9 Plant Shading (%)

4. Land use and Influence

ajor Land Use Categories:	4.2 Type of Influence
culture (Ag) b. Grazing land (Gl) c. Forest (Fr) d. Settlement (St) d (Rd) f. Fallow land (Fl) g. Others (specify)	a. Natural (i) Siltation (Si) (ii) Landslide (Ls) (iii) Flooding (Fo) (iv) Course change(Cc) (v) Side erosion (Er) b. Human (i) Embankment (Eb) (ii) Speed breaker (Sb) (iii) Dam (Dm) (iv) Sand quarrying (Sq) (v) Pebble collection (Pc) (vi) Channel (Cl) (vii) Reservoir (Rv)

5: River's Physico-chemical Parameters

our l (Fe) en(Ro) ny(Ey) our(Su) (Fs) ge(Se) (specify)	5.2 Colour a. Blue(Bl) b. Blue green (Bg) c. Green(Gr) d. Dark green(Dg) e. Gray (Gy) f. Dark gray (Dy) g. Yellowish(Y)	5.3 Transparency a. High (H) b. Medium (M) c. Low (L)	5.4 Temperature (°c):	5.5 Conductivity (μ S/cm):	5.6 pH Value:	5.7 Total Hardness (Mg/litre)	5.8 Reductive Feature (%):	Oxygen (mg/l)

6. Biotic habitat

6.1 Vegetation Cover (%):	6.2 Detritus Cover (%).
b. Filamentous Algae c. Moss d. Macrophyte e.	a. Living wood b. Dead wood c. Leaf d. CPOM e. FPOM f. Others

7. Remarks

minant Animal Species	7.2 Saprobic Water Quality Class	7.3 Other Descriptions. if any:	7.4 Sketch Map:	7.5 Photo/Slide
	a. I b. I-II c. II d. II-III e. III f. III-IV g. IV	a. b. c. d. e.		

Appendix B : Description of the sample site features

Site No.	Name of river	Locality	Description of prominent features
1	Samakhusi	Lazimpat	At Raniban ≈ 500 meters north from the bridge
2	Balkhu	Rind road	≈ 100 meters south from the bridge
3	Balkhu	Kalanki	≈ 500 meters southwest from the Kalanki ring road
4	Bagmati	Sundarighat	≈ 50 meters south from the suspension bridge
5	Tukucha	Baluwatar	≈ 50 meters north from the cross-road point
6	Dhobi	Chabel	≈ 100 meters north from the bridge leading to Chabel main road
7	Godavari	Balkot	Beside trail road leading to Matitar in the east and Balkot in the west
8	Hanumante	Imadol	≈ 50 meters away from the mixing point with the Manohara
9	Manahara	Koteswar	≈ 50 meters northeast from the mixing point with the Hanumante
10	Kodku	Imadol	≈ 100 meters southeast from the ringroad
11	Nakhu	Bungmati	≈ 800 meters down to the east from the main road
12	Nakhu	Nakhujail	≈ 100 meters away from the Jail-building or the main road to the west
13	Bagmati	Pashupatinath	≈ 50 meters north from the Bagmati dam
14	Godavari	Bishankhu	≈ 50 meters east from the bridge connecting Bishanku and main road
15	Kodku	Badegao	≈ 50 meters south from the irrigation dam
16	Bishnumati	Ringroad	≈ 500 meters north from the ring road new bus stop
17	Mahadev	Hiletol	≈ 20 meters away from the mixing point with the Bishnumati
18	Salinadi	Sankhu	At the temple site. some 2 kms southeast from Sankhu town
19	Manmati	Saranchok	≈ 50 meters south from the main road leading to Sankhu town
20	Indrayani	Indrayani	≈ 50 meters east from the bridge over the road leading to Sankhu
21	Manohara	Bramhakhel	≈ 200 meters south from the road or at the foothill of Changu hill
22	Bagmati	Gokarna	≈ 300 meters from the main road or nearby Gokarna jungle in the east
23	Hanumante	Sallaghari	≈ 400 meters northeast from the road or nearby Sallaghari in the north
24	Bishnumati	Narayanthan	≈ 50 meters north from the bridge over road leading to northern villages
25	Dhobi	Narayanthan	≈ 800 meters north from the temple or 10 meters from the village road
26	Bagmati	Sundarijal	Just below the reservoir or the trail leading to the northern villages
27	Bagmati	Sundarimai	Just below the Sundarimai temple before mixing point of the Nagmati
28	Nagmati	Sundarimai	Just before the mixing point of the Bagmati at Sundarimai
29	Syalmati	Sundarijal	≈ 2 kms down to the south from Sundarijal at the side of the trail
30	Nallu	Tikavairab	≈ 1500 meters south from the bazar
31	Lele	Tikavairab	≈ 50 meters east from the bridge at Tikabhairav
32	Bishnumati	Chisini village	≈ 100 meters down the main source area
33	Phedikhola	Budhanilkanth	At the locality of Phedikhola having newly built settlements
34	Mahadev	Budhanilkanth	≈ 1000 meters north from the temple
35	Mahadev	Shivpuri muhan	Just before the reservoir
36	Godavari	Godavari	The protected source inside the main wall
37	Gaurikund	Godavari	≈ 500 meters north from the Godavari site inside the Fishery compound
38	Bhageri	Godavari	Towards north inside the Fishery Department compound
39	Naudhara	Godavari	The protected source ≈ 500 meters southeast from the Godavari school
40	Kunokhola	Marblekhani	≈ 500 meters south from the school or forestry section
41	Bagmati	Kupandol	≈ 50 meters east from the bridge
42	Bagmati	Teku	≈ 50 meters east from the Kalopul (Suspension or Bridge)
43	Bagmati	Tekudovan	Just before the mixing point of the Bishnumati
44	Bagmati	Chovar George	≈ 20 meters south from the bridge or nearby temple
45	Bagmati	Khokana	≈ 500 meters down from the Leprosy hospital or opposite of Khokana
46	Chalti	Chalti	At the road point leading to Pharping
47	Bosan	Taudah	20 meters from the bridge ≈ 500 meters south from the Taudah
48	Kodku	Harisidhi	≈ 20 meters north from the road leading to Godavari (near the School)
49	Kodku	Gorphutar	≈ 200 meters south from the road leading to Godavari
50	Tukucha	Exhibition road	≈ 20 meters north from the road leading to Shankar Dev Campus
51	Mahadev	Balaju	At Daurinepani north from Balaju
52	Bishnumati	Gangolhu	≈ 100 meters north from the bus park
53	Bagmati	Kumarigal	≈ 500 meters east from the road leading to Baudha

Site No.	Name of river	Locality	Description of prominent features
54	Bagmati	Baneswar	At Shantinagar
55	Tukucha	Baluwatar	At the road side
56	Tukucha	Tudaldevi	≈ 15 meters from the temple
57	Tukucha	Tripureswor	≈ 15 meters west from the bridge before mixing the Bagmati
58	Dhobikhola	Thapathali	≈ 20 meters away before mixing the Bagmati
59	Dhobikhola	Baneswor	≈ 15 meters south from the road leading to Pashupati temple
60	Dhobikhola	Harigau	≈ 50 meters north from the bridge
61	Bishnumati	Dallu	≈ 80 meters south from bridge
62	Manamati	Ringroad	≈ 10 meters west from the ringroad leading to the north
63	Manamati	Kalimati	≈ 10 meters southwest from the road
64	Samakhusi	Bansbari	≈ 100 meters west from the road
65	Bagmati	Minbhavan	≈ 80 meters south from bridge
66	Mahadev	Manpokhari	≈ 200 meters east from the reservoir
67	Bagmati	Nayapati	≈ 50 meters east from the road
68	Bagmati	Gokarneswor	≈ 10 meters down from the temple site
69	Bagmati	Jorpati	≈ 20 meters south from the bridge
70	Indrawati	Dahchok	At Satganne ≈ 1500 meters north from the Thankot bazar
71	Matatirth	Matatirth	At the protected source
72	Dharapani	Gairigau	≈ 2 kms southwest from the road or ≈ 800 meters south from Matatirth
73	Khahare	Manapokhari	≈ 20 meters north from the road leading to Manapokhari source
74	Bagmati	Bagmati	≈ 50 meters south of the Bagmati bridge along the east-west highway
75	Bagmati	Karmaiya	≈ 50 meters north of the Bagmati bridge along the east-west highway
76	Bagmati	Sundarijal	≈ 50 meters east from the Sundarijal bus stop
77	Bagmati	Gaurighat	≈ 20 meters south from the bridge along the road leading to Guheswari
78	Godavari	Botanical garden	≈ 100 meters west from the main road inside the garden
79	Bagmati	Okhreni	≈ 100 meters down from the main Okhreni village

Source: *Filed survey (1995-96).*

Appendix C A summarized version on the description of river water quality classes due to organic pollution.(based on MOOG 1991)

Saprobic Classes / Mapping Colour	I / Blue	I - II / Blue-green	II / Green
Saprobity Level	Oligosaprobic	Oligo to ß - mesosaprobic	ß - mesosaprobic
Degree of Pollution	None/very slight pollution	Slight pollution	Moderate pollution
Cleanliness	Clean/with little organic matter & nutrient contents	considerably clean	Not clean/with high organic [illegible]
Clarity	High (glacier feeded brooks are turbid)	High (glacier feeded brooks are turbid)	as before (lowland rivers are [illegible]
Oxygen Contents	Well oxygenated (100%)	Well oxygenated (100%)	as before (oversaturation & [illegible] possible)
Reductions	Not at all	Not at all	Few (in very fine sediments at [illegible]
Faunal Diversity	Very high /	High	High
Abundance	Low	Medium	High
Floral Composition	a) Algae (mainly diatoms, specific blue green algae & red algae) b) Mosses (several species)	a) Algae (mainly diatoms, specific blue green algae & red algae) b) Mosses (several species)	a) Algae (all groups, high filamentous [illegible] b) Mosses (few species)
Faunal Composition	a) Dominant insect larvae (Plecopterans highly abundant) b) Trichoptera (Net spinning extremely scarce) c) Chironomidae (Few subfam.-Diamesinae & Orthocladinae) d) Worms (mainly Planarians, Lumbriculidae(Stylodrilus) & Haplotaxidae	Dominant insect larvae (Plec, Ephe, Tri, Coel present) b) Trichoptera (Net spinning may also occur) c) Chironomidae (Few subfam.-Diamesinae & Orthocladinae) d) Worms (mainly Planarians, Lumbriculidae(Stylodrilus) & Haplotaxidae	a) Many groups present (many [illegible] crustaceans) b) Trichoptera (Net spinning numerous) (eg. Polycentropodidae) c) Chironomidae (abundant, diversed) Lot: Diamesinae Len: Orthocladinae d) Worms (Diversed families; Oligochaeta-[illegible] (Stylodrilus) and some Naididae
Fish Fauna	Salmonids (Dominant in Europe & North America)	?	?
River Type	1) Spring 2) Spring feeded brooks 3) Cold water rivers (upper reach)	1) Spring 2) Spring feeded brooks 3) Cold water rivers (upper reach)	1) Brooks (Mod poll. up & [illegible] lower reach) 2) Rivers (Mod poll. up & [illegible] lower reach)
Water Use	Multipurpose (drinking, fishing, bathing etc.)	Restricted uses (drinking restricted for locals)	Restricted Uses (drinking possible after [illegible]
Other Remarks	1) Balanced trophic relations 2) Productivity exceeds the sum of reductive processes	1) Balanced trophic relations 2) Productivity prevails over the sum of reductive processes.	1)Balanced trophic relations 2)Productivity prevails over the sum [illegible] processes.

Continued from

Saprobic Classes / Mapping Colour	II - III / Green-yellow	III / Yellow	III - IV / Yellow-red	IV / Red
Saprobity Level	ß to α - mesosaprobic	α - mesosaprobic	α - meso. to polysaprobic	Polysaprobic
Degree of Pollution	Critical pollution	Heavy pollution	Very heavy pollution	Extreme pollution
Cleanliness	Polluted/with higher organic matter & nutrient contents	Heavily polluted	Very heavily polluted/with very high organic matter & nutrients contents	Extremely Polluted with huge organic matter & nutrient contents
Clarity	Occassionally turbid (Lowland rivers are additionally turbid)	Turbid (Local/occassional) (Lowland rivers are additionally turbid) Human influenced act. impart diversed colour	Turbid (Local/occassional (Point sources drifting fil.bacteria) Effluents impart specific odour and colour	Mostly turbid (Local/occassional (Point sources drifting fil.bacteria) Effluents impart specific odour and colour
Oxygen Contents	Fluctuating, causing injuries or kill to sensitive fish species	Oversaturation & heavy depletion, causing injuries & killing sensitive fishes	Oversaturation & very heavy depletion, excluding full time fish residency	Extreme oversaturation & depletion, prohibiting the survival of any kind of water breathing aquatic fauna
Reductions	Remarkable Putrified: Fine sed., lentic Black spots: stones	Remarkable Putrified: Fine sed., lentic Black patches : stones	Septic Release of H2S, large red spots in lot. & len. zones	Sapropelic Release of H2S after heavy degradation, large reduction patches beneath the stones (lotic) or on both sides (lentic)
Faunal Diversity / Abundance	Moderate / Moderate (Insect Fauna)	Low / High (Benthic Fauna)	Very Low / High (Benthic Fauna)	Extrremely Low / Very High (Airbreathing Benthic fauna only)
Floral Composition	a) Algae (Highly abundant filamentous algae) Green algal diversity increase b) Mosses (?) c) Macrophytes (Highly abundant covering large area of the river channel) d) Fungi (Sewage fungi in cold waters obvious)	a) Algae (filamentous algae of *Stigeoclonium*) Tolerant blue green may occur b) Tolerant diatoms (eg *Nitzschia palea* may occur large in lentic zones c) Tolerant macrophytes may grow in high abundance d) Sewage fungi (*Sphaerotilus, Fusarium, Leptomitus* may occur)	a) Algae ? b) Mosses (?) c) Macrophytes unable to grow d) Huge Sewage fungal growth	a) Algae (Reduced quantitatively and qualitatively) b) Mosses (?) c) Macrophytes (?) d) Fungi (?)
aunal Composition	a) Dominant ciliates followed by leeches (Tolerant groups: Porifera, Bryozoa, Molluscs, Crustacea, Leeches, several insect orders (with few tol. Plecop. & Heptag. spp) b) Trichoptera (Net spinning may be numerous) c) Chironomidae (Highly abundant at specific sites) -Tolerant species of Diamesinae & Orthocladinae in lotic zones and Prodiamesinae in sandy patches -In muddy zones Tanytarsini (mainly *Micropsectra*) and Chironomini (eg ,*Polypedilum*) d) Worms Oligochaeta- Lumbriculidae (non Stylodrilus) Naididae may be numerous Tubificidae may occur in remarkable numbers	a) Porifera, leeches, Asellus occur in large nos. (Ciliates occur in the colonies of sessile species (*Carchesium, Vorticella*) b) Trichoptera (?) c) Chironomidae (may be abundant at specific sites) -Tolerant species of Orthocladinae occur -Tanytarsini (mainly *Micropsectra*) and *Chironomini* are the dominant taxa d) Worms Oligochaeta-Lumbriculus Naididae, Enchytraeidae and certain tubificidae occur in remarkable number	a) Ciliates, flagellates, & bacterias dominating (Tol. groups of benthic fauna against oxygen deficiency occur in large nos. b) Trichoptera (?) c) Chironomidae (mainly at lentic zones are highly abundant) Few species of *Chironomini* and genus *Chironomous* predominates d) Worms (Oligochaeta-Enchytraeidae (Lumbriculus) Tubificidae-Tubifex,& Limnodrilus occur remarkably e) Sulphur bacteria may occur in visible spots	a) Free living bacteriophagus ciliates, flagellatus & bacteria with Colpidium-colpodae as typical. Filamentous sewage bacteria less abundant than in III-IV, b) Nearly no macroinvertebrates can colonize c) Chironomidae may occur sparsely -Few species of *Chironomi* -*Chironomous* predominate d) Worms (Oligochaeta-Enchytraeidae abundant) (Tubificidae-Tubifex, Limnodrilus occur in low numbers) e) Sulphur bacteria are highly abundant.
h Fauna	?	Reproduction not always possible, periodical fish injuries occur	Reproduction not always possible, periodical fish injuries occur	No fish fauna
er Type	Polluted rivers	Highly Polluted rivers	Very Heavily Polluted rivers	Extrremely Polluted rivers
ater Uses	Restricted Uses (drinking possible after treatment for locals)	Hazardous	Extremely hazardous. Unsuitable for any kinds of human uses.	Unfit for human use except as a receptacle for sewage
her Remarks	1) Increase of Decomposers 2) Excessive Productivity	Production<Reduction	Production<Reduction	Assisimilatory processes are always lower than the Reductive

Appendix D: Description of sample site features with reference to Field Protocol

Site no.	General Components											Substrate Composition (%)							SWQC
	River name	Locality	Date	Time (hrs)	Altitude (m)	Weather	Air temp. °C	River type	Water level	Water uses	Effluents	Boulder	Cobbler	Large Pebble	Small Pebble	Gravel	Sand	Silt	
1	Samakhusi	Lazimpat	02.11.95	16:00	1200	Sunny	23	Md	Medium-low	Ag. Do	Sc.Sw			5	5		80	10	IV
2	Balkhu	Kuleswor	03.11.95	10:45	1260	Sunny	24	Md	Medium-low	Cl. Do	Sc.Sw	2	3	45	40		10		III
3	Balkhu	Kalanki	04.11.95	11:00	1320	Sunny	22	Md	Medium-low	Do. Cl	Sc.Sw		25	30	30		5	10	II-III
4	Bagmati	Sundarighat	05.11.95	09:00	1272	Sunny	22	Md	Low	—	Sc.Sw			20	20		10	60	IV
5	Tukucha	Baluwatar	06.11.96	16:15	1320	Sunny	20	Md	Low	Co. Ag	Sc.Sw						35	65	IV
6	Dhobikhola	Chabel	06.11.95	17:15	1310	Sunny	17	Md	Low	Ag. Cl	Sc.Sw	5	5	5	5		65	20	IV
7	Godavari	Balkot	07.11.95	12:05	1300	Sunny	19	Md	Medium	Cl. Do	Ag.Sc. In		15	20	25	25	10	5	II
8	Hanumante	Imadol	07.11.95	14:30	1292	Sunny	18	Md	Medium	Ag. Cl. Do	Ag			10	20	30	40		III-IV
9	Manohara	Koteswar	07.11.95	16:00	1292	Sunny	18	Md	Medium	Ag. Cl. Do	Ag			20	30	40	10		III
10	Kodku	Imadol	07.11.95	18:00	1295	Sunny	15	Md	Medium-low	Ag. Do	Sc. In		5	40	20	20	10	5	III-IV
11	Nakhu	Bungmati	09.11.95	13:20	1324	Cloudy	17	Md	Medium-low	Ag. Do	Ag			10	25	30	35		II
12	Nakhu	Nakhujail	09.11.95	16:00	1265	Sunny	17	Md	Medium-low	Ag. Do. Co	Ag. Do		20	5	25	40	5	5	II-III
13	Bagmati	Pashupati	18.11.95	10:00	1300	Sunny	24	Md	Medium	Ag. Cl. Do. Re	Sc.Sw				5	5	80	10	III-IV
14	Godavari	Bishankhu	19.11.95	12:00	1432	Sunny	23	Md	Medium	Ag. Cl. Do	Ag	20	20	10	20	10	10	10	II
15	Kodku	Badegau	19.11.95	14:00	1407	Sunny	24	Md	Medium	Ag. Do	Ag. Sc		5	25	40	20	10		II-III
16	Bishnumati	Ringroad	19.11.95	16:30	1298	Sunny	21	Md	Medium-low	Ag. Cl. Do	Ag. Sc			15	20	30	25	10	III
17	Mahadev	Hiletol	17.11.95	10:00	1298	Sunny	22	Md	Medium	Ag. Do	Ag. Sc					80	20		III
18	Salinadi	Saankhu	22.11.95	12:00	1360	Sunny	22	Md	Medium-low	Ag. Do. Re	Do	5	10	5	10	45	20	5	I-II
19	Manmati	Saranchok	21.11.95	10:00	1340	Sunny	22	Md	Medium-low	Ag. Do	Ag			5	20	35	40		I-II
20	Mahadev	Indrayani	21.11.95	12:30	1352	Sunny	23	Md	Medium	Ag	Ag			5	20	65	10		II-III
21	Manohara	Bramhakhel	21.11.95	15:30	1335	Sunny	22	Md	Medium-low	Ag. Do	Ag				15	25	60		II
22	Bagmati	Gokarna	05.12.95	10:30	1315	Sunny	21	Md	Medium-low	Ag. Do	Ag. Do				10	40	50		II
23	Hanumante	Sallaghari	05.12.95	13:30	1322	Sunny	20	Md	Medium	Ag	Ag. Do				5	15	20	60	III-IV
24	Bishnumati	Narayanthan	27.12.95	11:30	1445	Sunny	20	Md	Medium	Cl. Do	Ag. Do	10	10	60	5	5	5	5	II
25	Dhobikhola	Narayanthan	27.12.95	13:45	1465	Sunny	21	Md	Medium	Do	Ag. Do	70	15	10			5		II-III
26	Bagmati	Sundarijal	04.01.96	11:45	1680	Sunny	16	Md	Medium	Do	Do	60	15	15	10				I
27	Bagmati	Sundarimai	04.01.96	13:30	1600	Sunny	15	St	Medium	Cl. Do	Do	45	25	25	5				I
28	Nagmati	Sundarimai	04.01.96	15:15	1600	Sunny	16	St	Medium	Cl. Do	Do	40	30	20	5	5			I
29	Syalmati	Sundarijal	04.01.96	16:30	1560	Sunny	16	St	Medium	Do	Do	20	30	20	15	15	5		I
30	Naidu	Tikabhairav	06.01.96	12:00	1440	Sunny	18	St	Medium	Ag. Do	Ag. Do	40	40	10	10				II
31	Lele	Tikabhairav	06.01.96	14:00	1430	Sunny	18	Md	Medium-low	Ag. Do	Ag		10	20	40	20	10		II
32	Bishnumati	Budhanilkanth	11.01.96	10:30	2000	Sunny	14	St	Medium	Do	Do	60	10	10	5	5	10		I
33	[illegible]	Budhanilkanth	11.01.96	12:45	1430	Sunny	15	St	Medium	Ag. Do	Do	30	20	15	15	15	5		II-III

Note: River type: Straight (St); Meandering (Md); Braided (Br), Water: Agriculture(Ag); Domestic(Do); Cleaning(Cl); Construction(Co); Effluents: Domestic(Do); Sewage(Sc); Solid waste(Sw); Industry(In); agriculture(Ag)

Appendix E: Description of sample site features with reference to Field Protocol

Site no.	River name	Locality	Date	Time (hrs)	Altitude (m)	Weather	Air temp. °C	River type	Water level	Water uses	Effluents	Boulder	Cobbler	Large Pebble	Small Pebble	Gravel	Sand	Silt	SWQC
General Components												Substrate Composition (%)							
34	Mahadev	Budhanilkanth	11.01.96	14.45	1800	Sunny	16	St	Medium	Ag. Do	Do	80	5	5		5	5		II
35	Mahadev	Budhanilkanth	11.01.96	16:30	1920	Sunny	16	St	Medium	Do	Do		10	20	40	20	20		I
36	Godavari	Godavari	13.01.96	10:15	1560	Sunny	15		Constant	Do	Do			50	20	15	15		I
37	Gaurikund	Godavari	13.01.96	12:15	1565	Sunny	16		Constant	Do	Do			15	15	65	5		I
38	Bhagerikhola	Godavari	13.01.96	14:00	1555	Sunny	16	St	Medium	Do. Fi	Do. Se			50	20	15	10	5	I-II
39	Naudhara	Godavari	13.01.96	16:15	1760	Sunny	16		Constant	Do									I
40	Kunokhola	Godavari	13.01.96	18:15	1710	Sunny	16	St	Medium-low	Do	Do. Sw			40	30	20	10		II
41	Bagmati	Kopundol	28.02.95	10:15	1292	Sunny	15	Md	Medium-low	Ag	Ag.Se.Sw				5	10	60	25	IV
42	Bagmati	Teku	28.02.95	12.30	1285	Sunny	15	Md	Medium-low	Ag	Ag.Se.Sw			5	5	5	50	30	IV
43	Bagmati	Tekudobhan	28.12.95	14:15	1280	Sunny	16	Md	Medium-low	Ag. Cl	Ag.Se.Sw					10	55	35	IV
44	Bagmati	Chobhar	08.02.96	10:30	1365	Sunny	16	St	Medium	Do. Cl. Re	Ag.Se.Sw	10			40		30	20	III-IV
45	Bagmati	Khokana	08.02.96	13:15	1255	Sunny	18	St	Low	Ag	Ag.Se.Sw			10	10	20	40	20	III-IV
46	Chalti	Chalti	08.02.96	15:30	1360	Sunny	15	St	Medium	Ag. Do	Do			10	15	35	40		I-II
47	Bosan	Tindah	08.02.96	17:45	1300	Sunny	16	St	Medium-low	Ag. Do	Do	5	5	10	10	20	50		II
48	Kodku	Harisidhi	28.12.95	10:15	1335	Sunny	19	Md	Medium-low	Ag. Cl. Do	Ag. In			5	10	30	45	10	II-III
49	Kodku	Gorphutar	28.12.95	12:15	1325	Sunny	18	Md	Medium	Ag. Cl. Do	Ag.Se. In			10	30	30	20	10	II-(III)
50	Tukucha	Kalobir road	02.01.96	09:45	1294	Sunny	17	St	Medium	Ag	Se.Sw				20	20	40	20	IV
51	Mahadev	Balaju	02.01.96	13:15	1350	Sunny	15	Md	Medium-low	Ag. Do	Ag. Do.Se. In			15	20	30	35		II-III
52	Bishnumati	Gongabu	02.01.96	15:45	1298	Sunny	16	Md	Medium	Ag. Cl. Do	Ag. Do.Se			10	5	5	70	10	III-IV
53	Bagmati	Kumarigal	03.01.96	09:15	1304	Sunny	17	Md	Low	Ag	Ag.Se. In					20	80		III
54	Bagmati	Baneswor	16.01.96	10:00	1298	Sunny	15	Md	Low	Ag	Ag.Se. In								III-IV
55	Tukucha	Baluwatar	16.01.96	12:30	1302	Sunny	18	St	Medium-low	Ag	Ag.Se. In				20	30	30	20	IV
	Tukucha	Tudaldevi	22.01.96	14:45	1304	Sunny	16	St	Medium-low	Ag	Ag.Se. In					20	40	40	IV
	Tukucha	Tripureswor	21.01.96	09:45	1293	Sunny	17	St	Medium-low	Ag	Se.Sw.In				5	20	40	35	IV
58	Dhobikhola	Thapathali	21.01.96	12:15	1296	Sunny	19	Md	Medium-low	Ag	Se.Sw.In			15	10	10	40	25	IV
59	Dhobikhola	Baneswor	21.01.96	14:45	1294	Sunny	18	Md	Medium-low	Ag	Se.Sw.In		5	10	15	30	30	10	IV
60	Dhobikhola	Haatigau	23.01.96	10:15	1302	Sunny	17	Md	Medium-low	Ag	Se.Sw.In	5	5		20	20	40	10	III-IV
61	Bishnumati	Dallu	23.01.96	12:45	1290	Sunny	15	Md	Low	Ag	Ag.Do.Se. In		10	5	20	15	40	10	III-IV
62	Manamati	Ringroad	04.02.96	08:45	1310	Sunny	19	Md	Medium-low	Ag. Cl. Do	Ag. Do.Se. In		15	15	20	30	20		III-IV
63	Manamati	Kalimati	04.02.96	10:30	1281	Sunny	18	Md	Low	--------	Ag. Do.Se. In			5	10	15	30	40	IV
64	Samakhusi	Bansbari	04.02.96	11:30	1360	Sunny	17	Md	Medium-low	Ag	Ag. Do.Se. In			10	15	15	40	20	III-IV
65	Bagmati	Minbhavan	23.12.95	12:30	1291	Sunny	16	Md	Medium-low	Ag	Ag. Do.Se. In			15	10	25	40	10	III-IV
66	Mahadev	Manpokhari	25.01.96	12:15	1795	Sunny	15	Md	Medium	Ag. Cl. Do		30	10	20	20	10	10		I-II
67	Bagmati	Nayapati	10.01.96	11:45	1300	Sunny	18	Md	Medium-low	Ag. Cl. Do	Ag		10	15	25	30	20		II
68	Bagmati	Gokarneswor	10.01.96	13.45	1355	Sunny	19	Md	Medium-low	Ag. Cl. Do	Ag			20	20	30	25	5	III
69	Bagmati	Jorpaati	10.01.96	15:30	1312	Sunny	21	Md	Medium-low	Ag	Ag. In				10	10	75	5	III
70	Indrawati	Dahchok	20.01.96	1::15	1460	Sunny	18	Md	Medium-low	Ag. Cl. Do	Ag		10	15	20	30	25		II
71	Matatirth	Matatirth	20.01.96	13:30	2000	Sunny	18	Md	Constant	Cl. Do									I
72	Dharapani	Gaingau	20.01.96	15:45	1960	Sunny	15	Md	Low	Ag. Cl. Do				15	20	40	25		I
73	Khahare	Manapokhari	25.01.96	14:45	1700	Sunny	18	Md	Low	Ag			10	20	30	35	5		I-II
74	Bagmati	Bagmati	03.03.96	14:30	265	Sunny	19	Br	Medium	Ag. Cl. Do	Ag				25	60	10	5	II
75	Bagmati	Karmaiya	03.03.96	16:15	260	Sunny	18	Br	Medium	Ag. Cl. Do	Ag				30	25	40	5	II-III
76	Bagmati	Sundarijal	04.01.96	11:15	1360	Sunny	19	Md	Medium	Ag. Cl. Do	Ag	50		25	10	10	5		I-II
77	Bagmati	Gaurighat	03.11.95	12:30	1302	Sunny	16	Md	Medium-low	Ag. Do. Re	Ag. Se				20	20	40	20	III-IV
78	Godavari	B. garden	04.02.96	14:45	1520	Sunny	17	Md	Medium	Ag				20	30	20	30		I-II
79	Bagmati	Okhreni	04.01.96	09:15	1800	Cloudy	15	St	Medium	Do		10	10	20	30	20	10		I

Note: River type: Straight (St); Meandering (Md); Braidded (Br); Water: Agriculture(Ag); Domestic(Do); Cleaning(Cl); Construction(Co). Effluents: Domestic(Do); Sewage(Se); Solid waste(Sw); Industry(In); agriculture(Ag)

Appendix F: Description of Sample Sites Features with Reference to Field Protocol

General Components			Physical component of river											Land use/Influence			Physical Parameter of water				
			Width (m)		Depth (m)		Bank type							Land	Influence type						
Site No.	Name of river	Name of locality	Max	Min	Max	Min	Nat	Artif.	Bank struc.	Chan.tp.	Flow tp.	Vel. m/s	Plant shad%	use	Natural	Human	Odor	color	Transp.	Temp.°C	Reduct feature %
1	Samakhusi	Lazimpat	3	1.5	0.5	0.2		A	Er	Tra	Me	0.17	-	St.Rd	Si	Sq	Fe	Dy	L	17	100
2	Balkhu	Kuleswor	6	2	2	0.5	N		Se	Ter	Me	0.25	-	Ag. St		Pc	Fe	Bg	M	16.0	30
3	Balkhu	Kalanki	6	2.5	1.4	0.6	N		Er	Ter	Me	0.35	-	Rd	Si. Es	Pc	Fs	Y	M	16.0	20
4	Bagmati	Sundarighat	20	15			N		Er	Ter	Me	0.4	-	St. Rd	Es. Cc	Sq. Pc	Fe. Se	Dy	L	15.0	100
5	Tukucha	Baluwatar	2	1	0.6	0.2	N		Er	Tra	Me	0.2	-	St. Ag	Fo	Eb	Fe	Dy	L	19.0	100
6	Dhobikhola	Chabel	5	2	1	0.3	N		Er	Ter	Me	0.3	-	Ag	Fo	Pc. Sq	Fe	Dy	M	17.0	100
7	Godavari	Balkot	5	2	1	0.4	N		Se	Tra	Me	0.5	-	Ag	Es	Pc	Ey	Gy	H	9.0	100
8	Hanumante	Imadol	9	2	1.5	0.5	N		Er	Ter	Sl	0.11	-	Ag. Fl	Fo	Sq	Ro. S	Gr	M	22.0	20
9	Manohara	Koteswar	10	5	1	0.3	N		Er	Ter	Sl	0.3	-	Ag	Fo	Sq	Ro. S	Gry	H	23.0	25
10	Kodku	Imadol	5	2	0.8	0.2	N		Er	Ter	Me	0.4	-	Ag			Ro	Gy	M	21.0	20
11	Nakhu	Bungmati	3	1	0.8	0.2	N		Er	Tra	Tb	1	-	Ag				Gy	M	17.0	
12	Nakhu	Nakhujail	8	5	0.8	0.2	N		Er	Ter	Me	0.6	-	Ag	Es	Pc	Ro. Fe	Gy	M	16.7	20
13	Bagmati	Pashupati	12	9	1.3	0.4		A	Hd	Ter	Me	0.25	-	St		Sb. Eb	S	Dy	M	16.0	50
14	Godavari	Bishankhu	5	2	0.9	0.4	N		Se	Tra	Me	0.75	30	Ag			Er	Gy	M	16.2	
15	Kodku	Badegau	4	3	1	0.5	N		Er	Tra	Me	0.5	-	Ag	Fo. Es	Dm	Ey	Gy	H	19.1	
16	Bishnumati	Ringroad	8	5	0.5	0.2	N		Er	Tra	Me	0.6	-	Ag. Fl	Si. Es	Sq. Pc	Ro	Gy	M	21.0	30
17	Mahadev	Hiletol	9	5	0.5	0.2	N		Er	Tra	Me	0.5	-	Ag. Fl	Es		Ey. Ro	Gy	M	21.8	30
18	Salinadi	Saankhu	5	2	0.9	0.1	N		S	Rec	Tb	0.45	60	Ag			Ey	Gy	H	17.0	
19	Manmati	Saranchok	8	3	0.5	0.2	N		E	Tra	Tb	0.6	-	Ag	Es		Ey	Gy	M	21.0	
20	Mahadev	Indrayani	5	2	0.5	0.2	N		Er	Tra	Me	0.42	40	Ag	Es		Ey	Gy	L	19.0	20
21	Manohara	Bramhakhel	12	5	1	0.2	N		Er	Tra	Me	0.6	-	Ag	Si. Fo	Sq. Sb		Gr	M	20.0	
22	Bagmati	Gokarna	25	15	0.5	0.1	N		Er	Tra	Me	0.42	-	Ag		Sq	Ey. Fs	Gy	M	19.0	
23	Hanumante	Sallaghari					N		Er	Tra	Sl	0.25	20	Ag	Si		Fe. Ro	Gr	L	13.0	100
24	Bishnumati	Narayanthan	8	3	0.2	0.1	N		S	V	Me	0.2	30	Rd. Fr		Pc	Ey. Ro	Gy	M	15.0	
25	Dhobikhola	Narayanthan	10	2	0.2	0.1	N		S	V	Me	0.2	-	Ag. St				Gy	M	16.0	20
26	Bagmati	Sundarijal	30	12	2	0.1	N		Se	V	Tb	0.9	60	Fr				Gy	H	13.0	
27	Bagmati	Sundarimai	40	11	1.5	0.5	N		Se	V	Tb	0.6	50	Fr			.	Gy	H	8.0	
28	Nagmati	Sundarimai					N		Se	V	Tb	0.4	60	Fr				Gy	H	9.0	
29	Syalmati	Sundarijal					N		Se	V	Tb	0.8	80	Fr		Cl		Gy	H	10.0	
30	Naldu	Tikabhairav	14	5	0.5	0.1	N		Se	V	Tb	0.75	-	Ag	Fo	Pc. Sq	Ey	Gr	M	14.0	
31	Lele	Tikabhairav	8	4	0.3	0.1	N		Se	Tra	Me	0.5	30	Ag. St	Es	Pc	Ro. Ey	Gy	L	16.0	40
32	Bishnumati	Budhanilkanth	5	2	0.3	0.1	N		S	V	Tb	0.7	70	Fr				Bl	H	7.0	
33	Phedikhola	Budhanilkanth	7	3	0.2	0.08	N		Se	V	Me	0.4	-	St				Gy	M	13.0	
34	Mahadev	Budhanilkanth	3	1.5	0.8	0.1	N		Se	V	Me	0.4	40	St				Bl	H	13.0	
35	Mahadev	Budhanilkanth	3	1.5	0.5	0.1	N		Se	V	Tb	0.6	90	Fr		Rv. Cl		Bl	H	12.0	
36	Godavari	Godavari	3.6	3	2	1	N		S	...	...		100	Fr				Bl	H	15.0	
37	Gaurikund	Godavari					N		Er	...	...		100	Fr				Bl	H	16.0	
38	Bhagerikhola	Godavari	3	2	0.5	0.1	N		Er	V	Me	1	60	Fr			Ey	Gy	H	12.0	
39	Naudhara	Godavari					N		S	...	...		100	Fr				Bl	H	15.0	
40	Kunokhola	Godavari	3	1	0.5	0.1	N		Se	V	Sl	0.2	50	St. Rd			Fe	Gr	M	13.0	10
41	Bagmati	Kopundol					N		Hd	Ter	Sl	0.25	-	St	Si	Sq. Eb. Sb	Ey. Rc	Gr	L	17.0	100
42	Bagmati	Teku					N		Hd	Ter	Me	0.35	-	St. Ag	Si	Sq. Eb	Ey. FEy. R	Dy	L	18.0	100
43	Bagmati	Tekudobhan					N		Hd	Ter	Tb	0.4	-	St. Ag	Si	Sq. Eb	Fe. Ro	Dy	L	18.0	100

Note: Bank type: Natural (N);. Artificial (A); Bank Vegetation: Tree (Tr); Shrub (Sh); Herb (Hr); Grass (Gr); Bank Structure; stable (Hd); Erodable (Er); Stony (Sn); Semihard (Se); .Odour: Fecal (Fe); Rotten(Ro); Earthy(Ey); Sulphur(Su); Fishy (Fs); Sewage(Se); Colour: Blue(Bl); Blue green (Bg); Green(Gr); Dark green(Dg): Gray (Gy); Dark gray (Dy); Yellowish(Y)

Site No	Name of river	Name of locality	Width (m) Max	Width (m) Min	Depth (m) Max	Depth (m) Min	Bank type Nat	Bank type Artif	Bank struc	Chan tp	Flow tp	Vel m/s	Plant shad%	Land use	Influence type Natural	Influence type Human	Odor	color	Transp	Temp °C	Reduct feature
44	Bagmati	Chobhar	15	10	1	0.05	N		S	S	Tb	1.5	-				S. Fe	Dy	L	19.0	100
45	Bagmati	Khokana					N		Se	V	Sl	1		Ag			Fe. Ro	Dy	L	19.0	100
46	Chalti	Chalti				–	N		Se	Tra	Me	0.2	50	Fr				Bl	H	12.0	
47	Bosan	Taudah					N		Se	V	Me	0.4	-	Fr.Ag				Y	M	16.0	
48	Kodku	Harisidhi					N		Er	Tra	Me	0.3	-	Ag. St	Es		Fe. E	Y	M	14.0	20
49	Kodku	Gorphutar					N		Er	Tra	Me	0.3	-	Ag. St	Es		Fe. Ey	Y	M	15.0	30
50	Tukucha	Exhibit road					N		Er	Tra	Me	0.2	-	St	Si		Fe	Dy	L	15.0	
51	Mahadev	Balaju	30	20			N		Er	Tra	Me	0.4	-	St. Ag	Es		S. Ey	Y	M	18	100
52	Bishnumati	Gongabu					N		Er	Tra	Me	~0.3	-	Ag. H	Es. Si	Sq	FEy. Ey	Gr	M	15	100
53	Bagmati	Kumarigal					N		Se	Ter	Me	0.35	-	Ag	Cc. Es	Sq	Ey	Gr	M	16	100
54	Bagmati	Baneswor					N		Er	Ter	Me	0.3	-	St.Ag	Si	Sq	Fe	Dy	L	14	100
55	Tukucha	Baluwatar					N		Er	Tra	Me	0.22	-	St		Em	Fe	Dy	L	15	100
56	Tukucha	Tudaldevi					N		Er	Tra	Me	0.23	-	St	Si	Em	Fe	Dy	L	15	100
57	Tukucha	Tripureswor					N		Er	Tra	Sl	0.21	-	St. Rd	Fo	Em	Fe	Dy	L	17	100
58	Dhobikhola	Thapathali					N		Er	Ter	Sl	0.3	-	St	Fo		Fe	Dy	L	16	100
59	Dhobikhola	Baneswor					N		Er	Ter	Sl	0.28	-	St. Ag		Em	Fe	Dy	L	13	100
60	Dhobikhola	Haatigau					N		Er	Ter	Me	0.3		St. Ag		Pe. Sq	Fe	Gr	L	16	100
61	Bishnumati	Dallu					N		Er	Ter	Me	0.25		St. Ag	Fo	Sq	Fe	Gr	L	16	100
62	Manamati	Ringroad					N		Se	Tra	Me	0.2	30	Ag			Ey	Y	M	17	20
63	Manamati	Kalimati					N		Er	Tra	Si	0.3		St	Es	Eb	Fe	Gr	L	16	100
64	Samakhusi	Bansbari					N		Er	Tra	Me	0.31	30	Ag. St			Ey	Y	M	17	30
65	Bagmati	Minbhavan					N		Er	Ter	Sl	0.3		St. Ag	Si	Sq	S. Fe	Dy	L	18	100
66	Mahadev	Manpokhari	7	4	0.8	0.1	N		Sn	V	Tb	1	85	Fr		Rv. Cl		Bl	H	9	
67	Bagmati	Nayapati					N		Se	Tra	Me	0.4		Ag			Ey	Gy	M	17	
68	Bagmati	Gokarneswor					N		Se	Tra	Me	0.45		Ag	Si	Sq	Ey	Gy	M	17	
69	Bagmati	Jorpaati					N		Er	Tra	Me	0.42		Ag. Fr	Si	Sq	Ey	Gy	M	18	20
70	Indrawati	Dahchok	3	1	0.5	0.1	N		Se	V	Me	0.5		Ag	Es		Ey. FEy	Gy	M	13	
71	Matatirth	Matatirth					N		Hd	..	....		90	Fe		Rv			H	16	
72	Dharapani	Gairigau					N		Se	V	Me	0.2		Rd		Sb		Bl	H	16	
73	Khahare	Manapokhari					N		Sn	V	Tb	1		Fr				Bl	H	13	
74	Bagmati	Bagmati	100	75	1	0.02	N		Er	Tre	Me	0.2		Ag. Rd	Si		Ey	Bl	M		20
75	Bagmati	Karmaiya	120	80	1	0.05	N		Er	Tre	Me	0.21		Ag. Rd	Si		Ey	Gy	M		30
76	Bagmati	Sundarijal	10	6	0.5	0.1	N		SE	V	Tb	0.5		Fr		Sq		Gy	H	14	
77	Bagmati	Gaurighat					N		Hd	Tre	Me	0.35		Fr. St. Ag	Si		Ey	G	L	19	100
78	Godavari	B. garden					N		Se	V	Tb	0.8	60	Fr. Rd				Bl	H	15	
79	Bagmati	Okheeni					N		Se	V	Tb	1.1	80	Fr				Bl	H	10	

Note: Bank type: Natural (N); Artificial (A); Bank Vegetation: Tree (Tr); Shrub (Sh); Herb (Hr); Grass (Gr); Bank Structure; stable (Hd); Erodable (Er); Stony (Sn); Semihard (Se); Channel type: V- shaped (V); Rectangular (Rec); Trapezoidal (Tra); Terraced (Ter) Odour: Fecal (Fe); Rotten(Ro); Earthy(Ey); Sulphur(Su); Fishy (Fs); Sewage(Sc); Colour: Blue(Bl); Blue green (Bg); Green(Gr); Dark green(Dg): Gray (Gy); Dark gray (Dy); Yellowish(Y)

Appendix G: Description of Sample Site Features with Reference to Field Protocol

Site No	Name of rivers	Localities' names	Vegetation coverage: Macro phyte	Moss	Filam. algae	Algae (B. G. D)	Fungus	Detritus coverage: Wood	leaf	CP OM	FP OM	Name of Dominant group of Animal
1	Samakhusi	Lazimpat				15	20	5		80	85	Chironomus sp (red) (2); Tubificidae(4)
2	Balkhu	Kuleswor	20		30	10	20			30	60	Physidae (3); Oligochaeta (2), Baetidae (2); Chironomidae (2)
3	Balkhu	Kalanki	10		20					25	30	Physidae (2); Sphaeridae (1); Oligochaeta (2), Baetidae (2), Leptophlebidae (2), Chironomidae (2); Hydropsychidae (3)
4	Bagmati	Sundarighat					30			60	80	Oligochaeta(3); Chironomidae (red) (3)
5	Tukucha	Baluwatar					20			45	85	Oligochaeta (4), Coleoptera (2)
6	Dhobi	Chabel					20			45	90	Physidae (1); Tubificidae (3), Corixidae (1), Micronectidae (1); Chironomidae (2)
7	Godavari	Balkot	30		20					20	30	Sphaeridae (1); Salifidae (1); Baetidae (1), Micronectidae (1); Nepidae (1); Glossosomatidae (1), Hydropsychidae (3); Chironomus sp (3)
8	Hanumante	Imadol			10					20	70	Physidae (2); Tubificidae (3); Aphelocheiridae (1); Corixidae (1); Hydropsychidae (2), Chironomidae (3)
9	Manohara	Koteswar			5					10	30	Physidae (1); Tubificidae (3), Baetidae (2); Hydropsychidae (2); Chironomidae (2)
10	Kodku	Imadol	20		30					15	40	Physidae (2); Tubificidae (3); Salifidae (2), Hydropsychidae (2); Chironomidae (2)
11	Nakhu	Bungmati			5	20		10		10	5	Ephemerellidae (2); Heptageniidae (2), Leptophlebiidae (2); Gomphidae (1); Perlidae (2), Glossosomatidae; (2), Hydropsychidae (2), Rhyacophilidae (2), Chironomidae (1)
12	Nakhu	Nakhupail			10					10	40	Lymnaeidae (1); Physidae (1); Baetidae (3), Ephemerellidae (2), Heptageniidae (2)
13	Bagmati	Pashupati				20	10	20		40	75	Chironomus sp (3), Baetidae (2), Corixidae (2), Oligochaeta (2); Hydropsychidae (2), Syrphidae (1)
14	Godavari	Bishankhu			5	20		10	10	20		Coleoptera (2), Tabanidae (2); Tipulidae (1), Baetidae (2), Ephemerellidae (2); Heptageniidae (2); Gomphidae (1). Hydropsychidae (2); Planaria (2)
15	Kodku	Badegau	10		30	30				10	40	Baetidae (3); Heptageniidae (2); Aphelocheiridae (2), Salifidae (2); Cordulidae (1), Gomphidae (1); Hydropsychidae (1)
16	Bishnumati	Ringroad	5		5	5				15	70	Coleoptera (2); Chironomus sp (3), Baetidae (2), Heptageniidae (2); Physidae (2)
17	Mahadev	Hiletol	40			20				15	60	Baetidae (3); Physidae (2); Hydropsychidae (1)
18	Salinadi	Saankhu	20	10	10			10	10	15	15	Coleoptera (2); Chironomidae (2), Baetidae (2), Ephemerellidae (2); Heteroptera (2); Nimouridae (2), Glossosomatidae (2), Hydropsychidae (2)
19	Manmati	Saranchok			10	10				15	5	Simuliidae (2); Baetidae (2); Ephemerellidae (1), Heptageniidae (2), Aphelocheiridae (1); Gomphidae (1), Perlidae (2); Hydropsychidae (2), Glossosomatidae (1)
20	Mahadev	Indrayani	10		15	20				10	30	Coleoptera (2), Chironomidae (2); Simuliidae (2), Baetidae (3); Caenidae (1), Ephemerellidae (2), Heteroptera (1). Hydropsychidae (2)
21	Manohara	Bramhakhel	10		5	5				10		Coleoptera (1); Simuliidae (3); Baetidae (2), Gomphidae (2), Perlidae (1); Hydropsychidae (1)
22	Bagmati	Gokarna	10		10			5		10	20	Coleoptera (1), Chironomidae (3); Simuliidae (2), Baetidae (2), Ephemerellidae (2); Gomphidae (2), Hydropsychidae (2,. Glossosomatidae (1)
23	Hanumante	Sallaghari				10	20				60	Chironomidae (2), Physidae (1); Aphelocheiridae (1), Micronectidae (1); Oligochaeta (3)
24	Bishnumati	Narayanthan		10	20	40		5	5	10	75	Psephenidae (2); Chironomidae (3), Baetidae (2), Ephemerellidae (2), Heptageniidae (1), Planorbidae (1), Aphelocheiridae (1); Gomphidae (1); Hydropsychidae (1)
25	Dhobikhola	Narayanthan				80				5	60	Coleoptera (1); Chironomidae (3), Baetidae (2), Heptageniidae (2); Salifidae (2); Hydropsychidae (2)
26	Bagmati	Sundarijal		10		5		20	15	20		Athericidae(1); Limoniidae (1); Tipulidae (1); Heptageniidae (1); Salifidae (2), Oligochaeta (2), Capniidae (1); Nemouridae (1), Lepidostomatidae (1)
27	Bagmati	Sundarimai		20		10		25	25	10		Elmidae (1); Athericidae (1); Chironomidae (1), Simuliidae (2); Baetidae (2), Heptageniidae (1), Capniidae (1); Nemouridae (1); Lepidostomatidae (1)
28	Nagmati.	Sundarimai		30	5	10		25	30	20		Elmidae (1); Athericidae (2); Tabanidae (1), Baetidae (1); Ephemerellidae (1), Odonata (2) Hydropsychidae (2); Rhyacophilidae (2)

Site	Name of	Localities'	Vegetation coverage					Detritus coverage				Name of Dominant group of Animal
No	rivers	names	Macro phyte	Moss	Filam algae	Algae (B. G. D)	Fungus	Wood	leaf	CP OM	FP OM	
29	Syalmati	Sundarijal		10				30	20	10		Elmidae (1); Psephenidae (2); Athericidae (2); Chironomidae (2); Simuliidae (2); Caenidae (1); Ephemerellidae (2); Heptageniidae (2), Sphaeriidae (2), Gomphidae (2) ; Lepidostomatidae (2); Rhyacophilidae (1); Stenopsychidae (1)
30	Naldu	Tikabhairav				20				10	10	Chironomidae (2), Limoniidae (2); Tipulidae (1); Baetidae (2); Ephemerellidae (1); Heptageniidae (1), Gomphidae (1); Corydalidae (1), Perlidae (2); Glossosomatidae (2); Hydropsychydae (2);
31	Lele	Tikabhairav				30				10	20	Psephenidae (1), Chironomidae (2); Limoniidae (2), Simuliidae (1); Baetidae (3), Hydropsychidae (2)
32	Bishnumati	Budhanilkanth		10	5	40 (D)		20	25	5		Elmidae (2), Athericidae (2); Chironomidae (1), Simuliidae (1), Baetidae (2); Heptageniidae (2); Aphelocheiridae (2), Salifidae (1), Perlidae (2), Hydropsychidae (2); Limnephilidae (1)
33	Phedikhola	Budhanilkanth				30		10	5	5	5	Elmidae (2), Chironomidae (2), Tabanidae (1), Baetidae (2), Heptageniidae (1); Hydropsychidae (2)
34	Mahadev	Budhanilkanth		10	10	20		5	5	5	10	Dytiscidae (1); Elmidae (2); Athericidae (1), Chironomidae (2), Limoniidae (2), Simuliidae (2); Tabanidae (2); Baetidae (3), Caenidae (2), Heptageniidae (2); Hydropsychidae (1); Lepidostomatidae (2),Planaria (1)
35	Mahadev	Budhanilkanth		20	5	10		10	20	10		Elmidae (2), Psephenidae (2); Athericidae (1); Chironomidae (1), Tabanidae (1), Tipulidae (1); Baetidae (1), Heptageniidae (1), Salifidae (1); Corydalidae (1); Oligochaeta (1); Perlidae (2); Hydropsychidae (2), Rhyacophilidae (2)
36	Godavari	Godavari		10								
37	Gaunkund	Godavari		20								
38	Bhagenkhola	Godavari				10		5	5	5	5	Elmidae (2); Psephenidae (1); Athericidae (2), Chironomidae (2) Simuliidae (3); Baetidae (2); Heptageniidae (1), Hydrobiidae (2); Corydalidae (1); Ephaedae (2); Perlidae (2); Hydropsychidae (1)
39	Naudhara	Godavari										
40	Kunokhola	Godavari	5		5	30		5	5	10	30	Chironomidae (1); Tipulidae (1); Baetidae (2), Ephemerellidae (1), Heptageniidae (2), Corydalidae (1), Gomphidae (2); Nemouridae (2); Hydropsychidae (2); Synlestidae (1)
41	Bagmati	Kopundol				30	20			20	100	Coleoptera (2); Chironomidae (2), Baetidae (2); Physidae (2), Oligochaeta (3)
42	Bagmati	Teku				20	30			20	100	Coleoptera (2); Chironomidae (3), Physidae (2); Oligochaeta (4);
43	Bagmati	Tekudobhan				15	10			10	100	Coleoptera (1), Physidae (2); Oligochaeta (3)
44	Bagmati	Chobhar				20	20			15	80	Chironomidae (2); Physidae (2); Oligochaeta (3)
45	Bagmati	Khokana			5	30	5			15	100	Chironomidae (2); Culicidae (1); Physidae (1); Oligochaeta (3); Hydropsychidae (1)
46	Chalti	Chalti	5	5		5		15	15	10		Coleoptera (1), Athericidae (1), Chironomidae (2); Simuliidae (2); Baetidae (2), Caenidae (1); Ephemeridae (2); Heptageniidae (2); Leptophlebiidae (2); Physidae (1); Nemouridae (2); Perlidae (1) Glossosomatidae (1); Hydropsychidae (2);Planaria (2)
47	Bosan	Taudah	10			20			5	5		Coleoptera (2). Chironomidae (1) Baetidae (2). Caenidae (1). Ephemerellidae (2) Heptageniidae (2). Leptophlebiidae (2) Oligochaeta (1) Nemouridae (2); Perlidae (2) Hydropsychidae (2) Glossosomatidae (1) . Potamidae (2) Planaria (2)
48	Kodku	Hansidhi	5		20	20				10	50	Coleoptera (2). Chironomidae (2) Empidae (1). Tabanidae (1) Tipulidae (1). Heptageniidae (2). Physidae (2) Sphaeriidae (2) Aphelochaeridae (2). Salifidae (2) Corydalidae (2) Gomphidae (2) Tubificidae (2) Perlidae (1) Hydropsychidae (2)
49	Kodku	Gorphutar	5		25	20				15	60	Chironomidae (2). Simuliidae (1) Baetidae (1). Physidae (1)Sphaeriidae (1). Corixidae (1). Salifidae (1). Gomphidae (1). Oligochaeta (2), Hydropsychidae (2)
50	Tukucha	Exhibit. road				20	20			15	100	Chironomidae (2). Physidae (2) Tubificidae (3)
51	Mahadev	Balaju	5		5	10				20	60	Coleoptera (1). Chironomidae (2). Simuliidae (1) Baetidae (2) Leptophlebiidae (2) Aphelochaeridae (1) Gomphidae (2) Oligochaeta (2) Hydropsychidae (2)
52	Bishnumati	Gongabu	5		10	20				10	40	Coleoptera (1) Chironomidae (3). Syrphidae (1) Tipulidae (1) Baetidae (2) Corixidae (1). Gomphidae (1)
53	Bagmati	Kumarigal			10	25				15	60	Coleoptera (1) Chironomidae (3). Tipulidae (1) Tabanidae (1) Baetidae (2). Lymnaeidae (2) Planorbidae (2) Corixidae (1) Naucoridae (1); Gomphidae (1)
54	Bagmati	Baneswor			20	15			30	100		Chironomidae (3) Gomphidae (2) Oligochaeta (2)
55	Tukucha	Baluwatar				15	15			20	100	Chironomidae (3) Oligochaeta (3)

Site No	Name of rivers	Localities' names	Vegetation coverage					Detritus coverage				Name of Dominant group of Animal
			Macrophyte	Moss	Filam algae	Algae (B. G. D)	Fungus	Wood	leaf	CPOM	FPOM	
56	Tukucha	Tudaldevi				10	10			20	100	Chironomidae (3). Tubificidae (4)
57	Tukucha	Tripureswor				20	10			10	100	Oligochaeta (5)
58	Dhobikhola	Thapathali				30	10			10	100	Chironomidae (3). Physidae (2). Corixidae (1) Tubificidae (2)
59	Dhobikhola	Baneswor				20	5			15	100	Coleoptera (2). Chironomidae (3). Physidae (2) Corixidae (1) Tubificidae (2)
60	Dhobikhola	Haangau				30	5			20	100	Chironomidae (2). Leptophlebiidae (2) Physidae (1) Corixidae (1) Gomphidae (2) Tubificidae (5)
61	Bishoumati	Dallu				20	10			15	100	Chironomidae (2). Physidae (2). Gomphidae (2) Tubificidae (2)
62	Manamati	Ringroad	5		10	20		5	5	20	100	Chironomidae (3). Simuliidae (1). Tabanidae (1) Physidae (2) Sphaeriidae (2). Tubificidae (2).
63	Manamati	Kalimati				20	5			30	100	Chironomidae (2) Physidae (1) Gomphidae (1) Tubificidae (3)
64	Samakhusi	Bansbari	5		10	10				20	60	Chironomidae (2) Coleoptera (1) Baetidae (1) Leptophlebiidae (2). Sphaeriidae (2). Corixidae (2). Gomphidae (2) Tubificidae (2)
65	Bagmati	Minbhavan				20	5			20	80	Coleoptera (1). Chironomidae (3) Culicidae (1) Syrphidae (2). Leptophlebiidae (1) Physidae (2) Corixidae (1). Gomphidae (1). Tubificidae (2)
66	Mahadev	Manpokhari		10		20		15	20	5		Elmidae (1) Psephenidae (1). Chironomidae (2) Simuliidae (1). Tabanidae (2). Tipulidae (1). Heptageniidae (2) Aphelocheiridae (2). Micronectidae (1) Nemouridae (1) Perlidae (2) Brachycentridae (1) Glossosomatidae (1) Hydropsychidae (2)
67	Bagmati	Nayapati	10		5	15				10	10	Coleoptera (1). Chironomidae (2). Tipulidae (1) Baetidae (2) Heptageniidae (1). Leptophlebiidae (2). Aphelocheiridae (1) Naucoridae (1). Perlidae (2) Hydropsychidae (1) Leptophlebiidae (2)
68	Bagmati	Gokarneswor	5		5	20				15	20	Ceratopogonidae (1) Coleoptera (1) Culicidae (1) Simuliidae (2) Baetidae (2). Leptophlebiidae (2) Physidae (2). Aphelocheiridae (2) Perlidae (1) Hydropsychidae (2)
69	Bagmati	Jorpaati	10		10	15				20	30	Chironomidae (2). Baetidae (2) Ephemerellidae (2) Leptophlebiidae (2). Physidae (1) Odonata (1)
70	Indrawati	Dahchok	10		15	15				10	20	Elmidae (1) Chironomidae (2) Simuliidae (2) Baetidae (2). Ephemerellidae (1); Caenidae (1); Heptageniidae (2) Leptophlebiidae (1). Gomphidae (2) Perlidae (2) Glossosomatidae (1) Hydropsychidae (2) Lepidostomatidae (1)
71	Matatirth	Matatirth		30								
72	Dharapani	Gaingau						5	5			Chiromomidae (2) Tabanidae (1) Baetidae (2) Heptageniidae (2). Lymnaeidae (1). Odonata (2) Perlidae (2) Hydropsychidae (2) Limnephilidae (2)
73	Khahare	Manapokhari						5	5			Simuliidae (2). Baetidae (2). Heptageniidae (2). Perlidae (2). Hydropsychidae (2).
74	Bagmati	Bagmati			5	20				5		Simuliidae (2). Baetidae (2) Heptageniidae (2) Gomphidae (1) Hydropsychidae (2)
75	Bagmati	Karmaiya			10	25				5		Simuliidae (2) Baetidae (2) Heptageniidae (2) Gomphidae (2). Hydropsychidae (2)
76	Bagmati	Sundarijal		10	5	5		5	5			Coleoptera (2) Elmidae (2). Athericidae (1) Chironomidae (2) Simuliidae (1) Limoniidae (2). Tabanidae (1). Tipulidae (1) Baetidae (2); Perlidae (2); Salifidae (1) Gomphidae (1); Oligochaeta (2) Hydropsychidae (1)
77	Bagmati	Gaurighat				20	5			5	60	Chironomidae (2). Syrphidae (1) Ephemerellidae (1). Physidae (2) Salifidae (1) Oligochaeta (2).
78	Godavari	B. garden		5		10		5	5	5		Elmidae (1) Psephenidae (1). Athericidae (1) Limoniidae (2) Tabanidae (2) Baetidae (2) Heptageniidae (2) Leptophlebiidae (1). Corydalidae (1) Gomphidae (2) Nemouridae (2) Perlidae (2) Hydropsychidae (2) Rhyacophilidae (2) Planaria (2)
79	Bagmati	Okhreni		10		10		10	10			Elmidae (1) Athericidae (2). Limoniidae (2) Tipulidae (2). Baetidae (2) Heptageniidae (2) Leptophlebiidae (1). Aphelocheiridae (1) Euphaeidae (1) Gomphidae (2) Capniidae (2) Nemouridae (2) Glossosomatidae (1) Hydropsychidae (2) Lepidostomatidae(1).

Appendix H: Faunal Record and Relative Abundance

Order	Family	RA	Order	Family	RA
Ephemeroptera			**Trichoptera**		
	Baetidae			Brachicentridae	
	Caenidae			Glossosomatidae	
	Ephemerellidae			Goeridae	
	Ephemeridae			Hydrobiosidae	
	Heptageniidae			Hydropsychidae	
	Leptophebidae			Lepidostomatidae	
				Limnephelidae	
Zygoptera				Philopotamidae	
	Calopterygidae Coenagrionidae				
	Euphaeidae			Polycentropodidae	
	Lestidae			Psychomyidae	
				Rhyacophilidae	
Anisoptera				Stenopsychidae	
	Corduliidae			Uenoidae	
	Gomphidae				
	Libellulidae				
			Diptera		
Plecoptera				Athericidae	
	Capniidae			Ceratopogonidae	
	Leuctridae			Chironomidae	
	Nemouridae			Culicidae	
	Perlidae			Limoniidae	
				Simuliidae	
Heteroptera				Tabanidae	
	Aphelocheiridae				
	Corixidae		**Tricladida**		
	Gerridae		**Gastropoda**		
	Hebridae			Lymnaeidae	
	Naucoridae			Physidae	
	Nepidae			Planorbidae	
	Micronectidae		**Bivalvia**		
				Sphaeriidae	
Coleoptera					
	Elmidae		**Oligochaeta**		
	Gyrinidae			Lumbricidae	
	Helodidae			Naidae	
	Hydraenidae			Tubificidae	
	Hydrophillidae				
	Noteridae		**Hirudinea**		
	Psephenidae			Glossiphoniidae	
	Scirtidae			Salifidae	
Megaloptera			**Crustacea**		
	Corydalidae			Potamidae	

Note: RA = Relative Abundance

Appendix I: Field water quality class by season and river profile region

Site no.	River name	FWQC PO	FWQC PR	RP Region
1	Samakhusi	IV	IV	VRM
2	Balkhukhola	III	III-IV	VRL
3	Balkhukhola	II-III	II-III	VRL
4	Bagmati	IV	IV	VRL
5	Tukucha	IV	IV	VRM
6	Dhobikhola	IV	IV	VRM
7	Godavari	II	II-III	VRU
8	Hanumante	III-IV	III-IV	VRM
9	Manahara	III	III	VRM
10	Kodku	III-IV	III-IV	VRU
11	Nakhu	II	II	VRL
12	Nakhu	II-III	III	VRL
13	Bagmati	III-IV	III-IV	VRM
14	Godavari	II	II	VRU
15	Kodku	II-III	II-III	VRU
16	Bishnumati	III	III	VRU
17	Mahade	III	III-IV	VRU
18	Salinadi	I-II	II	VRU
19	Manmati	I-II	II	VRU
20	Mahadev	II	III	VRU
21	Manahara	II	II	VRU
22	Bagmati	II	II-III	VRU
23	Hanumante	III-IV	III-IV	VRM
24	Bishnumati	II	II-III	HWL
25	Dhobikhola	II-III	II-III	HWL
26	Bagmati	I	I	HWu
27	Bagmati	I	I-II	HWu
28	Nagmati	I	I-II	HWu
29	Syalmati	I	I	HWu
30	Naldu	I-II	II	HWL
31	Lele	II	II-III	HWL
32	Bishnumati	I	I	HWu
33	Phedikhola.	II-III	II-III	HWL
34	Mahadev	II	II	HWL
35	Mahadev	I	I	HWu
38	Bhageri	I-II	II	HWL
40	Kunokhola	II	II-III	HWL
41	Bagmati	IV	IV	VRM
42	Bagmati	IV	IV	VRM
43	Bagmati	IV	IV	VRM
44	Bagmati	III-IV	IV	VRL
45	Bagmati	III-IV	IV	VRL
46	Chaltikhola	I-II		VRL
47	Bosankhola	II	II	VRL
48	Kodkukhola	II-III	II-III	VRU
49	Kodkukhola	II-III	II-III	VRU
50	Tukucha	IV	IV	VRM
51	Mahadev	II-III	III	VRU
52	Bshnumati	III	III-IV	VRM
53	Bagmati	III	III--IV	VRU

Site no.	River name	FWQC PO	FWQC PR	RP Region
54	Bagmati	III-IV	IV	VRM
55	Tukucha	IV	IV	VRM
56	Tukucha	IV	IV	VRM
57	Tukucha	IV	IV	VRM
58	Dhobikhola	IV	IV	VRM
59	Dhobikhola	IV	IV	VRM
60	Dhobikhola	III-IV	IV	VRM
61	Bishnumati	III-IV	IV	VRM
62	Manamati	III	III-IV	VRU
63	Manamati	IV	IV	VRM
64	Samakhusi	III-IV	III-IV	VRM
65	Bagmati	III-IV	IV	VRM
66	Mahadev	I	I-II	HWu
67	Bagmati	II	II	VRU
68	Bagmati	II-III	II-III	VRU
69	Bagmati	II-III	III	VRU
70	Satganne	II	III	VRL
72	Dharapanikhola	I-II		HWL
73	Khahare	I-II		HWL
74	Bagmati	II		LR
75	Bagmati	II-III		LR
76	Bagmati	I-II	I-II	HWL
77	Bagmati	III-IV	III-IV	VRM
78	Godavari	I-II	I-II	HWL
79	Bagmati	I	I	HWU

Note: VRU= Valley region upper; VRM = Valley region middle; HWL = Valley region lower; LR = Lower Region
HWU = Head water region upper; HWL = Head water region lower.
FWQC = Field water quality class; PO = Post rainy season; PR = Pre rainy season

Appendix J: Results of three bacterial parameter. post-monsoon season

Site no.	River name	Locality name	Date	Mean HPC cfu/ml	Mean EC cfu/100ml	Mean FS cfu/100ml
1	Samakhusi	Lazimpat	02.11.95	1243333	143330	22500
2	Balkhukhola	Rind road	03.11.95	51433	51700	7330
3	Balkhukhola	Kalanki	04.11.95	17616	21300	5030
4	Bagmati	Sundarighat	05.11.95	961000	213667	46660
5	Tukucha	Baluwatar	06.11.95	2753333	1833300	47660
6	Dholakhola	Chabel	06.11.95	566667	166700	80000
7	Godavari	Balkot	07.11.95	51933	4200	800
8	Hanumante	Imadol	07.11.95	67500	76700	12830
9	Manahara	Koteswar	07.11.95	8233	29300	200
10	Kodku	Imadol	07.11.95	500000	673300	10360
11	Nakhu	Bungmati	09.11.95	1572	1000	1000
12	Nakhu	Nakhujail	09.11.95	2740	3000	3100
13	Bagmati	Pashupatinath	18.11.95	283000	1320000	14830
14	Godavari	Bishankhu	19.11.95	14000	10000	700
15	Kodku	Badegao	19.11.95	21667	2700	5500
16	Bishnumati	Ringroad	19.11.95	117067	32900	14330
17	Mahadev	Hilerol	17.11.95	100333	111000	11660
18	Salinadi	Sankhu	22.11.95	9167	6000	200
19	Manmati	Saranchok	21.11.95	7833	37700	200
20	Mahadev	Indrayani	21.11.95	47000	33700	5030
21	Manahara	Bramhakhel	21.11.95	13300	9600	4630
22	Bagmati	Gokarna	05.12.95	54667	12600	600
23	Hanumante	Sallaghari	05.12.95	373333	1040000	41830
24	Bishnumati	Narayanthan	27.12.95	204333	26300	383
25	Dhobikhola	Narayanthan	27.12.95	54400	103700	3030
26	Bagmati	Sundarijal	04.01.96	539	90	11
27	Bagmati	Sundarimai	04.01.96	833	60	7
28	Nagmati	Sundarimai	04.01.96	903	66	22
29	Syalmati	Sundarijal	04.01.96	800	60	200
30	Naldu	Tikavairab	06.01.96	6480	700	150
31	Lele	Tikavairab	06.01.96	14557	1900	410
32	Bishnumati	Chisini village	11.01.96	674	50	0.1
33	Phedikhola.	Budhanilkanth	11.01.96	16267	1600	2500
34	Mahadev	Budhanilkanth	11.01.96	2370	3200	466
35	Mahadev	Shivpuri muhan	11.01.96	825	90	1
38	Bhagerikhola	Godavari	13.01.96	2233	60000	200
40	Kunokhola	Godavari	13.01.96	2767	2100	386
41	Bagmati	Godavari	28.02.95	2320000	6400000	40460
42	Bagmati	Godavari	28.02.95	1196667	17833300	61000
43	Bagmati	Marblekhani	28.12.95	109667	1500000	51000
44	Bagmati	Kupandol	08.02.96	740000	2316700	110100
45	Bagmati	Teku	08.02.96	916667	2183300	21400
46	Chaltikhola	Tekudovan	08.02.96	1887	1630	500
47	Bosankhola	Chovar George	08.02.96	9333	5833	2000
48	Kodkukhola	Khokana	28.12.95	35567	1760	3000
49	Kodkukhola	Chalti	28.12.95	56333	1830	1000
50	Tukucha	Taudah	02.01.96	3983333	4090000	70000
51	Mahadev	Harisidhi .	02.01.96	8833	3160	1500
52	Bshnumati	Gorphutar	02.01.96	115333	1473330	9500

Site no.	River name	River name	Date	Mean HPC cfu/ml	Mean EC cfu/100ml	Mean FS cfu/100ml
53	Bagmati	Kumarigal	03.01.96	210667	2163330	90000
54	Bagmati	Baneswor	16.01.96	643333	1546660	10500
55	Tukucha	Baluwatar	16.01.96	5560000	1666660	158000
56	Tukucha	Tudaldevi	22.01.96	1216667	3043300	168000
57	Tukucha	Tripureswor	21.01.96	3626667	7366660	138000
58	Dhobikhola	Thapathali	21.01.96	2753333	14123330	32800
59	Dhobikhola	Baneswor	21.01.96	5033333	3013330	118000
60	Dhobikhola	Haarigau	23.01.96	6400000	680666	10500
61	Bishnumati	Dallu	23.01.96	3180000	610000	23000
62	Manamati	Ringroad	04.02.96	86667	9200	500
63	Manamati	Kalimati	04.02.96	400000	666660	3000
64	Samakhusi	Bansbari	04.02.96	184333	623330	9000
65	Bagmati	Minbhavan	23.12.95	873333	183330	11500
66	Mahadev	Manpokhari	25.01.96	570	100	12
67	Bagmati	Nayapati	10.01.96	26600	1300	121
68	Bagmati	Gokarneswor	10.01.96	23467	3230	400
69	Bagmati	Jorpaati	10.01.96	643300	39500	2000
70	Satganne	Dahchok	20.01.96	12345	3500	1336
72	Dharapani	Gairigau	20.01.96	2000	100	2
73	Khahare	Manapokhari	25.01.96	3267	386	12
74	Bagmati	Bagmati	03.03.96	5600	386	300
75	Bagmati	Karmaiya	03.03.96	19667	633	400
76	Bagmati	Sundarijal	04.01.96	2578	83	35
77	Bagmati	Gaurighat	03.11.95	1000000	266666	9000
78	Godavari	B. garden	04.02.96	1233	500	400
79	Bagmati	Okhreni	04.01.96	597	200	100

Note: HPC = Heterotrophic plate count; EC = E. coli count; FS = Faecal streptococcus count.
cfu = colony forming unit

Appendix K: Results of three bacterial parameters. pre-monsoon season

SS	River name	Date	HPC mean cfu/ml	EC Mean cfu/100ml	FS Mean cfu/100ml
1	Samakhusi	24.03.95	7079458	258925	31620
2	Balkhukhola	05.04.96	693333	50000	28000
3	Balkhukhola	15.04.96	124500	29000	3700
4	Bagmati	27.05.96	3500000	935000	104500
5	Tukucha	24.04.96	51584893	995262	295100
6	Dhobikhola	24.04.96	3162278	109411	204200
7	Godavari	23.05.96	54500	5500	1400
8	Hanumante	23.05.96	575000	112150	1600
9	Manahara	23.05.96	150000	3456000	3600
10	Kodku	23.05.96	630957	707940	16220
11	Nakhu	27.04.96	26000	450	600
12	Nakhu	04.05.96	78000	1600	1200
13	Bagmati	31.05.96	5400000	2550000	120000
14	Godavari	25.04.96	10250	3000	800
15	Kodku	25.04.96	9500	8500	2200
16	Bishnumati	15.04.96	126000	22500	1310
17	Mahadevkhola	15.04.96	200000	45000	2580
18	Salinadi	30.04.96	8500	11000	5000
19	Manmati	30.04.96	50119	32359	1585
20	Mahadev	30.04.96	54000	32500	25600
21	Manahara	30.04.96	12750	6000	2000
22	Bagmati	30.04.96	75000	57000	8700
23	Hanumante	02.05.96	3162278	338844	22390
24	Bishnumati	24.05.96	67500	52000	1230
25	Dhobikhola	24.05.96	75000	52500	17700
26	Bagmati	24.05.96	4350	120	220
27	Bagmati	24.05.96	1413	158.8	7.4
28	Nagmati	24.05.96	1660	95	30.1
29	Syalmati	24.05.96	1800	320	400
30	Naldu	01.05.96	41500	1500	1300
31	Lele	01.05.96	150000	19700	1100
32	Bishnumati (Source)	20.05.96	1600	140	0.1
33	Phedikhola.	20.05.96	158489	20900	4900
34	Mahadev (Dhobi)	22.05.96	31623	38900	1622
35	Mahadev (Source)	22.05.96	2300	280	0.1
38	Bhagerikhola	02.05.96	5000	1640	900
40	Kunokhola	02.05.96	205500	1300	1200
41	Bagmati	05.05.96	5400000	2500000	120000
42	Bagmati	05.05.96	8128305	877880	31630
43	Bagmati	05.05.96	3311311	912090	51290
44	Bagmati	27.05.96	2623413	2589200	245500
45	Bagmati	27.05.96	9700000	5750000	450000
46	Bosankhola	27.05.96	31623	24500	5200
48	Kodkukhola	04.05.96	201500	12600	1900
49	Kodkukhola	04.05.96	562341	38900	2080

SS	River name	Date	HPC mean cfu/ml	EC Mean cfu/100ml	FS Mean cfu/100ml
50	Tukucha	06.05.96	89125090	2247100	70790
51	Mahadevkhola	06.05.96	257040	28200	25100
52	Bshnumati	15.04.96	524807	128310	58500
53	Bagmati	03.05.96	3100000	900000	44000
54	Bagmati	03.05.96	4900000	6200000	29100
55	Tukucha	03.05.96	8550667	9125090	125890
56	Tukucha	03.05.96	7798301	2801630	55000
57	Tukucha	07.04.96	12589254	12129560	89800
58	Dhobikhola	07.04.96	10739894	12830600	933300
59	Dhobikhola	07.04.96	1866667	1900000	150000
60	Dhobikhola	28.03.96	1584893	6982440	524800
61	Bishnumati	28.03.96	3890451	7624700	51200
62	Manamati	15.04.96	385000	125000	19400
63	Manamati	17.04.96	1584893	3182600	323600
64	Samakhusi	17.04.96	524807	5821800	12600
65	Bagmati	31.05.96	3250873	548130	23900
66	Mahadev (Source)	31.05.96	2051	200	31
67	Bagmati	28.05.96	137000	2500	280
68	Bagmati	28.05.96	37500	4300	3200
69	Bagmati	28.05.96	2517677	621800	34700
70	Satganne (Balkhu)	26.05.96	237500	127000	61000
76	Bagmati	07.03.96	5495	177	456
77	Bagmati	01.06.96	13273944	417380	50600
78	Godavari	20.05.96	4855	1000	450
79	Bagmati	24.05.96	1800	240	120

Note: HPC = Heterotrophic plate count; EC = E. coli count; FS = Faecal streptococcus count; cfu = colony forming unit

Appendix L: Records of three Bacterial parameters at Sample site 43 (1996 -1- 20)

Heterotrophic Plate Count at 22°C (cfu /ml)								
Cross Section			Diel record			Daily for consecutive 7 days		
R1	R2	R3	R1	R2	R3	R1	R2	R3
2000000	2240000	1850000	4100000	5900000	8680000	1480000	1620000	23000
1850000	1650000	1230000	2980000	3850000	5200000	1860000	1260000	16200
1500000	1500000	1100000	3500000	7850000	4200000	1120000	1680000	10400
1400000	900000	1100000	2120000	1880000	4090000	1220000	820000	15000
1400000	1950000	290000	3800000	4650000	2500000	650000	1250000	42500
2180000	2280000	1608000	1450000	2280000	1680000	1360000	1880000	65000
1200000	2600000	3750000				1560000	2180000	12100

E.coli count incubated at 37 °C cfu /100ml								
Cross Section			Diel record			Daily Record for consecutive 7 day		
R1	R2	R3	R1	R2	R3	R1	R2	R3
396000	185000	438000	1200000	450000	210000	460000	198000	4770
470000	315000	376000	600000	350000	310000	225000	650000	7600
128000	255000	685000	850000	630000	500000	210000	310000	3500
265000	158000	435000	480000	760000	310000	230000	185000	4150
287000	460000	190000	750000	670000	790000	440000	550000	2200
386000	270000	324000	620000	1200000	630000	185000	510000	12500
480000	690000	516000	1280000	250000	220000			

Faecal strptococcus incubated at 44°C cfu/100ml								
Cross Section			Diel record			Daily Record for consecutive 7 day		
R1	R2	R3	R1	R2	R3	R1	R2	R3
450	610	750	1250	900	1400	460	750	5
520	480	2318	450	800	1000	850	1100	7
1050	850	800	1100	750	820	560	1280	26
1420	950	780	860	570	580	460	1800	20
1210	690	1550	460	1150	940	750	830	2
1250	580	1050	1100	580	1500	760	890	13
1210	750	440	620	890	140			

R1 = Mean replicate 1; R2 = Mean replicate 2; R3 = Mean replicate 3;

Appendix M: Post-monsoon Bacterial Range

	Log HPC cfu/ml						
I WQC→ % SS↓	I	I-II	II	II-III	III	III-IV	IV
0%	2.73	3.09	3.20	3.44	3.92	4.83	5.04
25%	2.77	3.30	3.80	4.21	4.71	5.49	6.01
50%	2.87	3.41	4.13	4.29	4.94	5.75	6.23
75%	2.92	3.81	4.61	4.55	5.06	5.89	6.53
100%	2.96	3.96	4.31	4.75	5.32	6.00	6.75
	Log EC cfu/100ml						
WQC→ % SS↓	I	I-II	II	II-III	III	III-IV	IV
0%	1.78	1.92	2.59	2.80	3.51	5.76	6.56
25%	1.93	2.59	3.29	3.25	4.47	6.05	7.15
50%	1.95	2.85	3.58	3.43	4.60	6.30	7.29
75%	2.12	3.65	4.00	3.50	5.05	6.52	7.47
100%	2.24	3.65	4.51	5.02	6.21	7.02	7.61
	Log FS cfu/100ml						
WQC→ % SS↓	I	I-II	II	II-III	III	III-IV	IV
0%	-1.00	0.30	2.08	2.60	2.30	3.95	2.85
25%	0.63	2.18	2.59	3.48	2.70	4.02	4.54
50%	1.06	2.30	2.81	3.67	3.87	4.08	4.69
75%	1.51	2.54	3.26	3.74	4.07	4.34	5.03
100%	2.00	2.70	3.70	4.88	4.55	5.04	5.23

Appendix N:Premonsoon Bacterial Range

	Log HPC cfu/ml						
WQC→ % SS↓	I	I-II	II	II-III	III	III-IV	IV
0	3.20	3.15	3.93	3.98	4.73	4.76	6.50
25	3.26	3.22	4.01	4.74	4.89	5.30	6.54
50	3.26	3.31	4.11	4.83	5.10	5.80	6.73
75	3.30	3.69	4.41	4.88	5.18	5.84	6.85
100	3.31	3.96	4.70	4.88	6.40	6.73	7.71
WQC→ % SS↓	I	I-II	II	II-III	III	III-IV	IV
0	2.08	1.98	2.65	3.93	3.20	5.18	6.97
25	2.15	2.20	3.48	4.46	4.45	5.65	7.32
50	2.24	2.25	3.78	4.72	4.51	6.85	7.40
75	2.25	3.00	4.04	4.74	5.35	7.05	8.10
100	2.30	3.95	4.53	4.76	6.54	8.53	8.69
	Log FS cfu/100ml						
WQC→ % SS↓	I	I-II	II	II-III	III	III-IV	IV
0	-1.00	0.87	2.78	3.09	3.08	3.20	5.31
25	-1.00	1.48	2.90	3.15	3.56	4.41	5.47
50	2.08	1.49	3.30	3.34	4.12	4.45	5.50
75	2.10	2.65	3.70	3.57	4.40	5.21	6.02
100	2.12	2.78	4.20	4.95	4.95	6.08	6.08

Appendix O: **Results of the chemical parameters. post-monsoon season**

SS	River name	Date	Temp. (°C)	DO (mg/l)	O_2 sat. (%)	BOD_5 (mg/l) O_2	Cond. (µS/cm)	T. hardness $CaCO_3$ (mg/l)	Chloride (mg/l)	N-NH_4 (mg/l)	TP (mg/l)
1	Samakhusi	02.11.95	17	2.1	23	40	360	190	90	5.1	2.5
2	Balkhukhola	03.11.95	16.0	4.1	41	16	52	3.9	14.7	1.5	0.6
3	Balkhukhola	04.11.95	16.0	8.5	86	1.9	19	4.3	2.9	0.19	0.19
4	Bagmati	05.11.95	15.0	1.5	15	86	294	79.6	56.1	5.14	1.43
5	Tukucha	06.11.95	19.0	0.8	9	79	634	187.7	88.2	34.8	3.11
6	Dhobikhola	06.11.95	17.0	2.9	30	62	224	79.6	39.2	9.7	0.83
7	Godavari	07.11.95	9.0	10.2	88	3.3	38	11	2.9	1.6	0.09
8	Hanumante	07.11.95	22.0	5.3	61	26	293	124.4	18.6	2.2	0.82
9	Manahara	07.11.95	23.0	8.6	101	2.9	350	152.3	38.1	1.2	1.28
10	Kodku	07.11.95	21.0	4.5	50	4.6	307	117.3	12.7	1.45	0.51
11	Nakhu	09.11.95	17.0	9.6	100	1.1	200	97.9	6.4	0.05	0.08
12	Nakhu	09.11.95	16.7	9.8	102	1.3	195	135.2	2.1	0.2	0.08
13	Bagmati	18.11.95	16.0	2.3	23	46	294	74.5	42.7	3.4	0.56
14	Godavari	19.11.95	16.2	8.9	90	2	186	139.7	8.8	0.13	0.05
15	Kodku	19.11.95	19.1	8.8	95	3.3	202	107.1	6.9	0.09	0.29
16	Bishnumati	19.11.95	21.0	7.7	86	4.5	258	138.9	4.2	0.9	0.19
17	Mahadevkhola	17.11.95	21.8	4.3	49	5.4	35	9.2	5.9	1.09	0.05
18	Salinadi	22.11.95	17.0	8.2	85	1	54	6.5	7.8	0.08	0.09
19	Manmati	21.11.95	21.0	7.7	86	1.4	195	113.6	15.2	0.16	0.16
20	Mahadev	21.11.95	19.0	8.7	94	3.7	49	20.1	5.6	0.31	0.13
21	Manahara	21.11.95	20.0	8.9	98	3.1	270	22.8	7.8	0.2	0.13
22	Bagmati	05.12.95	19.0	8.2	89	4	60	31.1	20.2	0.1	0.51
23	Hanumante	05.12.95	13.0	1.2	11	58	432	128	27.4	4.3	1.1
24	Bishnumati	27.12.95	15.0	8.4	84	1.7	168	137	41	0.06	0.07
25	Dhobikhola	27.12.95	16.0	8.5	86	5.2	114	42.4	14.7	0.1	0.07
26	Bagmati	04.01.96	9.0	13	112	0.7	28	5.1	3.1	0.03	0.04
27	Bagmati	04.01.96	11.1	11.6	105	0.2	26	7.1	3.9	0.04	0.03
28	Nagmati	04.01.96	9.0	11.8	102	1.4	29	7.5	3.4	0.02	0.05
29	Syalmati	04.01.96	10.0	11.3	100	0.2	28	5.7	3.4	0.03	0.04
30	Naldu	06.01.96	14.0	9.2	89	2	168	93.8	5.9	0.05	0.04
31	Lele	06.01.96	16.0	8.3	85	2.3	172	148	32	0.09	0.05
32	Bishnumati	11.01.96	7.0	12.5	103	0.6	42	32.1	10.2	0.09	0.04
33	Phedikhola.	11.01.96	13.0	7.5	71	3.5	109	36.3	8.8	0.5	0.12
34	Mahadev (Dhobi)	11.01.96	13.0	8.5	80	1.9	61	19.2	5.9	0.06	0.06
35	Mahadev (Source)	11.01.96	12.0	11.2	104	0.1	30	7.8	2.9	0.03	0.03
38	Bhagerikhola	13.01.96	12.0	9.5	88	1.2	232	142	3.1	0.05	0.05
40	Kunokhola	13.01.96	13.0	7.5	71	2.8	253	136	6.9	0.4	0.08
41	Bagmati	28.02.95	17.0	1.8	18	46	360	79.6	44.4	4.6	0.93
42	Bagmati	28.02.95	18.0	2.1	22	32	350	71.2	41	5.8	1.3
43	Bagmati	28.12.95	18.0	2.8	30	31	326	71.4	32.3	7.2.	1.19
44	Bagmati	08.02.96	19.0	3.9	42	78	534	78.5	43.2	6.5	1.3
45	Bagmati	08.02.96	19.0	5.2	56	54	263	62.1	12.7	5.8	1.08
46	Chaltikhola	08.02.96	12.0	9.1	85	1.5	254	116	10.8	0.05	0.05
47	Bosankhola	08.02.96	16.0	8.9	91	2.1	354	138	33.5	0.05	0.05
48	Kodkukhola	28.12.95	14.0	7.5	72	3.5	231	137	10.1	0.86	0.2
49	Kodkukhola	28.12.95	15.0	7.8	78	3.4	187	139	14.1	0.67	0.15
50	Tukucha	02.01.96	15.0	1.1	10	63	1025	201	97	38.2	2.1
51	Mahadevkhola	02.01.96	18	7.5	79	3.8	178	76.5	9.8	1.1	0.6
52	Bshnumati	02.01.96	15	6.5	65	6.1	437	135	48.1	2.1	0.67
53	Bagmati	03.01.96	16	4.1	41	25	277	85.6	43.2	1.3	0.81
54	Bagmati	16.01.96	14	3.5	45	31	305	201.4	49.2	12.6	1.11

SS	River name	Date	Temp. (°C)	DO (mg/l)	O_2 sat. (%)	BOD_5 (mg/l)	Cond. (µS/cm)	T. hardness (mg/l)	Chloride (mg/l)	$N-NH_4$ (mg/l)	TP (mg/l)
55	Tukucha	16.01.96	15	0.6	5.3	181	878	235	102	40.6	2.1
56	Tukucha	22.01.96	15	0.5	5	155	759	301	89.3	27.4	4.21
57	Tukucha	21.01.96	17	1.2	11	187	972	:123	89.2	31.2	4.23
58	Dhobikhola	21.01.96	16	2.1	19	22	174	105	62.1	15.8	1.85
59	Dhobikhola	21.01.96	13	2.4	21	13	471	201	54.2	14.6	0.96
60	Dhobikhola	23.01.96	16	2.5	22	13	186	169	39.1	10.1	1.07
61	Bishnumati	23.01.96	16	2.1	23	20	359	141	3.8	9.6	1.21
62	Manamati	04.02.96	17	6.5	67	10	54	10.8	7.8	1.01	0.54
63	Manamati	04.02.96	16	2.1	23	38	271	158	3.9	5.4	0.12
64	Samakhusi	04.02.96	17	5.2	54	6.2	150	142	20.2	3.4	0.71
65	Bagmati	23.12.95	18	3.6	38	45	211	36.7	38.5	4	0.96
66	Mahadev	25.01.96	9	11.5	100	0.1	60	15.9	4.9	0.03	0.04
67	Bagmati	10.01.96	17	7.7	78	4.1	67	16.7	7.8	0.1	0.08
68	Bagmati	10.01.96	17	6.7	70	9.5	110	24.9	18.9	0.1	0.15
69	Bagmati	10.01.96	18	5.8	72	12	140	21.4	13.7	0.74	0.25
70	Satganne	20.01.96	13	8.5	80	1.8	137	62	7.8	0.07	0.1
72	Dharapanikhola	20.01.96	16	9.2	81.4	0.2	195	138	3.5	0.05	0.05
73	Khahare khola	25.01.96	13	8.6	94	0.9	192	104	5.4	0.04	0.05
74	Bagmati	03.03.96	20	9.4	104	4.1	254	136	12.7	0.08	0.08
75	Bagmati	03.03.96	23	8.9	104	3.8	256	130	13.2	0.09	0.1
76	Bagmati	04.01.96	14	10.2	99	1.4	65	16	7.4	0.05	0.1
77	Bagmati	03.11.95	19	4.5	42	12	201	119	36.9	2.1	1.14
78	Godavari	04.02.96	15	9.1	91	0.8	195	159	8.6	0.06	0.06
79	Bagnati	04.01.96	10	11.5	101	0.8	28	5.7	2.8	0.03	0.04

DO = Dissolved Oxygen; TP = Total Phosphate

Appendix P: Results of the chemical parameters. pre-monsoon season

S.S River name	Date	Temp °C	DO (mg/l)	O_2 sat (%)	BOD5 (mg/l)	Cond. (µS/cm)	T. hardness (mg/l)	Chloride (mg/l)	$N-NH_4$ (mg/l)	PO_4-P (mg/l)
1 Samakhusi	24.03.95	22	1.6	17	52.1	540	250	88	6.8	1.6
2 Balkhukhola	05.04.96	18.0	3.2	36	20.2	64	90	19.6	1.2	0.9
3 Balkhukhola	15.04.96	21.0	8	89	2.6	24	145	14.7	0.6	0.16
4 Bagmati	27.05.96	26.0	1.2	17	98.3	905	144	127.1	12.56	2.41
5 Tukucha	24.04.96	22.0	1	11	89.4	908	211	119.6	37.5	3.14
6 Dhobikhola	24.04.96	26.0	2.5	31	71.3	414	130	47.5	10.45	0.95
7 Godavari	23.05.96	29.0	8.5	111	3.1	42	155	9.3	2.3	0.2
8 Hanumante	23.05.96	29.0	4.2	55	19.6	605	138	22.3	3.1	1.1
9 Manahara	23.05.96	31.0	6.1	81	3.5	402	46	10	2.8	1.31
10 Kodku	23.05.96	27.0	4.1	52	6.5	428	381	18.9	2.1	0.72
11 Nakhu	27.04.96	22.0	9.2	105	2.1	227	106	19	0.06	0.07
12 Nakhu	04.05.96	29.0	7.5	98	3.5	179	113	19.8	0.4	0.06
13 Bagmati	31.05.96	21.0	3.0	40	48.2	491	152	58.8	10.7	1.1
14 Godavari	25.04.96	17.0	9.1	96	2.3	320	162	8.9	0.2	0.05
15 Kodku	25.04.96	18.0	8.5	89	4.7	207	115	12.1	0.2	0.31
16 Bishnumati	15.04.96	27.0	6.8	85	6.9	251	42	13.9	1.2	0.21
17 Mahadev	15.04.96	25.0	3.3	40	12.1	49	83	17.7	1.3	0.11
18 Salinadi	30.04.96	19.0	9	96	1.8	85	13	6.7	0.16	0.05
19 Manmati	30.04.96	25.0	7.8	93	3	263	15	8.6	0.5	0.21
20 Mahadev	30.04.96	24.0	6	71	4.1	65	8	9.6	0.6	0.23
21 Manahara	30.04.96	24.0	8.5	101	4.3	326	30	8.8	0.22	0.12
22 Bagmati	30.04.96	22.0	7.2	94	4.8	85	43	35.4	1.2	0.62
23 Hanumante	02.05.96	20.0	1.1	12	41.6	519	141	80.2	5.2	1.3
24 Bishnumati	24.05.96	20.0	6.8	75	2.7	263	16	5.9	0.23	0.12
25 Dhobikhola	24.05.96	22.0	7.5	86	6.5	155	51	25.1	0.8	0.61
26 Bagmati	24.05.96	17.0	9.8	102	0.5	38	9	4.1	0.03	0.04
27 Bagmati	24.05.96	19.0	10	107	1.1	32	9	3.5	0.05	0.05
28 Nagmati	24.05.96	18.0	8.7	92	1.5	34	7	6.9	0.06	0.05
29 Syalmati	24.05.96	15.0	9.6	96	0.3	35	8	6.4	0.05	0.05
30 Naldu	01.05.96	25.0	8.9	108	2.4	218	78	8.1	0.07	0.05
31 Lele	01.05.96	25.0	6.5	79	4	295	141	5.8	0.23	0.08
32 Bishnumati	20.05.96	16.0	9.1	93	1.2	91	9	5.9	0.16	0.05
33 Phedikhola.	20.05.96	20.0	7.1	79	4.6	205	50	15.6	0.8	0.09
34 Mahadev	22.05.96	21.0	8.2	94	3	80	23	10.1	0.08	0.77
35 Mahadev	22.05.96	15.0	8.7	87	1.3	35	10	4.9	0.05	0.05
38 Bhagerikhola	02.05.96	18.0	8.9	94	1.5	247	210	3.6	0.05	0.05
40 Kunokhola	02.05.96	20.0	6.5	72	3.2	280	202	15.2	0.7	0.1
41 Bagmati	05.05.96	23.0	1.5	18	54	440	106	76.1	6.23	1.1
42 Bagmati	05.05.96	23.0	1.1	13	65.9	520	85	58	6.7	1.4
43 Bagmati	05.05.96	22.0	2.1	24	35.8	540	95	79.5	9.4	1.23
44 Bagmati	27.05.96	25.0	3.5	43	81.6	848	159	120	26.3	1.45
45 Bagmati	27.05.96	24.0	4.4	52	59.3	392	155	107	17.12	1.05
47 Bosankhola	27.05.96	21.0	8.6	96	1.5	846	127	6.8	0.05	0.06
48 Kodkukhola	04.05.96	25.0	7.2	87	4.1	261	153	15.2	1.1	0.21
49 Kodkukhola	04.05.96	22.0	7	80	4.9	269	172	18.6	0.47	0.11
50 Tukucha	06.05.96	25.0	1	12	67.9	1010	245	121	29.6	1.8
51 Mahadev	06.05.96	21	6.8	76	4.9	266	206	46	1.02	0.64
52 Bshnumati	15.04.96	25	5.9	72	5.9	630	186	48	2.43	0.81
53 Bagmati	03.05.96	22	3.1	36	32.1	369	64	58.8	9.2	1.01
54 Bagmati	03.05.96	24	2.4	28	36.1	450	246	87	18.2	1.24
55 Tukucha	03.05.96	25	1.1	13	204.5	1040	286	165	39.4	2.1

SS	River name	Date	Temp. (°C)	DO (mg/l)	O_2 sat. (%)	BOD_5 (mg/l)	Cond. (µS/cm)	T. hardness (mg/l)	Chloride (mg/l)	$N\text{-}NH_4$ (mg/l)	TP (mg/l)
56	Tukucha	03.05.96	23	0.8	9	161	980	242	98.5	31.5	2.69
57	Tukucha	07.04.96	24	1.2	14	150	1140	169	141	29.5	3.91
58	Dhobikhola	07.04.96	22	1.4	16	31.6	210	139	74.2	12.6	2.16
59	Dhobikhola	07.04.96	23	2.1	25	17.5	510	226	65.1	15.2	1.02
60	Dhobikhola	28.03.96	21	2	22	18.2	250	188	58.3	10.5	0.98
61	Bishnumati	28.03.96	24	2.4	28	22.2	630	149	8.5	8.5	1.16
62	Manamati	15.04.96	23	5.2	61	11.2	78	55	24.3	1.5	0.31
63	Manamati	17.04.96	22	1.1	13	40.1	273	121	59.5	6.8	1.21
64	Samakhusi	17.04.96	20	4.6	51	12.1	244	161	23.7	4.1	0.65
65	Bagmati	31.05.96	22	3.1	36	64.7	509	99	88.6	10.5	1.1
66	Mahadev	31.05.96	18	9.2	98	0.8	630	12	3.1	0.05	0.05
67	Bagmati	28.05.96	23	6.9	81	4.4	77	19	7.84	0.05	0.1
68	Bagmati	28.05.96	21	6.2	70	8.4	140	45	34.5	0.5	0.1
69	Bagmati	28.05.96	22	5.2	60	18.4	180	53	32.8	1.2	0.21
70	Satganne	26.05.96	18	5.4	57	4.3	146	54	8.8	1.1	0.31
76	Bagmati	07.03.96	20	8.6	95	1.8	70	21	8.5	0.06	0.25
77	Bagmati	01.06.96	25	3.8	46	15.1	231	129	54.6	2.32	1.31
78	Godavari	20.05.96	20	9.2	102	1.1	314	138	4.5	0.05	0.05
79	Bagmati	24.05.96	19	9.2	100	1.2	35	9	6.4	0.05	0.05

DO = dissolved oxygen

Appendix Q: q^w value for each chemical parameter

LF

	0	10	20	30	40	50	60	70	80	90
0	1.346	1.356	1.363	1.368	1.371	1.373	1.375	1.376	1.377	1.378
100	1.379	1.379	1.380	1.380	1.380	1.380	1.380	1.380	1.380	1.379
200	1.379	1.378	1.378	1.377	1.376	1.375	1.374	1.373	1.372	1.371
300	1.370	1.369	1.367	1.366	1.365	1.363	1.362	1.360	1.359	1.357
400	1.355	1.354	1.352	1.350	1.348	1.346	1.344	1.342	1.341	1.339
500	1.336	1.334	1.332	1.330	1.328	1.326	1.324	1.322	1.319	1.317
600	1.315	1.313	1.311	1.308	1.306	1.304	1.301	1.299	1.297	1.295
700	1.292	1.290	1.288	1.285	1.283	1.281	1.278	1.276	1.274	1.272
800	1.270	1.267	1.265	1.263	1.261	1.259	1.257	1.255	1.253	1.250
900	1.248	1.247	1.245	1.243	1.241	1.239	1.237	1.235	1.234	1.232
1000	1.230	1.228	1.227	1.225	1.224	1.222	1.220	1.219	1.217	1.216
1100	1.214	1.213	1.212	1.210	1.209	1.207	1.206	1.205	1.203	1.202
1200	1.201	1.199	1.198	1.197	1.195	1.194	1.193	1.192	1.191	1.189
1300	1.188	1.187	1.186	1.185	1.184	1.183	1.182	1.181	1.180	1.179
1400	1.178	1.178	1.177	1.176	1.176	1.175	1.175	1.175	1.175	1.175
1500	1.175									

pH

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
3	0.0	0.930	1.006	1.042	1.073	1.100	1.124	1.147	1.168	1.189
4	1.208	1.226	1.244	1.261	1.278	1.294	1.309	1.325	1.339	1.354
5	1.368	1.382	1.396	1.409	1.422	1.435	1.447	1.460	1.472	1.484
6	1.495	1.507	1.518	1.529	1.540	1.550	1.560	1.568	1.574	1.579
7	1.583	1.585	1.585	1.585	1.584	1.581	1.576	1.571	1.563	1.554
8	1.543	1.531	1.518	1.505	1.492	1.479	1.466	1.452	1.438	1.424
9	1.409	1.395	1.380	1.364	1.349	1.333	1.317	1.300	1.283	1.266
10	1.249	1.231	1.213	1.195	1.176	1.157	1.138	1.119	1.099	1.078
11	1.057	1.034	1.009	0.980	0.943	0.887	0.85	0.79	0.7	0.6
12	0.0									

NO_3-N

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.585	1.583	1.581	1.578	1.576	1.574	1.572	1.570	1.567	1.565
1	1.563	1.560	1.558	1.555	1.553	1.550	1.548	1.545	1.542	1.540
2	1.537	1.534	1.531	1.528	1.525	1.522	1.519	1.516	1.513	1.510
3	1.507	1.503	1.500	1.497	1.493	1.489	1.486	1.482	1.477	1.473
4	1.469	1.465	1.461	1.456	1.452	1.448	1.443	1.439	1.435	1.430
5	1.426	1.422	1.417	1.413	1.408	1.404	1.400	1.395	1.391	1.387
6	1.382	1.378	1.374	1.370	1.366	1.361	1.357	1.354	1.350	1.346
7	1.342	1.339	1.335	1.332	1.329	1.326	1.323	1.320	1.318	1.315
8	1.313	.	.	.	.	.	.	.	.	.

o-PO_4-P

	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	1.585	1.583	1.580	1.577	1.573	1.568	1.562	1.556	1.549	1.541
0.1	1.533	1.524	1.514	1.503	1.493	1.484	1.474	1.464	1.454	1.444
0.2	1.434	1.425	1.415	1.405	1.395	1.386	1.376	1.366	1.357	1.348
0.3	1.338	1.329	1.320	1.312	1.303	1.295	1.286	1.278	1.271	1.263
0.4	1.256	1.249	1.243	1.236	1.230	1.225	1.220	1.215	1.210	1.206
0.5	1.202	1.199	1.196	1.193	1.190	1.187	1.185	1.183	1.181	1.179
0.6	1.178	1.176	1.175	1.173	1.172	1.171	1.170	1.168	1.167	1.166
0.7	1.164	1.163	1.162	1.160	1.159	1.157	1.155	1.153	1.152	1.150
0.8	1.148	1.146	1.144	1.142	1.140	1.138	1.136	1.134	1.132	1.130
0.9	1.128	1.126	1.124	1.123	1.121	1.120	1.119	1.118	1.117	1.116
1.0	1.114	1.112	1.110	1.109	1.107	1.106	1.104	1.103	1.102	1.100
1.1	1.098	1.097	1.095	1.094	1.092	1.090	1.088	1.086	1.084	1.082
1.2	1.080	1.078	1.076	1.074	1.071	1.068	1.066	1.063	1.061	1.059
1.3	1.056	1.053	1.051	1.050	1.049	1.047	1.045	1.044	1.042	1.040

LF	0	10	20	30	40	50	60	70	80	90
0	1.346	1.356	1.363	1.368	1.371	1.373	1.375	1.376	1.377	1.378
100	1.379	1.379	1.380	1.380	1.380	1.380	1.380	1.380	1.380	1.379
200	1.379	1.378	1.378	1.377	1.376	1.375	1.374	1.373	1.372	1.371
300	1.370	1.369	1.367	1.366	1.365	1.363	1.362	1.360	1.359	1.357
400	1.355	1.354	1.352	1.350	1.348	1.346	1.344	1.342	1.341	1.339
500	1.336	1.334	1.332	1.330	1.328	1.326	1.324	1.322	1.319	1.317
600	1.315	1.313	1.311	1.308	1.306	1.304	1.301	1.299	1.297	1.295
700	1.292	1.290	1.288	1.285	1.283	1.281	1.278	1.276	1.274	1.272
800	1.270	1.267	1.265	1.263	1.261	1.259	1.257	1.255	1.253	1.250
900	1.248	1.247	1.245	1.243	1.241	1.239	1.237	1.235	1.234	1.232
1000	1.230	1.228	1.227	1.225	1.224	1.222	1.220	1.219	1.217	1.216
1100	1.214	1.213	1.212	1.210	1.209	1.207	1.206	1.205	1.203	1.202
1200	1.201	1.199	1.198	1.197	1.195	1.194	1.193	1.192	1.191	1.189
1300	1.188	1.187	1.186	1.185	1.184	1.183	1.182	1.181	1.180	1.179
1400	1.178	1.178	1.177	1.176	1.176	1.175	1.175	1.175	1.175	1.175
1500	1.175									

pH	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
3	0.0	0.930	1.006	1.042	1.073	1.100	1.124	1.147	1.168	1.189
4	1.208	1.226	1.244	1.261	1.278	1.294	1.309	1.325	1.339	1.354
5	1.368	1.382	1.396	1.409	1.422	1.435	1.447	1.460	1.472	1.484
6	1.495	1.507	1.518	1.529	1.540	1.550	1.560	1.568	1.574	1.579
7	1.583	1.585	1.585	1.585	1.584	1.581	1.576	1.571	1.563	1.554
8	1.543	1.531	1.518	1.505	1.492	1.479	1.466	1.452	1.438	1.424
9	1.409	1.395	1.380	1.364	1.349	1.333	1.317	1.300	1.283	1.266
10	1.249	1.231	1.213	1.195	1.176	1.157	1.138	1.119	1.099	1.078
11	1.057	1.034	1.009	0.980	0.943	0.887	0.85	0.79 -	0.7	0.6
12	0.0									

NO_3-N	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.585	1.583	1.581	1.578	1.576	1.574	1.572	1.570	1.567	1.565
1	1.563	1.560	1.558	1.555	1.553	1.550	1.548	1.545	1.542	1.540
2	1.537	1.534	1.531	1.528	1.525	1.522	1.519	1.516	1.513	1.510
3	1.507	1.503	1.500	1.497	1.493	1.489	1.486	1.482	1.477	1.473
4	1.469	1.465	1.461	1.456	1.452	1.448	1.443	1.439	1.435	1.430
5	1.426	1.422	1.417	1.413	1.408	1.404	1.400	1.395	1.391	1.387
6	1.382	1.378	1.374	1.370	1.366	1.361	1.357	1.354	1.350	1.346
7	1.342	1.339	1.335	1.332	1.329	1.326	1.323	1.320	1.318	1.315
8	1.313	.	.	.	.	.	.	.	.	.

o-PO_4-P	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	1.585	1.583	1.580	1.577	1.573	1.568	1.562	1.556	1.549	1.541
0.1	1.533	1.524	1.514	1.503	1.493	1.484	1.474	1.464	1.454	1.444
0.2	1.434	1.425	1.415	1.405	1.395	1.386	1.376	1.366	1.357	1.348
0.3	1.338	1.329	1.320	1.312	1.303	1.295	1.286	1.278	1.271	1.263
0.4	1.256	1.249	1.243	1.236	1.230	1.225	1.220	1.215	1.210	1.206
0.5	1.202	1.199	1.196	1.193	1.190	1.187	1.185	1.183	1.181	1.179
0.6	1.178	1.176	1.175	1.173	1.172	1.171	1.170	1.168	1.167	1.166
0.7	1.164	1.163	1.162	1.160	1.159	1.157	1.155	1.153	1.152	1.150
0.8	1.148	1.146	1.144	1.142	1.140	1.138	1.136	1.134	1.132	1.130
0.9	1.128	1.126	1.124	1.123	1.121	1.120	1.119	1.118	1.117	1.116
1.0	1.114	1.112	1.110	1.109	1.107	1.106	1.104	1.103	1.102	1.100
1.1	1.098	1.097	1.095	1.094	1.092	1.090	1.088	1.086	1.084	1.082
1.2	1.080	1.078	1.076	1.074	1.071	1.068	1.066	1.063	1.061	1.059
1.3	1.056	1.053	1.051	1.050	1.049	1.047	1.045	1.044	1.042	1.040

O_2 - S.

	0	1	2	3	4	5	6	7	8	9
0	1.149	1.150	1.152	1.158	1.167	1.181	1.199	1.219	1.241	1.263
10	1.286	1.308	1.330	1.351	1.371	1.391	1.410	1.429	1.446	1.464
20	1.480	1.497	1.513	1.528	1.544	1.559	1.574	1.589	1.604	1.620
30	1.635	1.650	1.666	1.681	1.697	1.713	1.729	1.745	1.762	1.779
40	1.796	1.813	1.830	1.847	1.865	1.882	1.900	1.918	1.935	1.953
50	1.971	1.988	2.006	2.023	2.041	2.058	2.075	2.092	2.109	2.125
60	2.141	2.157	2.173	2.189	2.204	2.219	2.234	2.248	2.262	2.276
70	2.290	2.303	2.315	2.328	2.340	2.351	2.363	2.374	2.384	2.394
80	2.404	2.413	2.422	2.431	2.439	2.447	2.455	2.462	2.469	2.476
90	2.482	2.489	2.495	2.500	2.506	2.512	2.512	2.512	2.512	2.512
100	2.512	2.512	2.512	2.512	2.512	2.512	2.510	2.507	2.505	2.502
110	2.500	2.497	2.494	2.491	2.488	2.485	2.482	2.479	2.475	2.472
120	2.468	2.465	2.461	2.457	2.453	2.449	2.444	2.440	2.436	2.431
130	2.426	2.421	2.417	2.412	2.406	2.401	2.396	2.391	2.386	2.380
140	2.374	2.369	2.363	2.358	2.352	2.346	2.341	2.335	2.329	2.324
150	2.318	2.312	2.307	2.302	2.296	2.291	2.286	2.281	2.276	2.272
160	2.267	2.263	2.259	2.255	2.252	2.249	2.246	2.243	2.241	2.239
170	2.237									

WT

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.445									
10	1.445									
14	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445
15	1.444	1.444	1.444	1.444	1.444	1.444	1.444	1.444	1.443	1.443
16	1.443	1.442	1.442	1.442	1.441	1.441	1.441	1.440	1.440	1.439
17	1.439	1.438	1.438	1.437	1.436	1.436	1.435	1.434	1.433	1.432
18	1.432	1.430	1.429	1.427	1.426	1.424	1.422	1.421	1.419	1.418
19	1.416	1.414	1.412	1.411	1.409	1.407	1.405	1.404	1.402	1.400
20	1.398	1.396	1.394	1.392	1.390	1.388	1.386	1.383	1.381	1.379
21	1.377	1.374	1.372	1.369	1.367	1.364	1.362	1.359	1.356	1.354
22	1.351	1.348	1.345	1.342	1.339	1.335	1.332	1.329	1.325	1.321
23	1.318	1.314	1.310	1.305	1.301	1.297	1.292	1.287	1.282	1.276
24	1.271	1.267	1.263	1.259	1.256	1.252	1.248	1.244	1.240	1.236
25	1.232	1.228	1.223	1.219	1.215	1.211	1.206	1.202	1.198	1.193
26	1.189	1.184	1.180	1.175	1.170	1.166	1.161	1.156	1.151	1.146
27	1.141	1.136	1.131	1.126	1.121	1.116	1.110	1.105	1.100	1.094
28	1.089	1.083	1.077	1.072	1.066	1.060	1.054	1.048	1.042	1.036
29	1.030	1.023	1.017	1.011	1.004	0.998	0.991	0.984	0.977	0.970
30	0.963	0.956	0.949	0.942	0.934	0.926	0.918	0.909	0.901	0.891
31	0.881	0.870	0.857	0.843	0.825	0.802	0.768	0.691		
32	0.0									

BSB_5

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	2.512	2.512	2.512	2.512	2.511	2.511	2.510	2.509	2.507	2.504
1	2.502	2.498	2.495	2.491	2.487	2.482	2.477	2.472	2.466	2.460
2	2.454	2.447	2.440	2.433	2.426	2.418	2.411	2.403	2.394	2.386
3	2.377	2.368	2.359	2.350	2.340	2.330	2.321	2.311	2.300	2.290
4	2.280	2.269	2.258	2.247	2.236	2.225	2.214	2.202	2.191	2.179
5	2.168	2.156	2.144	2.132	2.120	2.108	2.096	2.083	2.071	2.059
6	2.047	2.034	2.022	2.010	1.997	1.985	1.973	1.960	1.948	1.936
7	1.923	1.911	1.899	1.887	1.875	1.863	1.851	1.840	1.828	1.817
8	1.805	1.794	1.783	1.772	1.761	1.750	1.740	1.729	1.719	1.709
9	1.699	1.690	1.680	1.671	1.662	1.653	1.644	1.636	1.628	1.619
10	1.611	1.604	1.596	1.588	1.581	1.574	1.567	1.560	1.553	1.547
11	1.540	1.534	1.527	1.521	1.515	1.509	1.502	1.496	1.490	1.484
12	1.478	1.472	1.466	1.460	1.453	1.447	1.441	1.434	1.428	1.421
13	1.415	1.408	1.402	1.395	1.388	1.381	1.375	1.368	1.361	1.355
14	1.348	1.342	1.336	1.330	1.325	1.320	1.315	1.311	1.308	1.306
15	1.304									

NH_4-N

	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.1	1.995	1.995	1.995	1.984	1.976	1.968	1.960	1.952	1.945	1.938
0.2	1.930	1.923	1.916	1.910	1.903	1.897	1.891	1.884	1.879	1.873
0.3	1.867	1.862	1.857	1.852	1.847	1.843	1.838	1.834	1.830	1.826
0.4	1.822	1.819	1.815	1.812	1.809	1.806	1.803	1.800	1.797	1.795
0.5	1.792	1.790	1.787	1.785	1.782	1.780	1.778	1.776	1.773	1.771
0.6	1.769	1.766	1.764	1.761	1.759	1.756	1.753	1.750	1.747	1.743
0.7	1.740	1.736	1.732	1.727	1.722	1.717	1.712	1.706	1.702	1.701
0.8	1.700	1.699	1.698	1.697	1.696	1.695	1.694	1.693	1.692	1.692
0.9	1.691	1.690	1.689	1.688	1.687	1.686	1.685	1.684	1.683	1.682

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	1.681	1.672	1.663	1.654	1.645	1.636	1.626	1.617	1.608	1.599
2	1.589	1.580	1.571	1.562	1.553	1.544	1.535	1.526	1.517	1.508
3	1.499	1.490	1.481	1.473	1.464	1.456	1.447	1.439	1.431	1.423
4	1.415	1.408	1.400	1.393	1.386	1.380	1.373	1.367	1.361	1.355
5	1.350	1.345	1.340	1.335	1.331	1.327	1.324	1.320	1.317	1.315
6	1.313	1.310	1.307	1.304	1.301	1.298	1.294	1.291	1.288	1.285
7	1.282	1.279	1.277	1.274	1.272	1.269	1.267	1.264	1.262	1.259
8	1.257	1.255	1.253	1.251	1.249	1.247	1.244	1.242	1.240	1.238
9	1.236	.	.	.	.	.	.	.	.	.

O_2 - S.

	0	1	2	3	4	5	6	7	8	9
0	1.149	1.150	1.152	1.158	1.167	1.181	1.199	1.219	1.241	1.263
10	1.286	1.308	1.330	1.351	1.371	1.391	1.410	1.429	1.446	1.464
20	1.480	1.497	1.513	1.528	1.544	1.559	1.574	1.589	1.604	1.620
30	1.635	1.650	1.666	1.681	1.697	1.713	1.729	1.745	1.762	1.779
40	1.796	1 813	1.830	1.847	1.865	1.882	1.900	1.918	1.935	1.953
50	1.971	1.988	2.006	2.023	2.041	2.058	2.075	2.092	2.109	2.125
60	2.141	2.157	2.173	2.189	2.204	2.219	2.234	2.248	2.262	2.276
70	2.290	2.303	2.315	2.328	2.340	2.351	2.363	2.374	2.384	2.394
80	2.404	2.413	2.422	2.431	2.439	2.447	2.455	2.462	2.469	2.476
90	2.482	2.489	2.495	2.500	2.506	2.512	2.512	2.512	2.512	2.512
100	2.512	2.512	2.512	2.512	2.512	2.512	2.510	2.507	2.505	2.502
110	2.500	2.497	2.494	2.491	2.488	2.485	2.482	2.479	2.475	2.472
120	2.468	2.465	2.461	2.457	2.453	2.449	2.444	2.440	2.436	2.431
130	2.426	2.421	2.417	2.412	2.406	2.401	2.396	2.391	2.386	2.380
140	2.374	2.369	2.363	2.358	2.352	2.346	2.341	2.335	2.329	2.324
150	2.318	2.312	2.307	2.302	2.296	2.291	2.286	2.281	2.276	2.272
160	2.267	2.263	2.259	2.255	2.252	2.249	2.246	2.243	2.241	2.239
170	2.237									

WT

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.445									
10	1.445									
14	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445	1.445
15	1.444	1.444	1.444	1.444	1.444	1.444	1.444	1.444	1.443	1.443
16	1.443	1.442	1.442	1.442	1.441	1.441	1.441	1.440	1.440	1.439
17	1.439	1.438	1.438	1.437	1.436	1.436	1.435	1.434	1.433	1.432
18	1.432	1.430	1.429	1.427	1.426	1.424	1.422	1.421	1.419	1.418
19	1.416	1.414	1.412	1.411	1.409	1.407	1.405	1.404	1.402	1.400
20	1.398	1.396	1.394	1.392	1.390	1.388	1.386	1.383	1.381	1.379
21	1.377	1.374	1.372	1.369	1.367	1.364	1.362	1.359	1.356	1.354
22	1.351	1.348	1.345	1.342	1.339	1.335	1.332	1.329	1.325	1.321
23	1.318	1.314	1.310	1.305	1.301	1.297	1.292	1.287	1.282	1.276
24	1.271	1.267	1.263	1.259	1.256	1.252	1.248	1.244	1.240	1.236
25	1.232	1.228	1.223	1.219	1.215	1.211	1.206	1.202	1.198	1.193
26	1.189	1.184	1.180	1.175	1.170	1.166	1.161	1.156	1.151	1.146
27	1.141	1.136	1.131	1.126	1.121	1.116	1.110	1.105	1.100	1.094
28	1.089	1.083	1.077	1.072	1.066	1.060	1.054	1.048	1.042	1.036
29	1.030	1.023	1.017	1.011	1.004	0.998	0.991	0.984	0.977	0.970
30	0.963	0.956	0.949	0.942	0.934	0.926	0.918	0.909	0.901	0.891
31	0.881	0.870	0.857	0.843	0.825	0.802	0.768	0.691		
32	0.0									

BSB_5

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	2.512	2.512	2.512	2.512	2.511	2.511	2.510	2.509	2.507	2.504
1	2.502	2.498	2.495	2.491	2.487	2.482	2.477	2.472	2.466	2.460
2	2.454	2.447	2.440	2.433	2.426	2.418	2.411	2.403	2.394	2.386
3	2.377	2.368	2.359	2.350	2.340	2.330	2.321	2.311	2.300	2.290
4	2.280	2.269	2.258	2.247	2.236	2.225	2.214	2.202	2.191	2.179
5	2.168	2.156	2.144	2.132	2.120	2.108	2.096	2.083	2.071	2.059
6	2.047	2.034	2.022	2.010	1.997	1.985	1.973	1.960	1.948	1.936
7	1.923	1.911	1.899	1.887	1.875	1.863	1.851	1.840	1.828	1.817
8	1.805	1.794	1.783	1.772	1.761	1.750	1.740	1.729	1.719	1.709
9	1.699	1.690	1.680	1.671	1.662	1.653	1.644	1.636	1.628	1.619
10	1.611	1.604	1.596	1.588	1.581	1.574	1.567	1.560	1.553	1.547
11	1.540	1.534	1.527	1.521	1.515	1.509	1.502	1.496	1.490	1.484
12	1.478	1.472	1.466	1.460	1.453	1.447	1.441	1.434	1.428	1.421
13	1.415	1.408	1.402	1.395	1.388	1.381	1.375	1.368	1.361	1.355
14	1.348	1.342	1.336	1.330	1.325	1.320	1.315	1.311	1.308	1.306
15	1.304									

NH_4-N

	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.1	1.995	1.995	1.995	1.984	1.976	1.968	1.960	1.952	1.945	1.938
0.2	1.930	1.923	1.916	1.910	1.903	1.897	1.891	1.884	1.879	1.873
0.3	1.867	1.862	1.857	1.852	1.847	1.843	1.838	1.834	1.830	1.826
0.4	1.822	1.819	1.815	1.812	1.809	1.806	1.803	1.800	1.797	1.795
0.5	1.792	1.790	1.787	1.785	1.782	1.780	1.778	1.776	1.773	1.771
0.6	1.769	1.766	1.764	1.761	1.759	1.756	1.753	1.750	1.747	1.743
0.7	1.740	1.736	1.732	1.727	1.722	1.717	1.712	1.706	1.702	1.701
0.8	1.700	1.699	1.698	1.697	1.696	1.695	1.694	1.693	1.692	1.692
0.9	1.691	1.690	1.689	1.688	1.687	1.686	1.685	1.684	1.683	1.682

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	1.681	1.672	1.663	1.654	1.645	1.636	1.626	1.617	1.608	1.599
2	1.589	1.580	1.571	1.562	1.553	1.544	1.535	1.526	1.517	1.508
3	1.499	1.490	1.481	1.473	1.464	1.456	1.447	1.439	1.431	1.423
4	1.415	1.408	1.400	1.393	1.386	1.380	1.373	1.367	1.361	1.355
5	1.350	1.345	1.340	1.335	1.331	1.327	1.324	1.320	1.317	1.315
6	1.313	1.310	1.307	1.304	1.301	1.298	1.294	1.291	1.288	1.285
7	1.282	1.279	1.277	1.274	1.272	1.269	1.267	1.264	1.262	1.259
8	1.257	1.255	1.253	1.251	1.249	1.247	1.244	1.242	1.240	1.238
9	1.236	.	.	.	.	.	.	.	.	.

Appendix:R Record of the animals and their abundance by sample site

Sample site →	1		2		3		4		5		6		7		8		9		10		11		12	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Tricladida																								
indet. Family						1																		
GASTROPODA																								
Lymnaeidae																								
Radix sp.																							2	
Physidae																								
Physella acuta			3	2	2	2					2	3		1	3	2	2	2	2	2			2	
BIVALVIA																								
Sphaeriidae																								
Pisidium sp.					2	1								1						1				
Sphaerium indicum			2										2				2							
Oligochaeta																								
Lumbricidae/Glossoscolecidae			2	1																				
Tubificidae																								
indet.	4	4					3	4	4	4	3	3				2	2	1				1		
Branchiura sowerbyi				1			2	1	1					1					3	4				2
Limnodrilus hoffmeisteri															2									
Limnodrilus sp.															2									
Limnodrillus profundicola															1									
Limnodrillus undekemianus																								
HIRUDINEA																								
Salifidae																								
Barbronia cf. weberi			2	2	2	1							2	2					2	2				
CRUSTACEA																								
Potamidae																								
indet.					2																			
EPHEMEROPTERA																								
Baetidae																								
Baetis sp.1													2				2					2		
Baetis sp.2			2	2	1									2			2	1					2	2
Baetis sp.3			1			2								2				2					2	
Baetis sp.5			1																					
Caenidae																								
Caenis sp.																							2	
Caenis 1																						1		
Caenis 2					2	2																		
Ephemerellidae																								
Torleya nepalica					2	1															2	2	1	2
Heptageniidae																								
Cinygmina ?assamensis																					1	2	2	2
Electrogena wittmeri					2	2																		1
Leptophlebiidae																								
Euthraulus sp.					2	2								2							2	2		
ODONATA																								
Gomphidae																								
indet.																						2	2	
PLECOPTERA																								
Perlidae																								
? Kamimuria sp.																					2	1		
? Neoperla sp.																						2		
HETEROPTERA																								
Aphelocheiridae																								
Aphelocheirus sp.															2	2							1	
Corixidae																								
Sigara sp.											2				2	1								
Micronectidae																								
Micronecta sp.											2		2											
Nepidae																								
Laccotripus sp.													2											

Appendix:R Record of the animals and their abundance by sample site

Sample site →	1		2		3		4		5		6		7		8		9		10		11		12	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
MEGALOPTERA																								
Corydalidae																								
indet.					2	2																		
COLEOPTERA																								
Hydrophilidae																								
Ametor rugosus														2										
Noteridae																								
Canthydrus sp.									2		2	2												
indet.																								
TRICHOPTERA																								
Glossosomatidae																								
indet.													1								2			
Hydropsychidae																								
cf. Cheumatopsyche sp.																						1		
indet.					2	1							3		1	2	2	2	2	1	3	1	2	
Psychomyiidae														1										
indet.																								
Rhyacophilidae																								
indet.																					2	1		
DIPTERA																								
Chironomidae																								
Chironominae																								
Chironomus sp.	1	2	2	2	2	2	3				1		2	2	3	2	2	2				2		2
Chironomus sp. cf. riparius																								
Cladotanytarsus sp.																		2						
Polypedilum sp.					2								2								2			
Rheotanytarsus group															2									
Orthocladiinae																								
Cricotopus cf. bicinctus																		2	2					
Rheocricotopus cf chalybeatus						2								2				2						
Rheocricotopus sp.																		2						
Tanypodinae																								
Rheopelopia sp.																							1	
Culicinae																								
indet..										2														
Limoniidae																								
indet.					2																			

Appendix:R Record of the animals and their abundance by sample site

Sample site →	13		14		15		16		17		18		19		20		21		22		23		24	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Tricladida																								
indet.			1	2		2																		
GASTROPODA																								
Ancylidae																								
indet.																							2	
Lymnaeidae																								
Radix sp.	2					2																		
Physidae																								
Physella acuta							2	2	2	2							2	2			2	1		
Planorbidae																								
Gyraulus sp.			2		2	1																	3	
BIVALVIA																								
Sphaeriidae																								
Pisidium sp.				1																				
Pisidium atkinsonianum				2																				
Oligochaeta																								
Lumbricidae/Glossoscolecidae																					2	1		
Naididae	2																							
Tubificidae	2	2																			3	3		
Branchiura sowerbyi			2	2																				
Limnodrilus hoffmeisteri				2																				
HIRUDINEA																								
Salifidae																								
Barbronia cf. weberi					2																			
EPHEMEROPTERA																								
Baetidae																								
Baetis sp.1	1		1	2			2		2		2	2	2	1			2						2	2
Baetis sp 2	2	1				1	2		2					2	1	1	1	2	2	2				
Baetis sp.3	2			2	2		2	2	2						2		2	2	2	2				
Baetis sp.4																							2	1
Baetis sp.5					2			2	1			1	1											
Baetiella ausobskyi																							1	
Centroptilum sp.											2			2										
Caenidae																								
Caenis sp.										3				2	2									2
Caenis 1																								1
Caenis 2				2		1																		
Ephemerellidae																								
Cincticostella ?levanidovae							2																	
Drunella serrata			1																					
Drunella uneoi																							1	
Torleya nepalica			3	2		3					3	1	2		2	2			3	2				2
Heptageniidae																								
Electrogena wittmeri			2																					
Epeorus bispinosus			1																					
Iron psi							2																	
Cinygmina ?assamensis			2	2	2	2						2	2	1										

Appendix:F Record of the animals and their abundance by sample site

Sample site →	13		14		15		16		17		18		19		20		21		22		23		24
Sampling season →	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
Animals ↓																							
Notacanthurus cristatus																							1
Leptophlebiidae																							
Euthraulus sp.				2				2									2	1					
ODONATA																							
Cordulidae																							
indet.																			2				2
Gomphidae																							
indet.			3	2		1							3	2			2	1	2	2			
Libellulidae																							
indet.																							
PLECOPTERA																							
Nemouridae																							
Amphinemura sp.											2							2					
Perlidae																							
? Neoperla				2	1	2						2	2	2			2	2					
HETEROPTERA																							
Aphelocheiridae																							
Aphelocheirus sp 1					2	2					1	2	2	2	2								2
Aphelocheirus sp 2					1																		
Corixidae																							
Sigara sp.	2																			2	2		
Gerridae																							
Neogaris parvulus Stal	2																						
Micronectidae																							
Micronecta sp.																					2		
Naucoridae																							
Laccocoris sp.											2	2											
COLEOPTERA																							
Dytiscidae																							
Hydaticus sp.							2																
indet.																	2	2					
Nebrioporus sp.											2	2						2					
ELMIDAE																							
Grouvelinus sp.			2	2								2											
GYRINIDAE																							
indet.			2	1																			
Hydrophilidae																							
Laccobius	1																						
Noteridae																							
Canthydrus sp.							1								1	2		2	2	1			
Psephenidae																							
Eubrinae											2												2

Sample site →	13		14		15		16		17		18		19		20		21		22		23		24	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
MEGALOPTERA																								
Corydalidae																								
indet.			2		2																			
TRICHOPTERA																								
Glossosomatidae																								
indet.			1								1		1						1	1				
Hydropsychidae																								
cf. Cheumatopsyche sp.																								
indet.	1		1	2	2	2			2		2	2	2	2	1	1	2		2	2			2	
Lepidostomatidae																								
indet.				1							1													
Rhyacophilidae																								
indet.			2	1																				
DIPTERA																								
Chironomidae																								
Chironominae																				2	2	2	2	2
Chironomus sp.	2	3					3	4		2	2													
Microtendipes Chloris group				1																				
Polypedium cf. convictum		1									1				1	1								
Polypedilum sp.	2																							
Rheotanytarsus group																								
Orthocladiinae																			1	2				
Brillia sp.																								
Cricotopus cf. bicinctus																								
Cricotopus sp.																								
Eukiefferiella sp.					2																			
Orthocladius (orthocladius) sp.										2														2
Rheocricotopus cf chalybeatus																							2	
Rheocricotopus sp.																								
Tanypodinae																								
Clinotanypus																							1	1
indet.																			1	1				
Thienemannimyia group																								
Limoniidae																								
indet.																		1						
Simuliidae																								
indet.													1	2	3	2	2	2	2	2			2	2
Syrphidae																								
Eristalis sp.	2																							
Tabanidae																								
indet.			2										2	2										
Tipulidae																								
indet.			1									1												

Note : Two new species of Aphelocheirus are recorded and they are *Aphelocheirus sp. 1* and *Aphelocheirus sp. 2.* These two species are given name by expert as *Aphelocheirus nepalensis* for *A. sp.1* and *Aphelocheirus pradhanensis* for *A. sp.2.*

Appendix:F Record of the animals and their abundance by sample site

Sample site →	25		26		27		28		29		30		31		32		33		34		35	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Tricladida											2											
indet.																						
GASTROPODA																						
Lymnaeidae														2								
Radix sp.																						
Planorbidae														2								
Gyraulus sp.																						
BIVALVIA																						
Sphaeriidae																						
Pisidium atkinsonianum									2	2												
Oligochaeta																			3	3	1	
Lubricidae/Glossoscolecidae					2																	
Naididae																						
indet			2																			
Tubificidae																						
Limnodrillus hoffmeisteri			2																			
Limnodrilus profundicolata			2																			
HIRUDINEA																						
Salifidae															1						2	2
Barbronia sp.			2																			
Barbronia cf. weberi	2	2																				
EPHEMEROPTERA																						
Baetidae															2							
Baetiella ausobskyi															1							
Baetilla ?muchei													1									
Baetiella marginata											2	3	3		2	2	3	2	2	2	2	2
Baetis sp.2	2				2	2	2	2								2		2	2	2	1	
Baetis sp.2		1			1	1								1		1			1			
Baetis sp.3												2			2							
Baetis sp.4												1		5					1			
Baetis sp.5																						
Centroptilum sp.						1					1											
Cloeodes sp.																						
Caenidae																						
Caenis sp.																			1	1		
Caenis 1									1	2												
Caenis 2										1												
Ephemerellidae																						
Cincticostella ? levanidovae									2	2						2						1
Drunella ? submontata							1	1	1													
Drunella uenoi									1	1	2											
Ephemerella sp.												2		2					1			
Torleya nepalica									1			1										1
Serratella sp.										1												
Ephemeridae																						
indet.										1												

Sample site →	25		26		27		28		29		30		31		32		33		34		35	
Sampling season → **Animals ↓**	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Ephemera sp.									1	2												
Heptageniidae																			1	1		
Cinygmina ?assamensis					1	2		1							2		2		2	2		
Electrogena wittmeri	2	2													1	1			2	2	1	1
Epeorus bispinosus			1	2				1	1	2						2						
Epeorus rhithralis											2	2			1	2						2
Iron psi					1										1							1
Notacanthurus cristatus	2	2						1														
Leptophlebiidae												2										
Euthraulus sp.					1	2		1	1	1												
ODONATA																						
Cordulegastridae																2						2
indet.										2												
Gomphidae											1			1		1						
Synlestidae																						
indet.							1	2														
indet.								2	2	2												
PLECOPTERA																						
Capniidae																						
indet.			2	1	1	1																
Capniidae/Leuctridae																						
indet.						1																
Nemouridae																						
Amphinemora sp.			2		2	2		1														
Nemoura sp.				1																		
Perlidae												1		2	2						2	2
? Kamimuria											1			2	1							
? Neoperla								2								2					1	
? Phanoperla															1	2					2	
? Togoperla																						
HETEROPTERA																						
Aphelocheiridae															1							
Aphelocheirus								2							1							
Hebridae								2														
COLEOPTERA																						
Dytiscidae																2			2	2		
Nebrioporus sp.	1	2						2														
ELMIDAE															2	2	2	2	2	2	2	2
Grouvellinus sp.					2	1	2	2	1	2												
indet.																					1	
Stenelmis sp.																						
Eulichadidae																					1	2
Eulichus sp.																						
GYRINIDAE																			1		1	
indet.																						
Hydrophilidae																					2	
Ametor rugosus																						
Pelthydrus sp.							1															
Psephenidae																						
Eubriinae																						
indet Genus													2								2	

Sample site →	25		26		27		28		29		30		31		32		33		34		35	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Eubrianax sp.																						
indet.									1	2												
Scirtidae (Helotidae)																						
indet.								1														
MEGALOPTERA																						
Corydalidae											1			1							2	2
indet.									2	2												
TRICHOPTERA																						
Glossosomatidae											2	2				2					2	1
indet.																						
Hydrobiosidae													1									
indet.																						
Hydropsychidae																						
cf. Cheumatopsyche								1			2		2	2	1		3	2	1	1	2	1
indet.	3	2				2	3	2														
Lepidostomatidae																			2	2		2
indet.			2	2	1	1		1	1	2												
Limnephilidae																2					2	
indet.																						
Philopotamidae															2							
indet.																						
cf. Wormaldia								2	2	1											1	
Chimerra sp.								2														
Polycentropodidae															1							
indet.							2															
Psychomyiidae																	2		1	2		
indet.																						
Rhyacophilidae																					1	2
indet.							2		1	2												
Stenopsychidae																						2
indet.								2	1	2									2	2		2
DIPTERA																						
Athericidae															1							
Atherix sp.									2	2						1			2		2	2
indet.			2	2	2		1	2														
Chironomidae														2								
Chironominae														2								
Chironomus sp.	3	3											1									
Cryptochironomus sp.														1								1
indet.																			1	1	1	
Microtendipes sp.																	2	2				
Polypedilum sp.																						
Orthocladiinae															1							
Eukiefferiella devonica group																						1
Eukiefferiella sp.									1	1												
indet.											1											

Sample site →	25		26		27		28		29		30		31		32		33		34		35	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Orthocladius (Euorthocladis) cf. rivulorum													1									
Orthocladius (orthocladius) sp.																						
Tanypodinae																						
Clinotanypus sp.									1	2				1								
Thienemannimyia group																						
Tvetenia cf. calvescens					1										1							
Tvetenia discoloripes gr.											1											
Limoniidae											2		1									
Cf. Dicranot												1							1	1		
indet.			1	1																		
Simuliidae													1	1	1	1			1	1		1
indet.					2	1			1	1												
Tabanidae																1	2	2	2	2	1	1
indet.							1	2														
Tipulidae											1	1									2	1
indet.			1	2																		

Appendix:R Record of the animals and their abundance by sample site

Sample site →	36		37		38		39		40		41		42		43		44		45		46
Sampling season →	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
Animals ↓																					
Tricladida						2				2											1
GASTROPODA																					
Hydrobiidae																					
? Tricula sp.					2																
Lymnaeidae																					
Radix sp.										2											
Physidae																					
Physella acuta											2	3	2	2	3	2	1	3	1	3	1
Planorbidae																					
Gyraulus sp.			3	2						1											1
Sphaeriidae																					
Pisidium atkinsonianum			2																		
P. kuiperi					1																
Sphaerium sp.			1																		
S. indicum					2																
OLIGOCHAETA																					
Lumbricidae/Glossoscolecid											2	2	2	1	1	2	2		1		
ae															2	2	2	2	2	4	
Tubificidae																					
Branchiura sowerbyi											2		3						1		
Limnodrilus hoffmeisteri											3	3	3	3	1		2	2			
Limnodrilus udekemianus											1										
HIRUDINEA																					
Salifidae																					
Barbronia cf. weberi																			1		
CRUSTACEA																					
Potamidae																					
indet.			2	2																	
EPHEMEROPTERA																					
Baetidae																					
Baetis sp.1					2	1				2											1
Baetis sp.2						2			2		2										
Baetis sp.3					1														1		
Baetis sp.4										1											
Centroptilum sp.			2	1																	
Cloeodes sp.																					1
Caenidae																					
Caenis sp.						1															
Caenis 1								1													2
Caenis 2						2															
Ephemerellidae																					
Torleya nepalica					2				2										1		
Ephemeridae																					
Ephemera sp.			1	2		1															2
Heptageniidae																					

Sample site →	36		37		38		39		40		41		42		43		44		45		46
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
Cinygmina lassamensis						2															
Electrogena wittmeri																					2
Epeorus bispinosus									2												
Iron psi									2												
Notacanthurus cristatus			2	2	2	2															
Leptophlebiidae																					
Euthraulus sp.																			2		2
Habrophlebiodes sp.																					
ODONATA																					
Coenagrionidae																					
indet.			2	2																	
Corduliidae																					
indet.			2	2																	
Cordulegastridae																					
indet.									2	2											
Corydalidae																					
Corydalus sp.									1												
Euphaeidae																					
indet.					2																
Gomphidae																					
indet.						2			2	2					2				2		
Libellulidae																					
indet.			2	2											2						
Synlestidae																					
indet.									1												
PLECOPTERA																					
Nemouridae																					
Amphinemura sp.									1												
Nemoura sp.																					2
Perlidae																					
? Kamimuria																					2
? Neoperla					2	2				2											
COLEOPTERA																					
Dytiscidae																					
Hydaticus sp.			2	2																	
Hydrovatus sp.											1	2									
indet.													2	2							
Laccophilus sp.											2	2									
Nebrioporus sp.										2					1						
ELMIDAE																					
Graucellinus sp.					2					2											
GYRINIDAE																					
indet.																					2
Hydrophilidae																					
indet.						1					2										
Noteridae																					
Canthydrus sp.			2	2							2										
Psephenidae																					
Eubriinae					2																

Sample site →	36		37		38		39		40		41		42		43		44		45		46
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
MEGALOPTERA																					
Corydalidae																					
indet.					2				2												
TRICHOPTERA																					
Glossosomatidae																					
indet.																					2
Hydropsychidae																					
cf. Cheumatopsyche sp.					1																
indet.					3	2			2										2		2
Lepidostomatidae																					
indet.										2											
Limnephilidae																					
indet.						2															
Philopotamidae																					
indet.																					
DIPTERA																					
Athericidae																					
Atherix sp.																					1
indet.					1	1															
Chironomidae																					
Chironominae																					
Chironomus sp.			1								2	3	3	3			3		2		
Cryptochironomus sp.											2								2		2
Polypedilum sp.			1																		
Tanypodinae																					
Clinotanypus			1	1																	
indet.																					
Macropelopia sp.											2	3									
Rheopelopia											2	2									2
Thienemannimyia group									2												
Culicidae																					
indet.											2	2	2	2				2	3		
Ephidridae																					
indet.																		3			
Simuliidae																					
indet.					3	3															2
Syrphidae																					
Eristalis sp.																		3			
Tabanidae																					
indet.						2															
Tipulidae																					
indet.									2												

Appendix:F Record of the animals and their abundance by sample site

Sample site →	47		48		49		50		51		52		53		54		55		56		57	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Tricladida																						
indet.	2																					
GASTROPODA																						
Lymnaeidae																						
Radix sp.				2									2									
Physidae																						
Physella acuta			2	2	2	1	2	1				1						2		2		
Planorbidae													2	2								
Gyraulus sp.																						
Bivalvia																						
Sphaeriidae																						
Pisidium sp.				2	2	2																
Sphaeridium indicum			2																			
OLIGOCHAETA																						
Lumbricidae/Glossoscolecidae	2	2			2	1		1	1								2		2		2	3
Tubificidae	1	2	2		2	2	5	4	4		2	3	3	2	2		3	4	3	4	4	3
indet.					2								2		1							
Limnodrillus hoffmeisteri			2	2											3	3	2	2	2			
Limnodrilus sp.	1																					
L. undekemianus															1	2	1	1	1			
Branchura sowerbyi			2														1	2	2			
HIRUDINEA																						
Salifidae																						
Barbronia cf. weberi			2	2	1	1																
CRUSTACEA																						
Potamidae																						
indet.	1	2																				
EPHEMEROPTERA																						
Baetidae																						
Baetis sp.2	2	2																				
Baetis sp.2	2	3	2		2	2			2	2	1		1									
Baetis sp.3	1			2	2				2	1	1	1	1									
Baetis sp.5		1									2											
Platybaetis uenoi	2																					
Caenidae																						
indet.																						
Caenis sp.	2																					
Caenis 1		2																				
Ephemerellidae																						
Torleya nepalica	2	2																				
Heptageniidae																						
Cinygmina ? assamensis	2	2																				
Electrogena apicata	2																					
Electrogena wittmeri	2	2										2										
Epeorus bispinosus			2																			
Iron psi			2																			
Notacanthurus cristatus	2	1																				

Sample site →	47		48		49		50		51		52		53		54		55		56		57	
Sampling season → **Animals ↓**	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Leptophlebiidae																						
Euthraulus sp.	2								2	2												
ODONATA																						
Corduliidae																						
indet.			2																			
Gomphidae	2						1		1				2								3	
PLECOPTERA																						
Nemouridae																						
Nemoura sp.	1																					
Perlidae			1																			
? Kamimuria	2																					
? Neoperla		1																				
? Phanoperla	1																					
HETEROPTERA																						
Aphelocheiridae																						
Aphelocheirus sp. 1			2						1													
Corixidae																						
Sigara sp.			1	1	2	2							2									
Gerridae											2											
Limnogorus sp.																						
Neogaris parvulus Stal																						
Micronectidae																						
Micronecta sp.													2									
Naucoridae																						
Laccocoris sp.													2									
Nepidae																						
Laccotripus sp.											1											
COLEOPTERA																						
Dytiscidae																						
Hydaticus sp.			2																			
indet.			2								2		2	2								
Nebrioporus sp.												2										
GYRINIDAE																						
indet.	2		2																			
Hydrophilidae																						
Ametor rugosus													2									
Pelthydrus sp.									2	2												
MEGALOPTERA																						
Corydalidae																						
indet.			2																			
TRICHOPTERA																						
Glossosomatidae																						
indet.	2	2																				
Hydrobiosidae																						
indet.	2																					
Hydropsychidae																						
cf. *Cheumatopsyche sp.*		1																				
indet.	2	2	3	2	2	3			1	2												

Sample site →	47		48		49		50		51		52		53		54		55		56		57	
Sampling season → Animals ↓	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Lepidostomatidae																						
indet.		2																				
Limnephilidae																						
indet.	2	1																				
Philopotamidae	1																					
indet.																						
DIPTERA																						
Chironomidae																						
Chironominae																						
Chironomus sp.		2		2	3	3	4	3	3		3	3	4		3		3		2			
Chironomus sp. cf. riparius																						
Cladotanytarsus sp.																						
Cryptochironomus sp.		2																				
Microtendipes chloris group		2																				
Polypedium cf. convictum																						
Polypedilum sp.	2																					
Rheotanytarsus group			2																			
Tanytarsus		2																				
Diamesinae																						
Diamesinae Type 1																						
Orthocladiinae																						
Eukiefferiella sp.																						
indet.																						
Orthocladius (Euorthocladis) cf. rivulorum												1										
Culicidae																						
indet.													2			2						
Empididae																						
indet.			3																			
Limoniidae																						
Cf. Dicranot																						
indet.												2										
Simuliidae																						
indet.					3	2			2	2												
Syrphidae																						
Eristalis sp.											2	2				2						
indet.																						
Tabanidae																						
indet.			2									2	1									
Tipulidae																						
indet.			1								2		1									

Appendix:F Record of the animals and their abundance by sample site

Sample site →	58		59		60		61		62		63		64		65		66		67		68	
Sampling season →	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Animals ↓																						
GASTROPODA																						
Physidae																						
Physella acuta	2	2	2	2	1	1	2	2	2	3	1	2		2	2	2						
Planorbidae																					1	1
Gyraulus sp.																						
Bivalvia																						
Sphaeriidae																						
Pisidium sp.									2	3			1									
OLIGOCHAETA																						
Lumbricidae/Glossoscolecidae																						
Tubificidae																						
indet.	4	3	4	4	3	3	4	3	3	3		4	4	3	4	4						
Branchiura sowerbyi										3												
Limnodrilus hoffmeisteri			1						2		4											
EPHEMEROPTERA																						
Baetidae																						
Baetis sp1																	1	2	1	1	2	2
Baetis sp2													2									
Baetis sp3																	2	2	2	2	2	3
Caenidae																						
Caenis sp.																			2	2		
Ephemerellidae																						
Torleya nepalica																			2			
Ephemeridae																						
Ephemerella sp.																			2			
Heptageniidae																						
Cinygmina ?assmensis																			2			
Electrogena wittmeri																	1					
Epeorus bispinosus																	1	1				
Iron psi																						
Leptophlebiidae																						
? Euthraulus sp.					2	2							2	2	2				2	2	2	3
ODONATA																						
Coenagrionidae																						
indet.		1			1																	
Gomphidae																						
indet.						2	2	2			2		2	2	2	2						
Libellulidae																						
indet.																						
PLECOPTERA																						
Nemouridae																						
Nemoura sp.																	2	1				

Sample site →	58		59		60		61		62		63		64		65		66		67		68	
Sampling season →	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Animals ↓																						
Perlidae																						
indet.																						
? Kamimuria																	1	1	2	2	1	
HETEROPTERA																						
Aphelocheiridae																						
Aphelocheirus sp 1																	1	1	1	1	2	2
Aphelocheirus sp 2																					1	1
Corixidae																						
Sigara sp.	2		2	2	2								2	2	3	2						
Micronectidae																						
Micronecta sp.			2		2									2			2	1				
Naucoridae																						
indet.																				1		
Laccocoris sp.																			1			
COLEOPTERA																						
Dytiscidae																						
Laccophilus sp.																			1			
Nebrioporus sp.			2										2	3	3	2				2	2	2
ELMIDAE																						
Grouvellinus sp.																	2	2				
GYRINIDAE																						
indet.																	2	2				
Hydrophilidae																						
Laccobius sp.																			2			
Pelthydrus sp.																						
Indet.			2																			
Psephenidae																						
Eubriinae																						
Eubrianax sp.																	2	2				
TRICHOPTERA																						
Brachycentridae																						
indet.																	2	2				
Glossosomatidae																						
indet.																	2	2				
Hydrobiosidae																						
indet.																	2					
Hydropsychidae																						
cf. Cheumatopsyche																						
indet.													3	3			2	2	3	3	2	2
Lepidostomatidae																						
indet.																	2	2	2			
DIPTERA																						
Ceratopogonidae																						
indet.																					2	
Chironomidae																						
Chironominae																						
Chironomus sp.	2	2	3	2	3	4	3	2	3	3	3	4			2	3	3			2	1	
Chironomus sp. Cf. Riparius																					1	
Cladotanytarsus sp.																						
Cryptochironomus sp.																			1			
indet.																						

Sample site →	58		59		60		61		62		63		64		65		66		67		68	
Sampling season → **Animals ↓**	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Microtendipes sp.																						
Microtendipes chloris group																			1			
Polypedium cf. Convictum													1	2	1							
Polypedilum scalanon gr.																						
Polypedilum sp.																	1	1				
Rheotanytarsus group													1	2								
Tanytarsus sp.																						
Diamesinae																						
Diamesinae Type 1																	1	2				
Orthocladiinae																						
Brillia sp.											1											
Cricotopus cf. Bicinctus				1																	2	
Cricotopus sp.																						
Eukiefferiella devonica group									1													
Eukiefferiella sp.																	2					
indet.																	2	2				
Orthocladius (Euorthocladis) cf. Rivulorum																	2	2				
Orthocladius (Euorthocladis) cf. Rivicola gr																	2					
Orthocladius (orthocladius) sp.																	1	1				
Paratrichocladius sp.																	1					
Rheocricotopus cf chalybeatus																	2	2			2	
Rheocricotopus sp.																		1				
Tanypodinae																						
Clinotanypus																	1					
indet.																			2			
Macropelopia sp.																2						
Procladius sp.											2									2		
Rheopelopia sp					2										2							
Thienemanniella group																		2				
Tvetenia cf. Calvescens																			2			
Tvetenia cf. Verralli calvescentipes group								2							2							
Zavrelimyia sp.							2														2	
Culicidae																						
indet.															2							
Limoniidae																						
Cf. Dicranot														2								
indet.																	2	2		1		
Simuliidae																						
indet.									3								2	2	3	2	3	3
Syrphidae																						
Eristalis sp.															3	2						
indet.																						
Tabanidae																						
indet.									2						2		1					
Tipulidae																						
indet.																	1	1	2	2	3	2

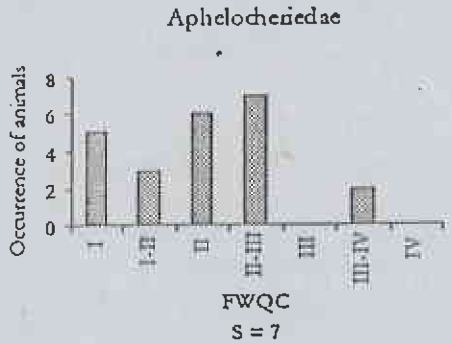
Appendix:R Relative abundance of each individual animal by sample site and season

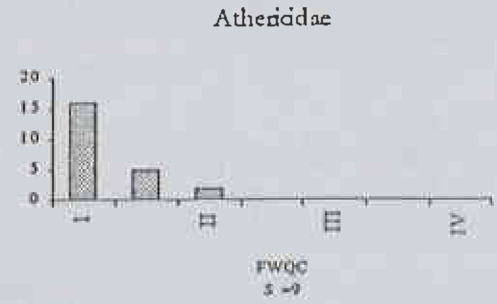
Sample site →	69		70		71		72		73		74		75		76		77		78		79	
Sampling season →	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Animals ↓																						
Tricladida																						
indet.																			2	2		
GASTROPODA																						
Ancylidae																						
indet.																						
Hydrobiidae																						
? Tricula sp.																						
Lymnaeidae																						
Radix sp.					2	2																
Physidae																						
Physella acuta	2	2															3	3				
Planorbidae																						
Gyraulus sp.					4	3																
Bivalvia																						
Sphaeriidae																						
Pisidium sp.																	1	1				
Sphaerium indicum																						
OLIGOCHAETA																						
Lumbricidae																						
indet.																	1	1		1		
Tubificidae																						
indet.																	5	2				
HIRUDINEA																						
Glossiphoniidae																						
indet																			1	2		
Salifidae																						
Barbronia sp.															2	1						
Barbronia cf. Weberi																	1	1				
CRUSTACEA																						
Potamidae																						
indet.			1																			
EPHEMEROPTERA																						
Baetidae																						
Baetiella sp.																			2			
Baetis sp.1			2	1			1		1				1		2					1	1	1
Baetis sp.2	2		1	1		1	1		2		1		1						2			
Baetis sp.3		1	1	1																		
Baetis sp. 4																			1	2		
Baetis sp. 5									3													
Centroptilum sp.																					1	1
Caenidae																						
Caenis sp.							1												2			
Caenis sp.1			1	2																		1
Ephemerellidae																						
Drunella ?submontana																					2	1
Tarleya nepalica	2		1	2													1		2			
Ephemeridae																						
indet.																			3	2		
Heptageniidae																						
Cinygmina ?assamensis			3	2									2							1		1
Epeorus bispinosus																				2	2	
Iron ?paraguttatus					1	2																
Iron psi																						
Notacanthurus cristatus			1	2			3		3										2	2		
Leptophlebiidae																						

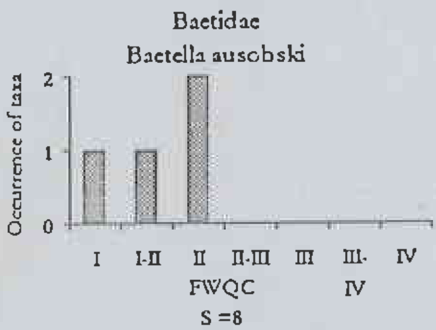
Sample site →	69		70		71		72		73		74		75		76		77		78		79	
Sampling season →	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Animals ↓																						
Euthraulus sp.	2		2	1			3	1			2									2		
Habrophlebiodes sp.																			2	2	1	1
ODONATA																						
Corduliidae																						
indet.							1															
Cordulegastridae																						
indet.																				1		
Euphaeidae																						
indet.																					1	1
Gomphidae																						
indet.		2	1	2							2				2	3		2	1	3		1
Libellulidae																						
indet.	2										2											
PLECOPTERA																						
Capniidae																						
indet.																					2	1
Nemouridae																						
Amphinemura sp.																			2	2	1	2
Nemoura sp.									2										2	3		
Perlidae																						
? Kamimuria																			1			
? Neoperla			1	1			2															
HETEROPTERA																						
Aphelocheiridae																						
Aphelocheirus sp.1																						
Aphelocheirus sp.2																			1		2	1
Corixidae																						
Sigara sp.																	2	1				
Micronectidae																						
Micronecta sp.															2	2						
MEGALOPTERA																						
Corydalidae																						
indet.																			1	1		
COLEOPTERA																						
Dytiscidae																						
Hydaticus sp.															2							
ELMIDAE																						
Grouvellinus sp.			1												2	2			3	2		2
indet.																						
Stenelmis sp.			1																		1	
Psephenidae																						
Eubriinae																						
Eubrianax																			2	2		
TRICHOPTERA																						
Glossosomatidae																						
indet.			1																		1	1
Hydrobiosidae																						
indet.									1													
Hydropsychidae																						
cf. Cheumatopsyche																						
indet.			2	2			3		3						3		2		2	2	1	1
Lepidostomatidae																						
indet.			2	1			2								2						2	2
Limnephilidae																						
indet.			1																			

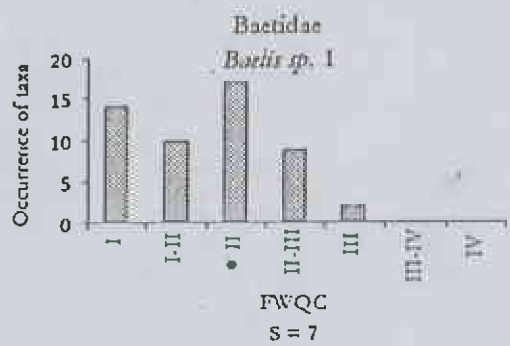
Sample site →	69		70		71		72		73		74		75		76		77		78		79	
Sampling season →	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR
Animals ↓																						
Philopotamidae																						
indet.																						1
Polycentropodidae																						
Plectrocnemia sp.															1							
indet.															2				2	1	2	
Psychomyiidae																						
indet.																					1	
Rhyacophilidae																						
indet.																2			2		2	1
Stenopsychidae																						
indet.																					2	1
Uenoidae																						
indet.																					1	2
DEPTERA																						
Athericidae																						
Atherix sp.																				2		
? Atrichops crassipes															1	1					2	1
Ceratopogonidae																						
indet.	1																		2			
Chironomidae																						
Chironominae																						
Chironomus sp.	2	3	1										1				2	2				
Cryptochironomus sp.																				1		
Polypedium cf. convictum			1			1																
Polypedium scalaenum gr.			1																			
Polypedilum sp.			1			1																
Rheotanytarsus sp.															1	1						
Tanytarsus sp.																						
Diamesinae																						
Diamesinae Type 1																						1
Diamesa cinerella gr./ zernyi gr.			1												1	1						
Orthocladiinae																						
Rheocricotopus cf. chalybeatus			1																			
Tanypodinae																						
Clinotanypus sp.																						
indet.				1		1																
Macropelopia sp.				1			1															
Rheopelopia sp.																						
Thienemannimyia group				1																		
Limoniidae																						
Cf. Dicranota							1															
indet.															1	2			2		1	1
Psychodidae																						
indet.															2	2						
Simuliidae																						
indet.			2	3					2		3		2		1	1						1
Syrphidae																						
Eristalis sp.																	1	1				
indet.																						
Tabanidae																						
indet.							1								2	2		2	3			
Tipulidae																						
indet.															2					1	1	1

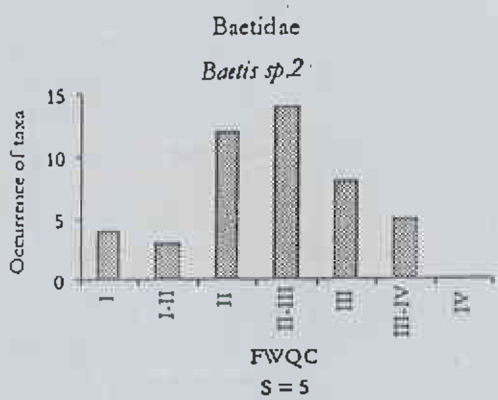
Appendix S: Occurrence of some of the taxa by water quality class and their scores

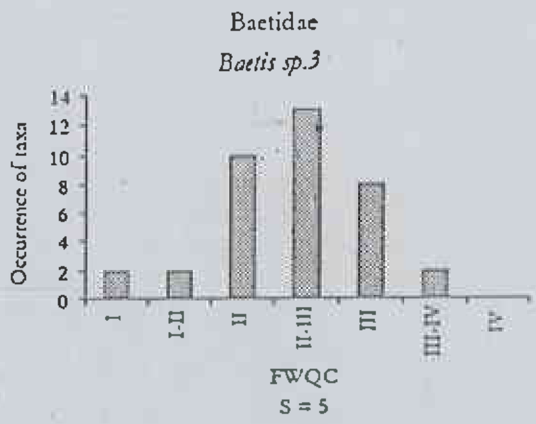


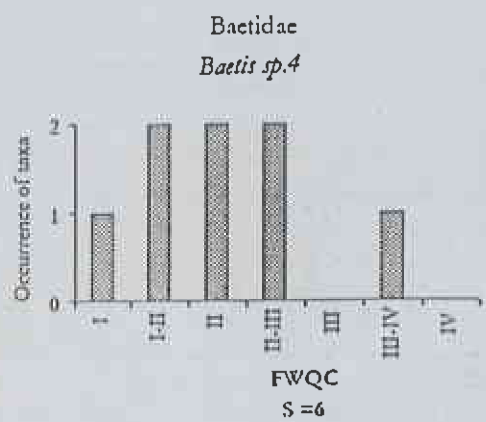


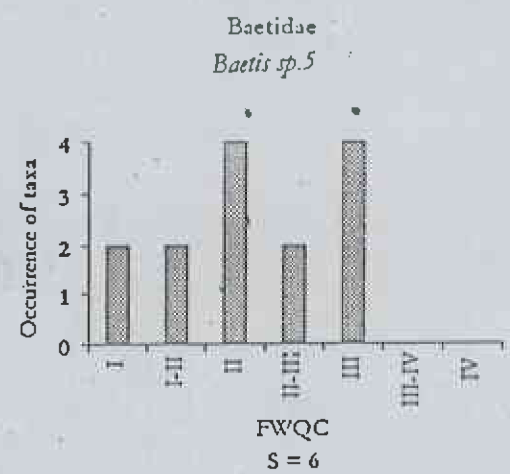


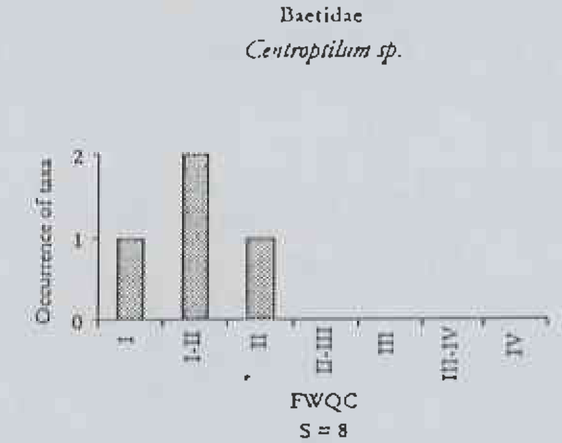


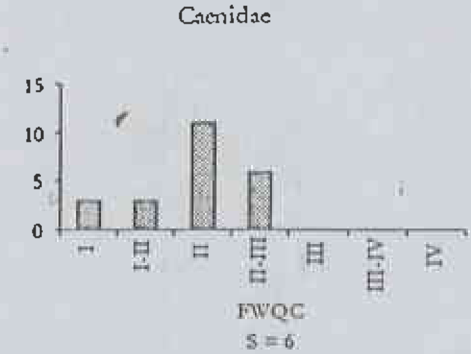


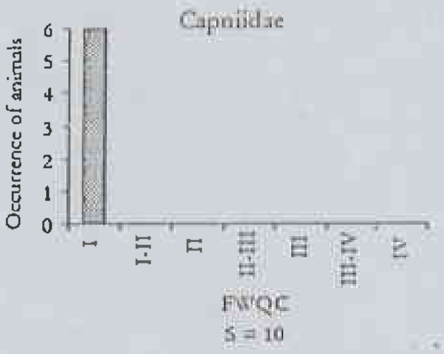


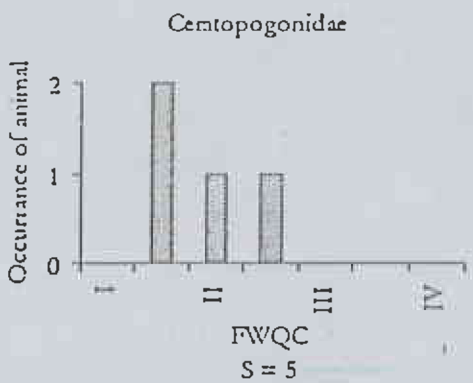


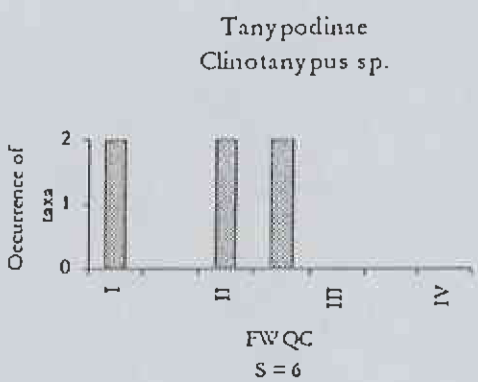


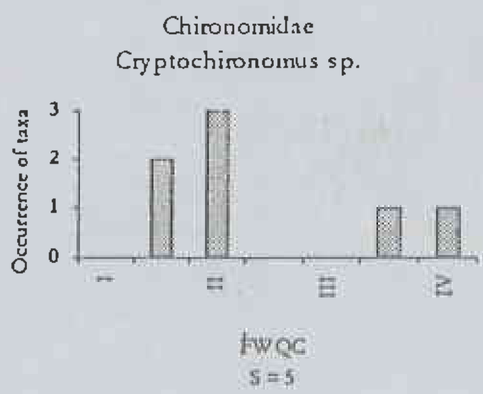

Baetidae
Centroptilum sp.
Occurrence of taxa
FWQC
S = 8

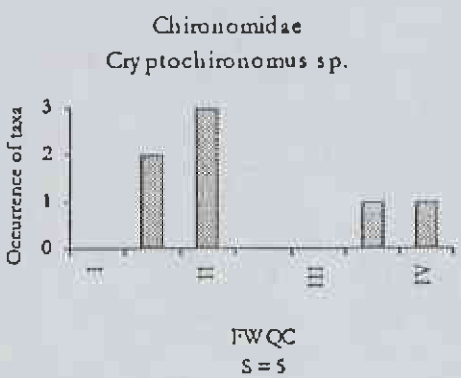

Caenidae
FWQC
S = 6

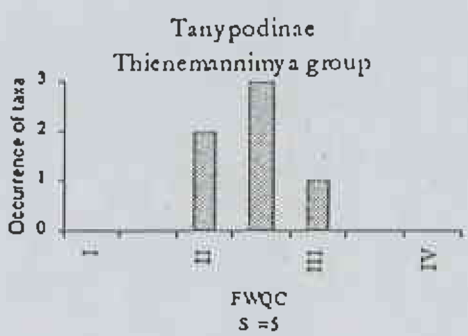

Capniidae
Occurrence of animals
FWQC
S = 10

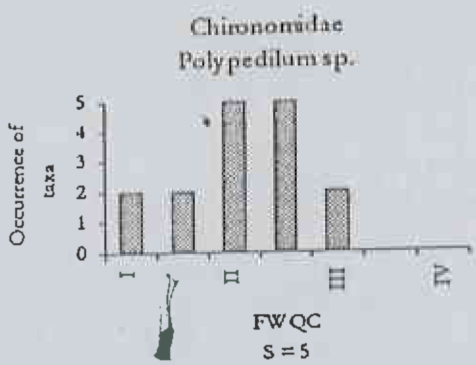

Cerntopogonidae
Occurance of animal
FWQC
S = 5

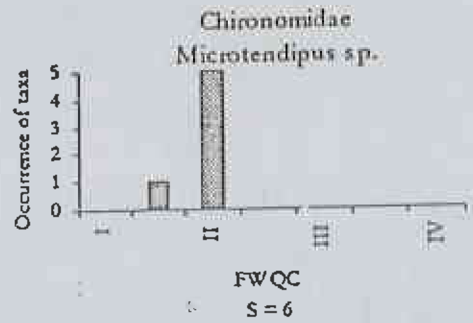

Tanypodinae
Clinotanypus sp.
Occurrence of taxa
FWQC
S = 6

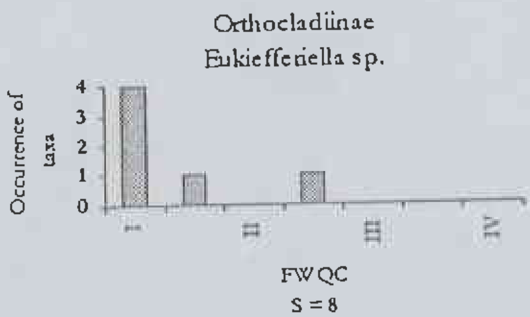

Chironomidae
Cryptochironomus sp.
Occurrence of taxa
FWQC
S = 5

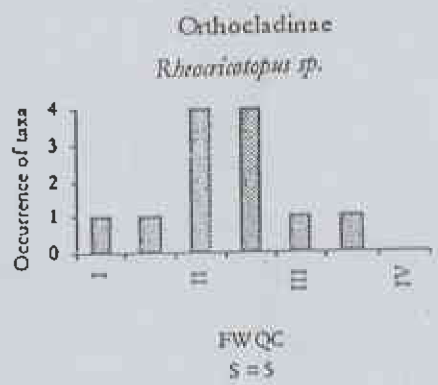

Chironomidae
Cryptochironomus sp.
Occurrence of taxa
FWQC
S = 5

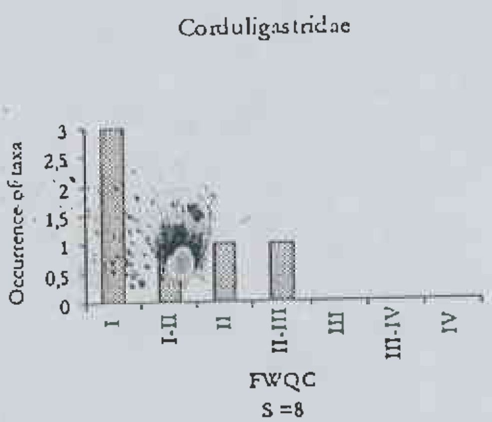

Tanypodinae
Thienemannimya group
Occurrence of taxa
FWQC
S =5

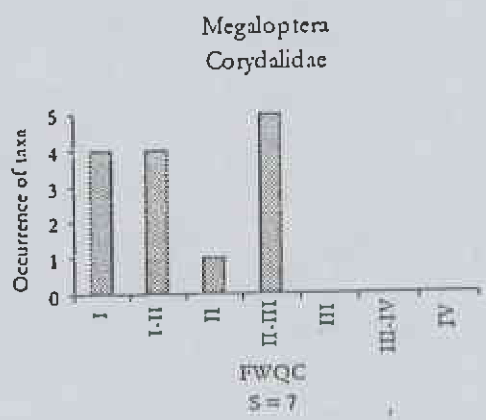

Chironomidae
Polypedilum sp.
Occurrence of taxa
I
II
III
IV
FWQC
S = 5

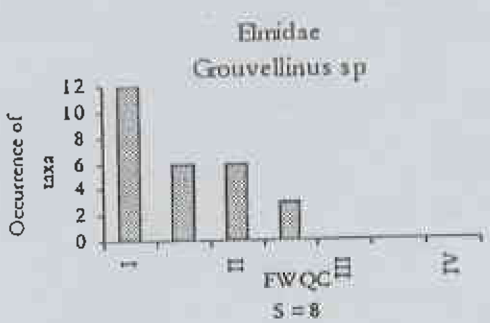

Chironomidae
Microtendipus sp.
Occurrence of taxa
I
II
III
IV
FWQC
S = 6

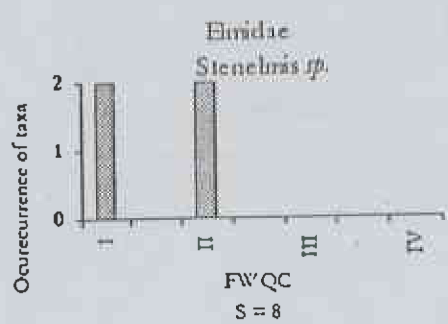

Orthocladiinae
Eukiefferiella sp.
Occurrence of taxa
I
II
III
IV
FWQC
S = 8

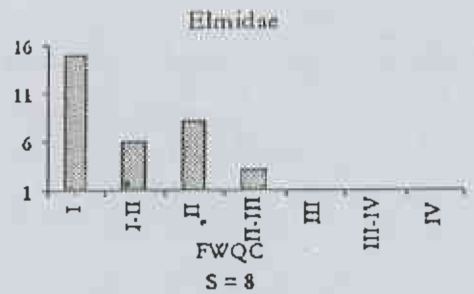

Orthocladinae
Rheocricotopus sp.
Occurrence of taxa
I
II
III
IV
FWQC
S = 5

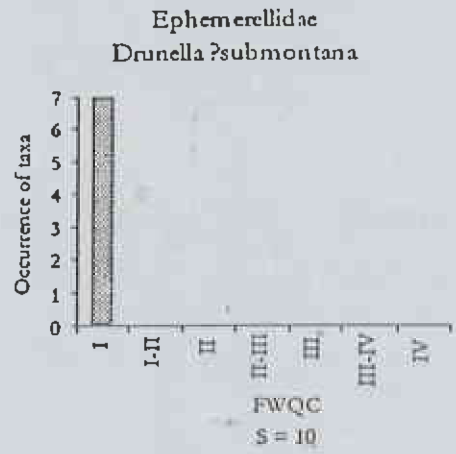

Corduligastridae
Occurrence of taxa
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 8

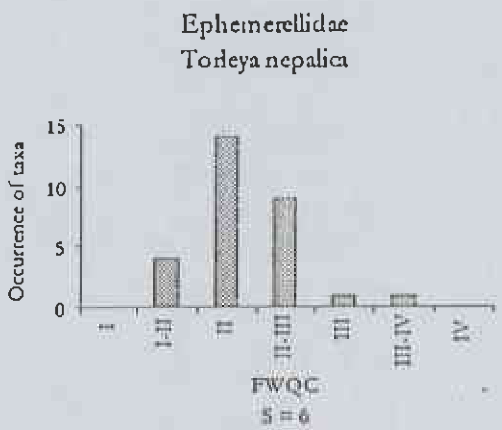

Megaloptera
Corydalidae
Occurrence of taxa
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 7

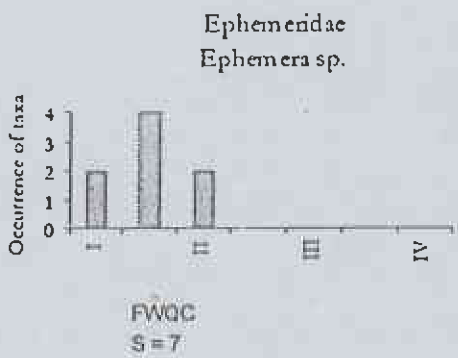

Elmidae
Grouvellinus sp
Occurrence of taxa
I
II
III
IV
FWQC
S = 8

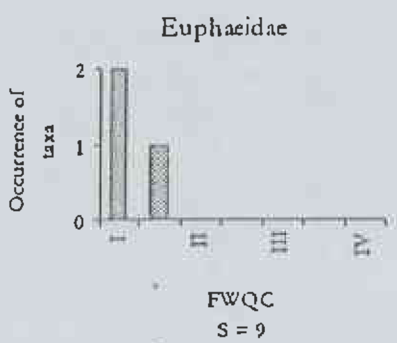

Elmidae
Stenelmis sp.
Ocurecurrence of taxa
I
II
III
IV
FWQC
S = 8

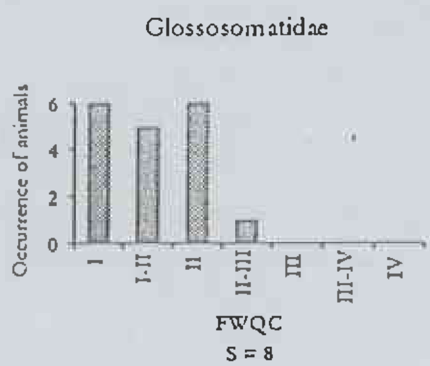

Elmidae
16
11
6
1
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 8

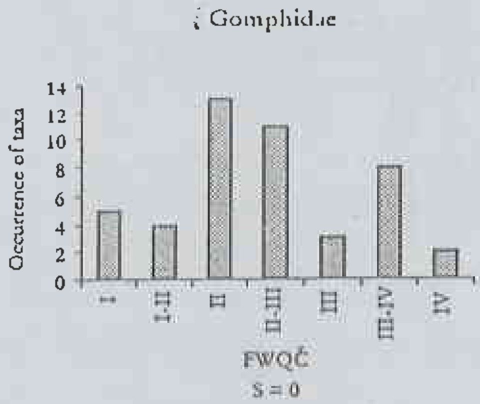

Ephemerellidae
Drunella ?submontana
Occurrence of taxa
7
6
5
4
3
2
1
0
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 10

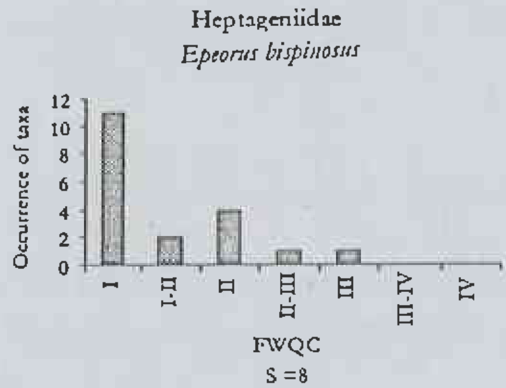

Ephemerellidae
Torleya nepalica
Occurrence of taxa
15
10
5
0
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 6

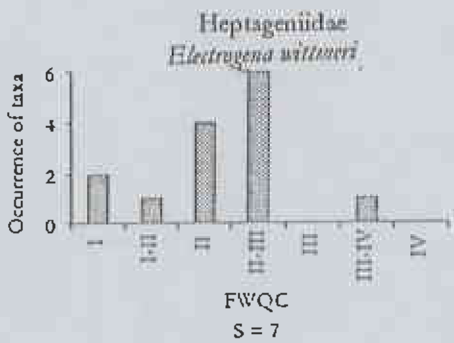

Ephemeridae
Ephemera sp.
Occurrence of taxa
4
3
2
1
0
I
II
III
IV
FWQC
S = 7

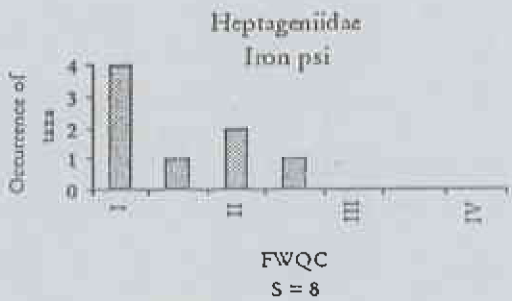

Euphaeidae
Occurrence of taxa
2
1
0
I
II
III
IV
FWQC
S = 9

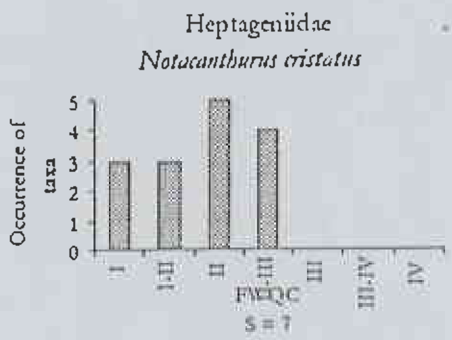

Glossosomatidae
Occurrence of animals
6
4
2
0
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 8

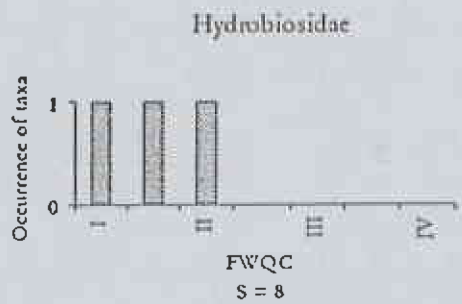

Gomphidae
Occurrence of taxa
0 2 4 6 8 10 12 14
I I-II II II-III III III-IV IV
FWQĈ
S = 0

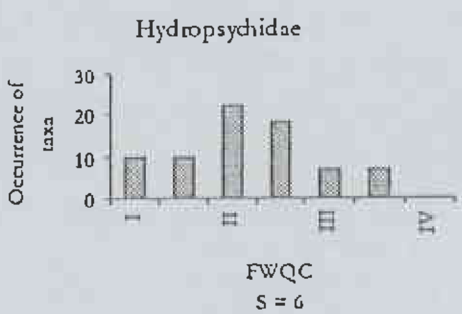

Heptageniidae
Epeorus bispinosus
Occurrence of taxa
0 2 4 6 8 10 12
I I-II II II-III III III-IV IV
FWQC
S =8

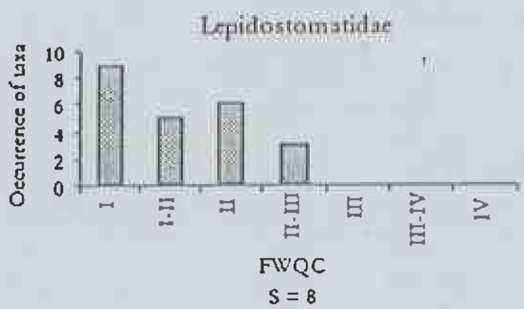

Heptageniidae
Electrogena wittmeri
Occurrence of taxa
0 2 4 6
I I-II II II-III III III-IV IV
FWQC
S = 7


Heptageniidae
Iron psi
Occurrence of taxa
0 1 2 3 4
I II III IV
FWQC
S = 8

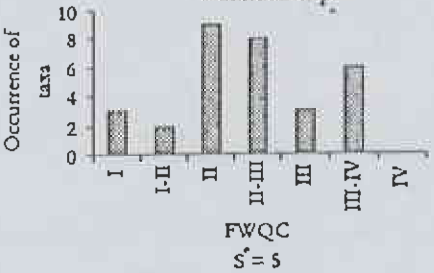

Heptageniidae
Notacanthurus cristatus
Occurrence of taxa
0 1 2 3 4 5
I I-II II II-III III III-IV IV
FWQC
S = 7


Hydrobiosidae
Occurrence of taxa
0 1
I II III IV
FWQC
S = 8

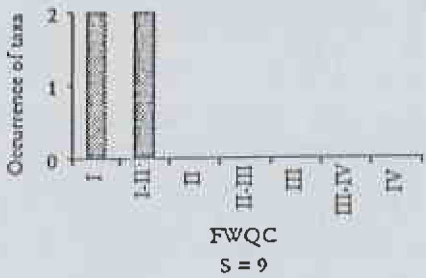

Hydropsychidae
Occurrence of taxa
0 10 20 30
I II III IV
FWQC
S = 6


Lepidostomatidae
Occurrence of taxa
0 2 4 6 8 10
I I-II II II-III III III-IV IV
FWQC
S = 8

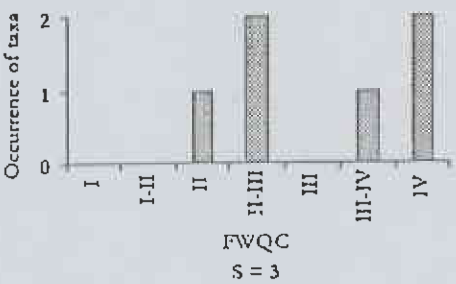
Leptophlebiidae
Euthraulus sp



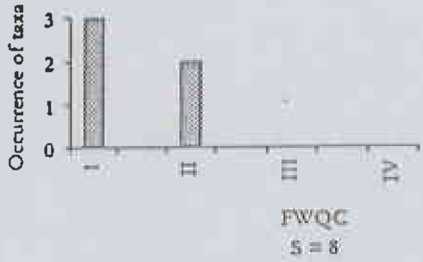
Leptophlebiidae
Habrophlebiodes sp



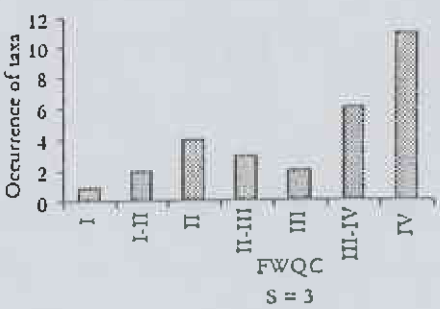
Libellulidae



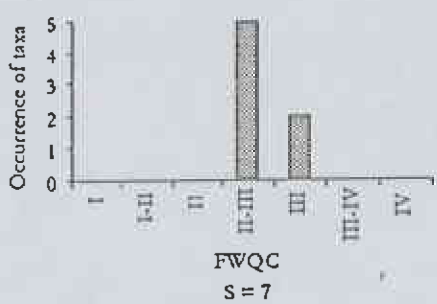
Limnophilidae



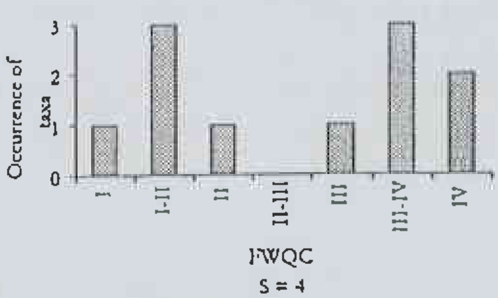
Lumbricidae



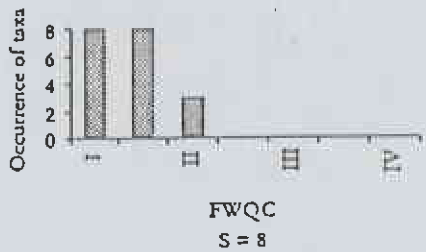
Lymnaeidae
Radix sp.



Micronectidae
Micronecta sp.

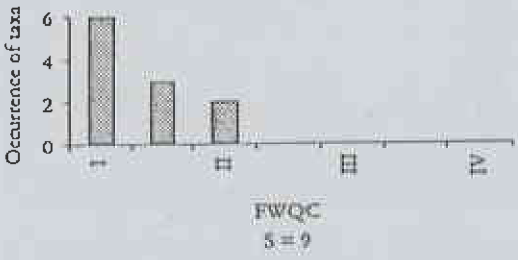


Nemouridae

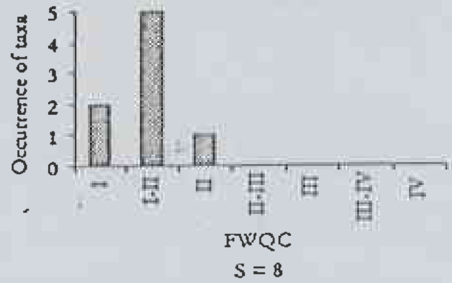


Nemouridae

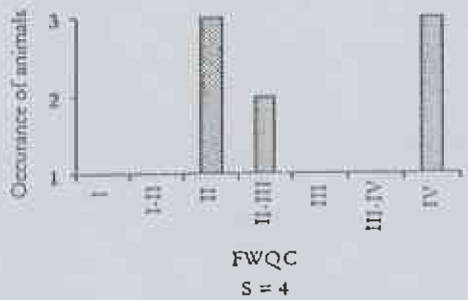
Amphinemura sp.



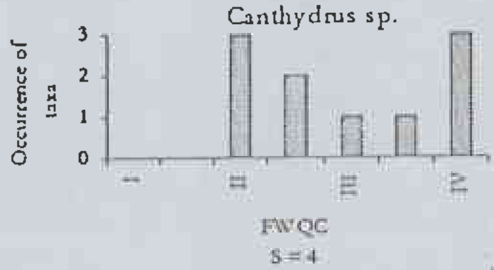
Nemouridae
Nemoura sp.



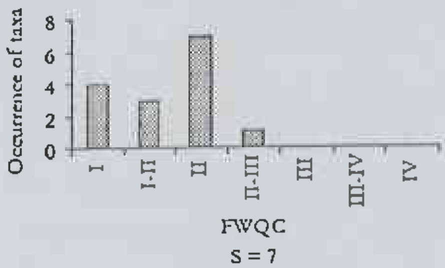
Notaridae



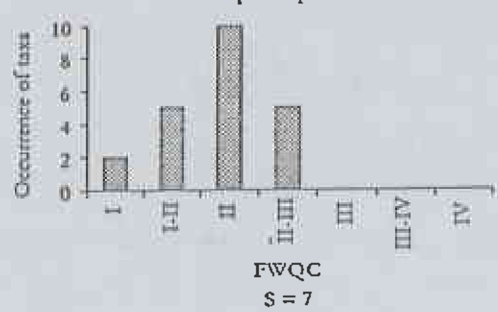
Noteridae
Canthydrus sp.



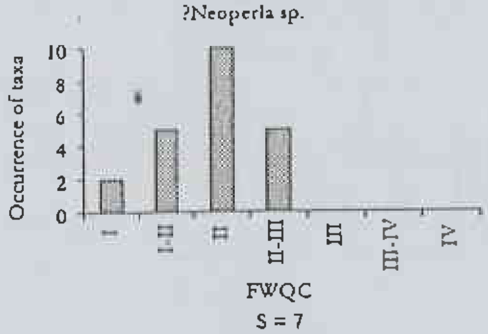
Perlidae
? Kamimura sp.



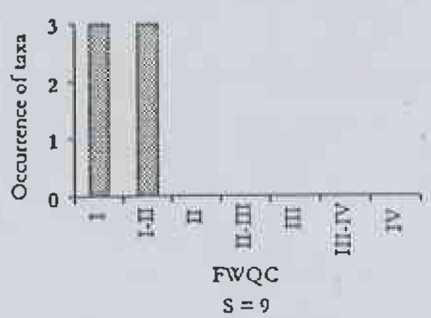
Perlidae
?Neoperla sp.

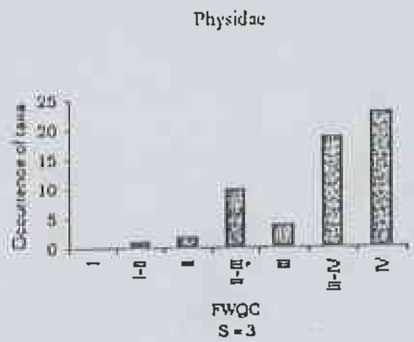


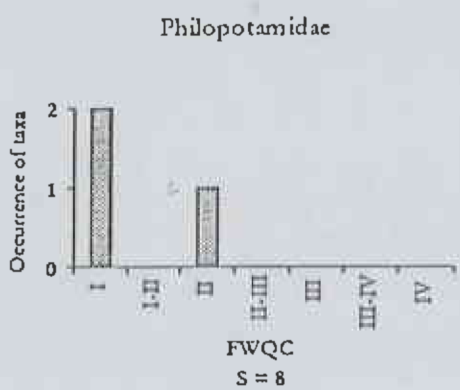
Perlidae
?Neoperla sp.

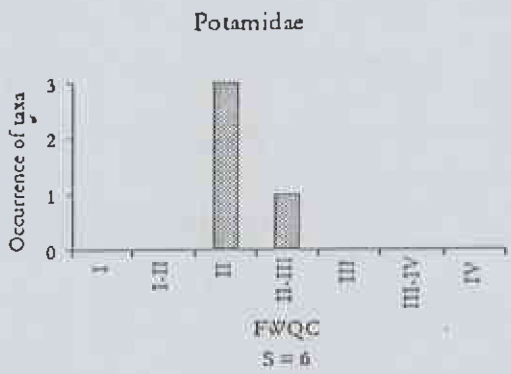


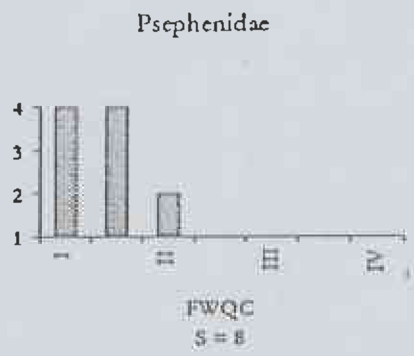
Polycentropodidae

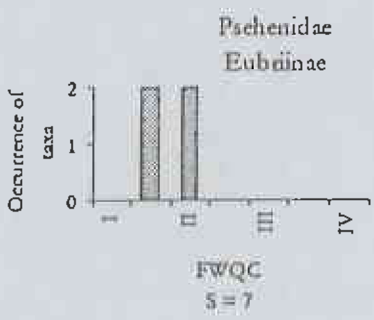


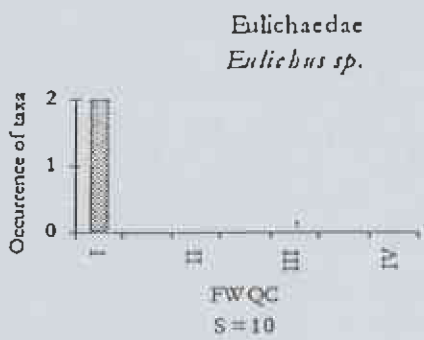

Physidae
Occurrence of taxa
25
20
15
10
5
0
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 3

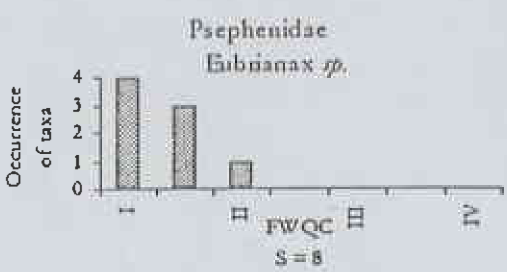

Philopotamidae
Occurrence of taxa
2
1
0
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 8

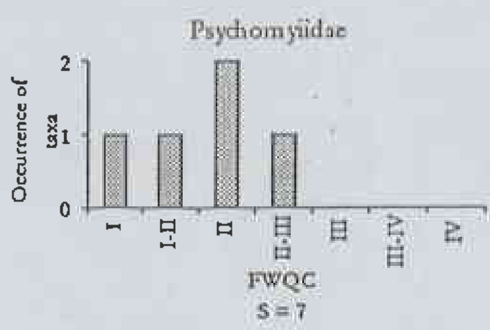

Potamidae
Occurrence of taxa
3
2
1
0
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 6

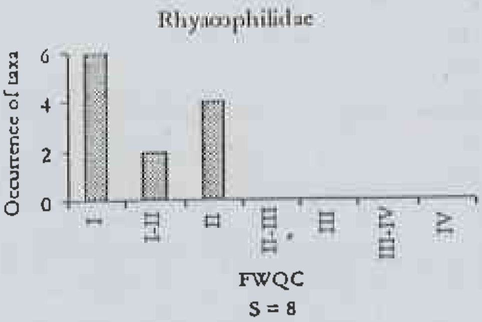

Psephenidae
4
3
2
1
I
II
III
IV
FWQC
S = 8

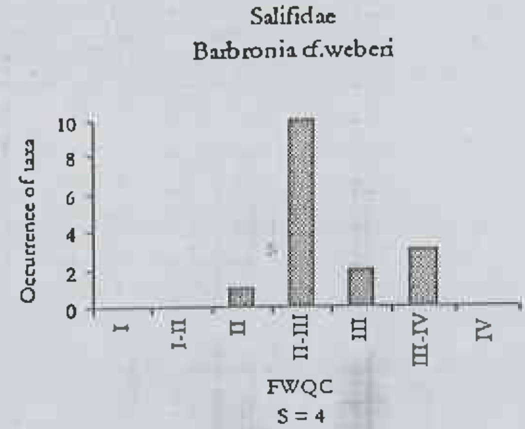

Psehenidae
Eubriinae
Occurrence of taxa
2
1
0
I
II
III
IV
FWQC
S = 7

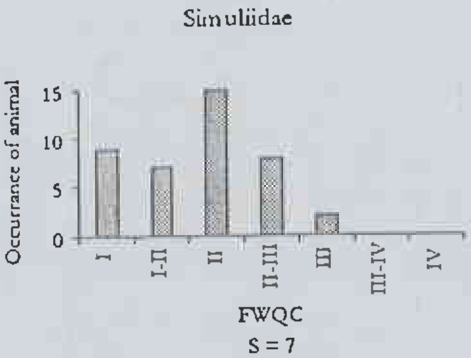

Eulichaedae
Eulichus sp.
Occurrence of taxa
2
1
0
I
II
III
IV
FWQC
S = 10

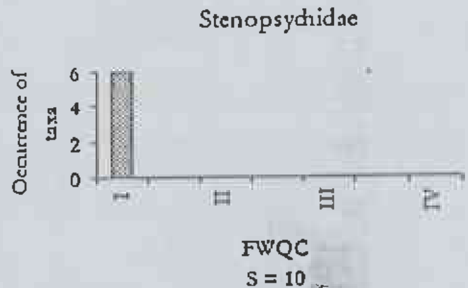

Psephenidae
Eubrianax sp.
Occurrence of taxa
4
3
2
1
0
I
II
III
IV
FWQC
S = 8

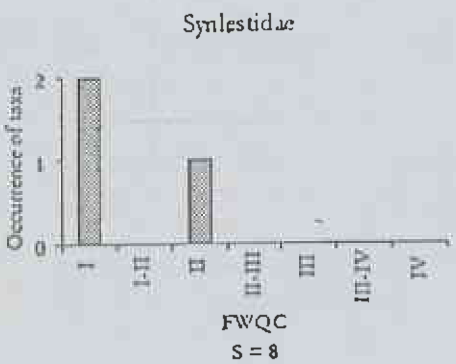

Psychomyiidae
Occurrence of taxa
2
1
0
I
I-II
II
II-III
III
III-IV
IV
FWQC
S = 7

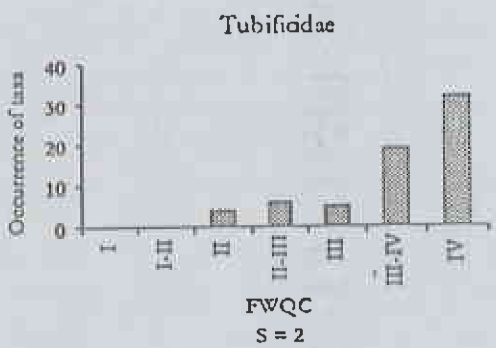

Rhyacophilidae
Occurrence of taxa
0 2 4 6
I I-II II II-III III III-IV IV
FWQC
S = 8

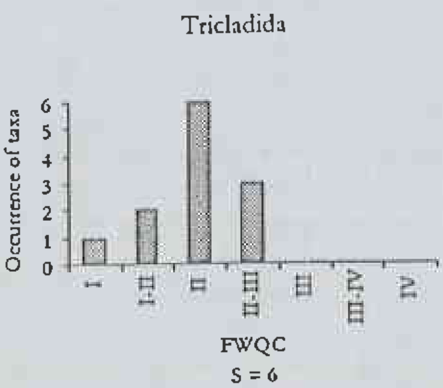

Salifidae
Barbronia cf.weberi
Occurrence of taxa
0 2 4 6 8 10
I I-II II II-III III III-IV IV
FWQC
S = 4

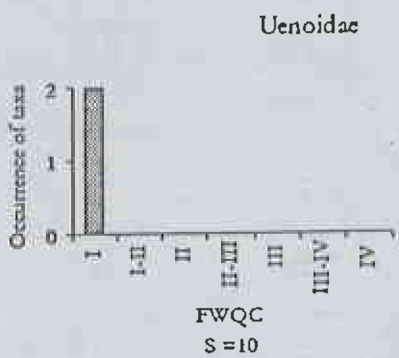

Simuliidae
Occurrance of animal
0 5 10 15
I I-II II II-III III III-IV IV
FWQC
S = 7


Stenopsychidae
Occurrence of taxa
0 2 4 6
I II III IV
FWQC
S = 10


Synlestidae
Occurrence of taxa
0 1 2
I I-II II II-III III III-IV IV
FWQC
S = 8


Tubificidae
Occurrence of taxa
0 10 20 30 40
I I-II II II-III III III-IV IV
FWQC
S = 2


Tricladida
Occurrence of taxa
0 1 2 3 4 5 6
I I-II II II-III III III-IV IV
FWQC
S = 6


Uenoidae
Occurrence of taxa
0 1 2
I I-II II II-III III III-IV IV
FWQC
S =10

Appendix: T Score assigned to the taxa [family, genus and species levels] the Bagmati river system

Name of Taxa	Saprobic water quality class							Score
	I	I-II	II	II-III	III	III-IV	IV	
Tricladida								
indet.	1	2	6	3				6
GASTROPODA								
Ancylidae			1					
*indet.**								
Hydrobiidae								
? *Tricula sp.*		1		1				6
Lymnaeidae								
Radix sp.				5	2			5
Physidae								
Physella acuta		1	2	9	5	19	23	3
Planorbidae						1		
Gyraulus sp.		1	4	5				6
BIVALVIA								
Sphaeriidae								
Pisidium sp.	2		2	5		6	1	5
OLIGOCHAETA								
Lumbricidae								
indet	1	2	4	3	2	6	11	3
Glossoscolecidae								
indet.				1	1			
Tubificidae								
indet.			4	6	5	19	32	2
HIRUDINEA								
indet.	1							
Glossiphoniidae								
indet.		1						
Salifidae								
Barbronia sp.	4	3	3	2		1		7
Barbronia cf. weberi			1	10	2	3		4
Crustacea								
indet.			3	1				6
EPHEMEROPTERA								
Baetidae								
Baetiella ausobskyi	1	1	2					7
Baetiella marginata			1					
Baetiella ?muchei	1							
Baetiella sp.	2	1	3					8
Baetis sp.1	14	10	17	9	2	1		7
Baetis sp.2	4	3	12	14	8	5	1	5
Baetis sp.3	2	2	10	13	8	2		5
Baetis sp.4	1	2	2	2		1		6
Baetis sp.5	2	2	4	2	4			6
Centroptilum sp.	1	1	1					8
Cloeodes sp.		2	1					7
Platybaetis uenoi			1					
Caenidae	3	3	11	6				6
Caenis sp.		2	5	3				6
Caenis 1	3	1	4	1				8

Taxa	I	I-II	II	II-III	III	III-IV	IV	Score
Caenis 2			2	2				6
Ephemerellidae								
Cincticostella ? levanidovae	2	1	1		1			8
Drunella serratta	?							
Drunella ? submontana	7							10
Drunella uenoi	2							10
Ephemerella sp.		1						
Serratella sp.	1							
Torleya nepalica		4	13	9	2	1		6
Ephemeridae								
Ephemera sp.	2	2	4					7
Heptageniidae								
Cinygmina ?assamensis	4	2	14	4	1			7
Electrogena apicata			2					6
Electrogena wittmeri	2	1	4	6		1		7
Epeorus bispinosus	11	2	3	1	1			8
Epeorus rhithralis	1							
Iron ? paraguttatus	2							
Iron psi	4	1	2	1				8
Notacanthurus cristatus	3	3	5	4				7
Leptophlebiidae								
Euthraulus sp.	3	4	9	8	1	6		5
Habrophlebiodes sp.	2	2						9
ODONATA								
Coenagrionidae								
indet.								
Corduliidae								
indet.		1	3			1		5
Cordulegastridae								
indet.	3	1	1	1				8
Euphaeidae								
indet.	2	1						9
Gomphidae								
indet.	5	4	12	12	2	8	2	5
Libellulidae								
indet.			1	1		1	2	3
Synlestidae								
indet.	1	1	1					8
PLECOPTERA								
Capniidae								
indet.	5	1						10
Leuctridae								
indet.	2							
Nemouridae								
Amphinemura sp.	6	3	2					9
Nemoura sp.	2	5	1					8
Perlidae				1				
? Kamimuria	4	3	7	1				7
? Neoperla	2	5	10	5				7
? Phanoperla	2		1					9

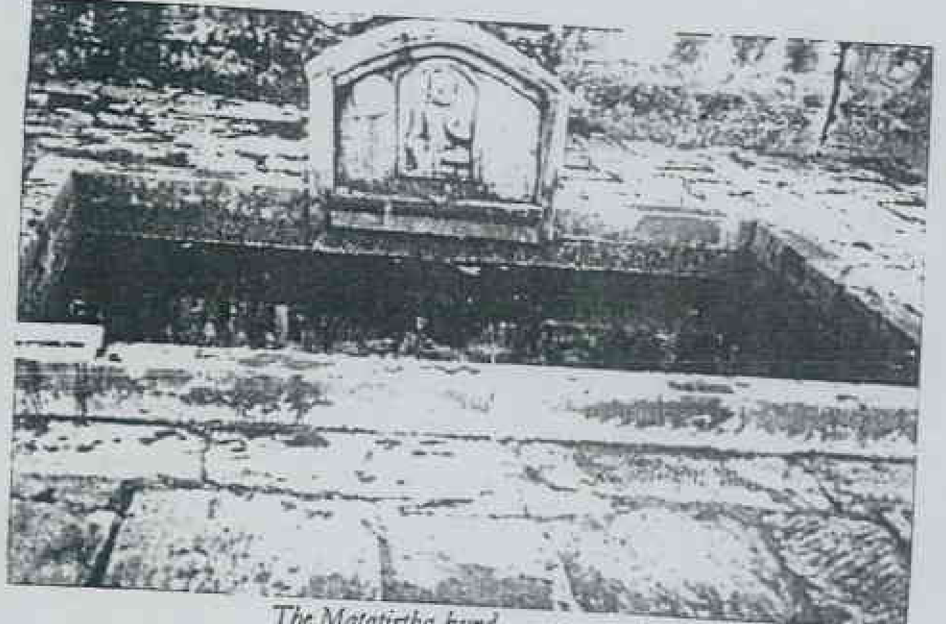
Name of Taxa	I	I-II	II	II-III	III	III-IV	IV	Score
? Togoperla	3							10
HETEROPTERA								
Aphelocheiridae								
Aphelocheirus sp.1	5	3	6	7		2		7
Aphelocheirus sp.2	1	1		1				
Corixidae								
Sigara sp.				6	2	10	4	3
Gerridae					2			4
Limnogorus sp.					1			
Neogaris parvulus Stal					1			
Hebridae	2							10
Micronectidae								
Micronecta sp.	1	3	1		1	3	2	4
Naucoridae			1					
Laccocoris sp.		1	2			1		6
Nepidae								
Lacotripus sp.			1					
MEGALOPTERA								
Corydalidae								
indet	4	4	1	5				7
COLEOPTERA								
Dytiscidae								
Hydaticus sp.		2	3	1	3	1		5
Hydrovatus sp.							2	1
indet.			1	2	2	1	2	3
Laccophilus sp.			1				2	2
Nebrioporus sp.	2		5	4		7	2	7
Platynectus sp.								
Elmidae								
Grouvellinus sp.	16	6	8	3				8
indet.								
Stenelmis sp.	2		2					8
Eulichadidae								
Eulichas sp.	2							10
indet.								
GYRINIDAE								
indet.	2	2	4	1				7
Haliplidae								
Haliplus sp.								
indet.								
Hydraenidae								
Hydraena sp.								
indet								
Hydrophilidae								
Ametor rugosus	1			1	1			6
Enochrus esuriens								
Laccobius sp.			1		1			5
Pelthydrus	1			1	1		1	5
Noteridae								

Name of taxa	I	I-II	II	II-III	III	III-IV	IV	Score
Canthydrus sp.			3	2	1	1	3	4
indet			3	2	1	1	3	3
Psephenidae								
Eubriinae								
indet		1	1					7
Eubrianax sp	2	3	1					8
indet.	2							10
Scirtidae (Helodidae)								
indet.	1							
TRICHOPTERA								
Brachycentridae								
indet.	1	1						9
Glossosomatidae								
indet.	6	5	6	1				8
Hydrobiosidae								
indet	1	1	1					8
Hydropsychidae								
cf. Cheumatopsyche sp.			1					
indet	10	10	22	18	7	7		6
Lepidostomatidae								
indet.	9	5	6	3				8
Limnephilidae								
indet.	3		2					9
Philopotamidae								
indet.	2		1					9
cf. Wormaldia sp.	3							10
Chimarra sp.	1							
Polycentropodidae								
indet.	3	3						9
Plectrocnemia sp.	1							
Psychomyiidae								
indet.	1	1	2	1				7
Rhyacophilidae								
indet.	6	2	4					8
Stenopsychidae								
indet.	6							10
Uenoidae								
indet.	2							10
DIPTERA								
Athericidae								
Atherix sp.	3	2						9
? Atrichops crassipes	2	2						8
indet.	11	1	2					9
Ceratopogonidae								
indet.		2	1					7
Chironomidae								
Chironominae								
Chironomus sp.		1	6	16	7	20	20	3

Taxa	I	I-II	II	II-III	III	III-IV	IV	Score
Chironomus sp. Type 1								
Cladotanytarsus sp.			1					
Cryptochironomus sp.		2	3			1	1	5
indet.								
Microtendipes sp.	1		2					7
Microtendipes chloris gr.			3					6
Polypedilum type 1ʳ		1	1	2	1	5		4
Polypedilum scalaenum gr.			1					
Polypedilum sp.	2	1	4	2	1			7
Rheotanytarsus sp.		2		2		3		5
Tanytarsus sp.			1					
Diamesinae								
Diamesinae Type 1	2	1						
Diamesa cinerella gr./ zernyi gr.		2	1					
Potthastia gaedii gr.								
Orthocladiinae								
Brillia sp.			1	1				6
Cricotopus cf. Bicinctus			1	1	2			5
Cricotopus sp.				1				
Eukiefferiella devonica group	1							
Eukiefferiella sp.	1			1				
indet.	4	1						9
Orthocladius (Euorthocladis) cf. Rivulorum	1	2				1		7
Orthocladius (Euorthocladis) cf. Rivicola gr.	1							
Orthocladius (Orthocladius) sp.	1	2	1			1		7
Paratrichocladius sp.	1							
Rheocricotopus cf. Chalybeatus	1	1	2	4		1		6
Rheocricotopus sp.			2		1			5
Tvetenia cf. Calvescens	1							
Tvetenia discoloripes gr.	1							
Tanypodinae								
Clinotanypus sp.	2			1				8
indet.			2	1				6
Macropelopia sp.		1		1			2	4
Procladius sp.			1					
Rheopelopia sp.		1		1			2	4
Thienemannimyia gr.			2	3	1			5
Zavrelimyia sp.			1					
Culicidae								
indet.					1	2	7	2
Ephydridae								
indet.				1				
Empididae							1	
indet.				1				
Limoniidae								
Cf. Dicranota	2	3	3					7
indet.	3	4	5	1		1		7
Psychodidae								
indet.		2						8
Simuliidae								

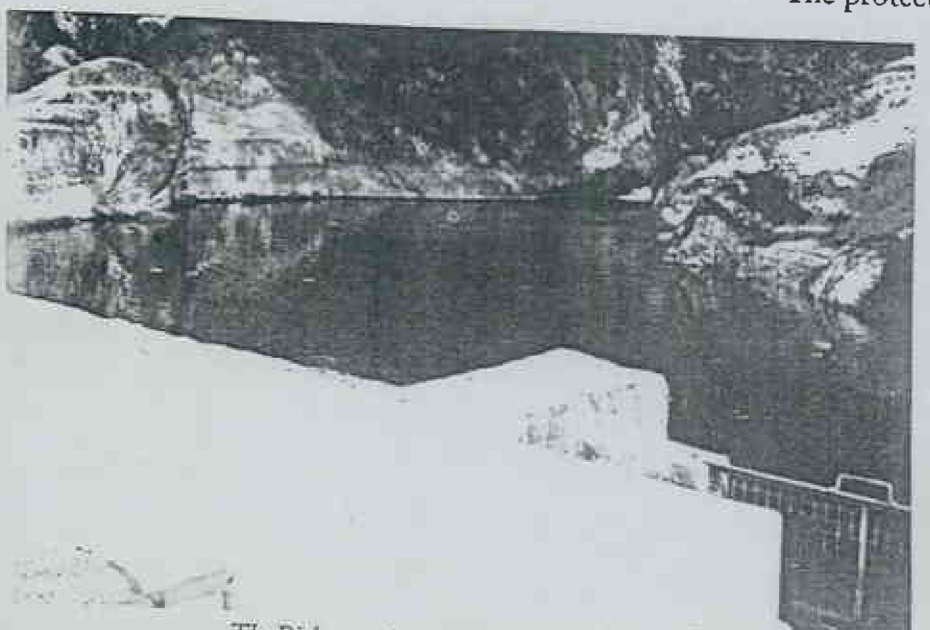
Taxa	I	I-II	II	II-III	III	III-IV	IV	Score
indet.	9	7	14	8	2	1		7
Syrphidae								
Eristalis sp.					2	4	3	2
Tabanidae								
indet.	6	5	5	3	1	5		6
Tipulidae								
indet.	8	5	7	1	2	1		7

Appendix: Photo

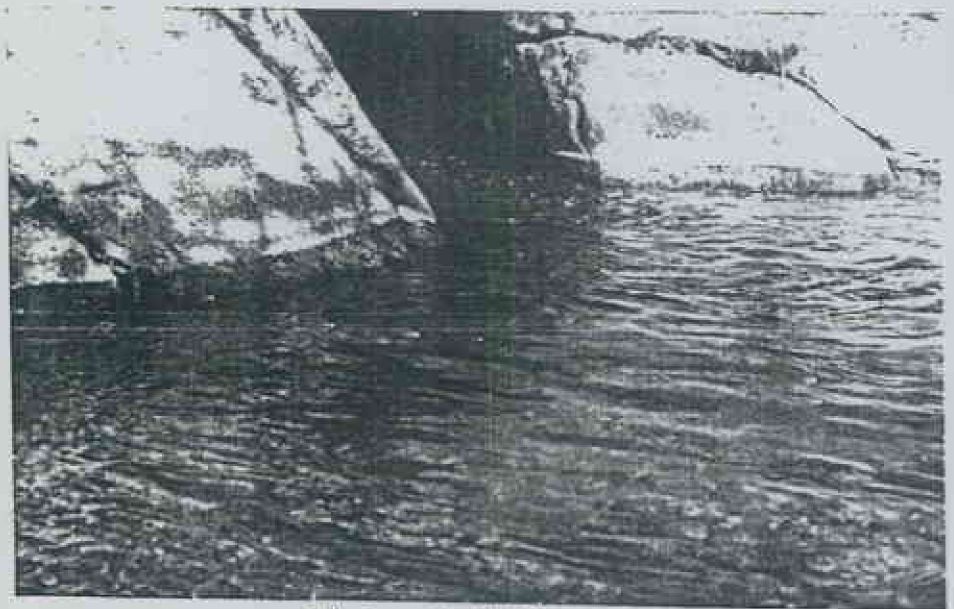

The Matatirtha kund


Stone sprouts for public use at Matatirtha

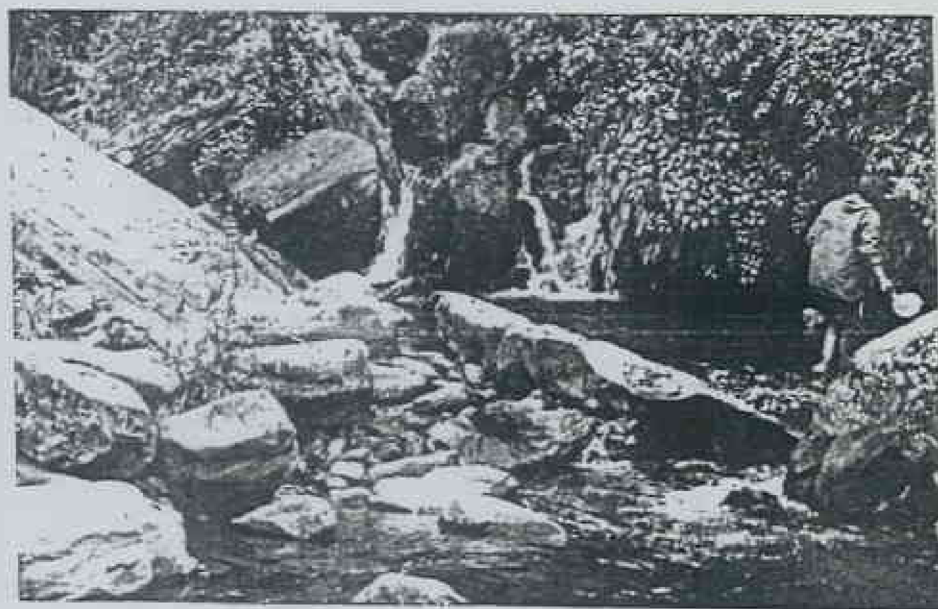
The protected stream water source


The Bishnumati water reservoir


The Mahadev water collection for reservoir at Manapokhari

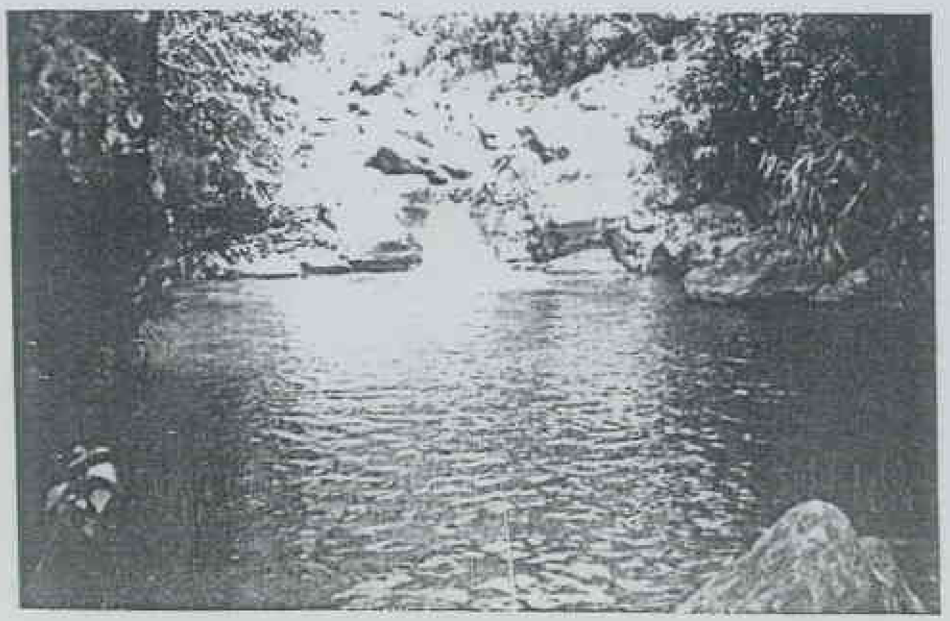


The Bagmati at Maithan



The Mahadev (Source of the Hanumante)

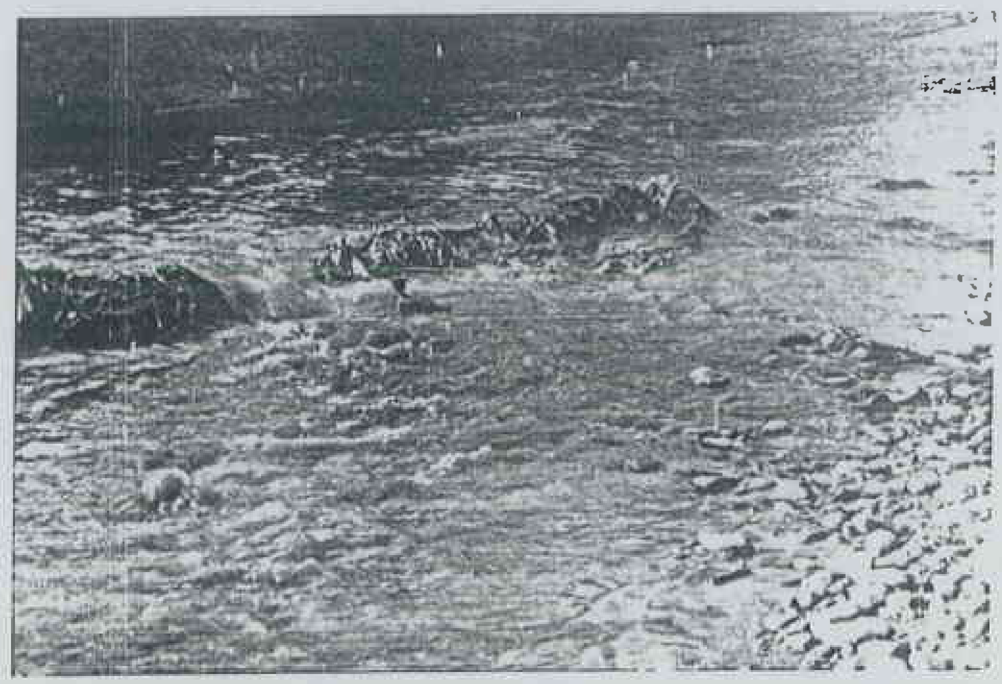
Headwater streams: clean water, adequate volume of water and no human interference



The Mahadev at Manpokhari

The Nallu, Tikabhairav

Streams at lower headwater region: relatively high velocity and low human interference

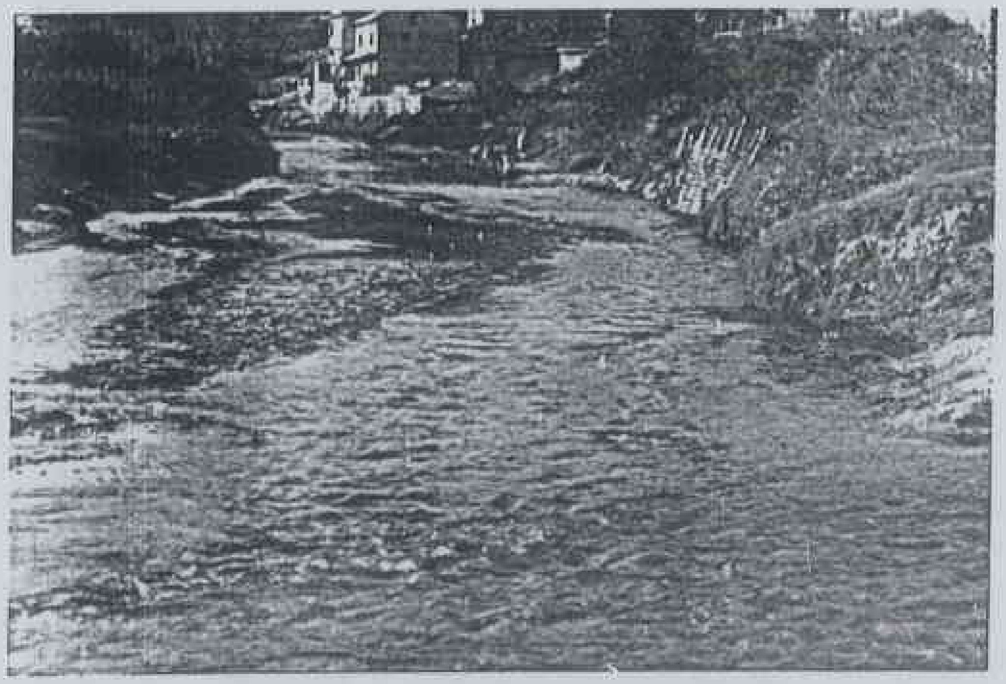


The Indrayani

During pre-rainy season

Different levels of stream water, The Nakhu at Bungmati

During post-rainy season

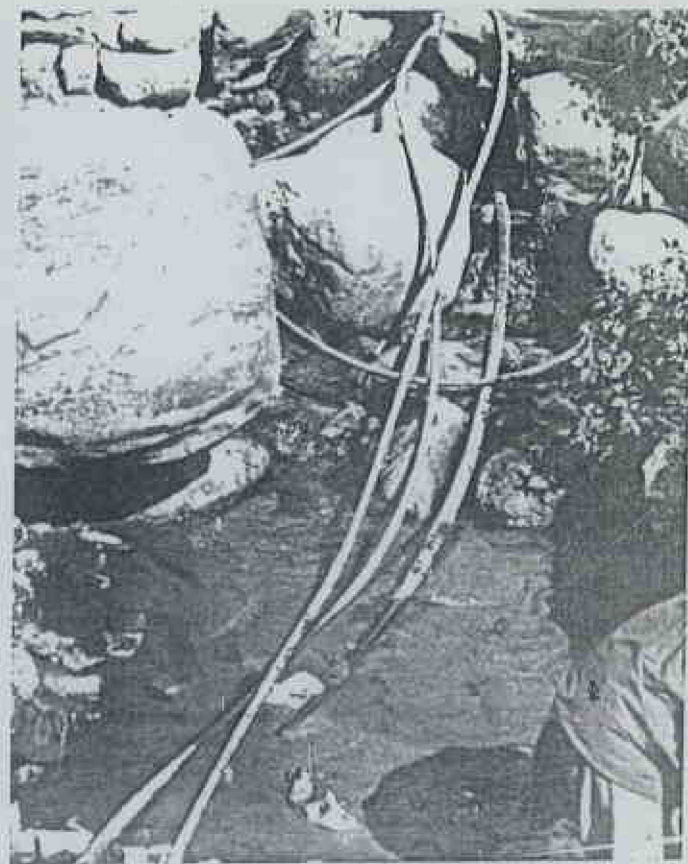


Houses at stream bank, the Mahadev at Hiletol

Bank enchroachment: awaiting for its protection!

Disorganized bank due to human activity, the Manohara at Koteswor

A river at head water region with allochthonus input at the Dhobikhola



Stream water for heavy domestic use, the lower headwater region of the Bishnumati

Types of influence

Water pumping station for public drinking water supply, the Bagmati at Sundarighat

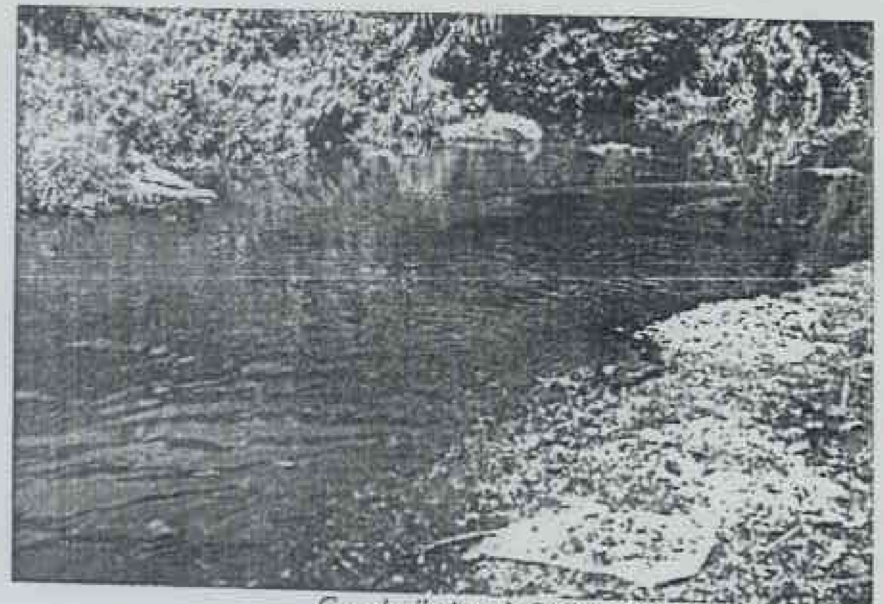
Cleaning marketable vegetables, the Godavari at Balkot

Cleaning and washing, the Bishnumati at Narayanthan

Uses of stream water for domestic and entertainment purposes

Bathing and washing, the Balkhu at Khasibazar

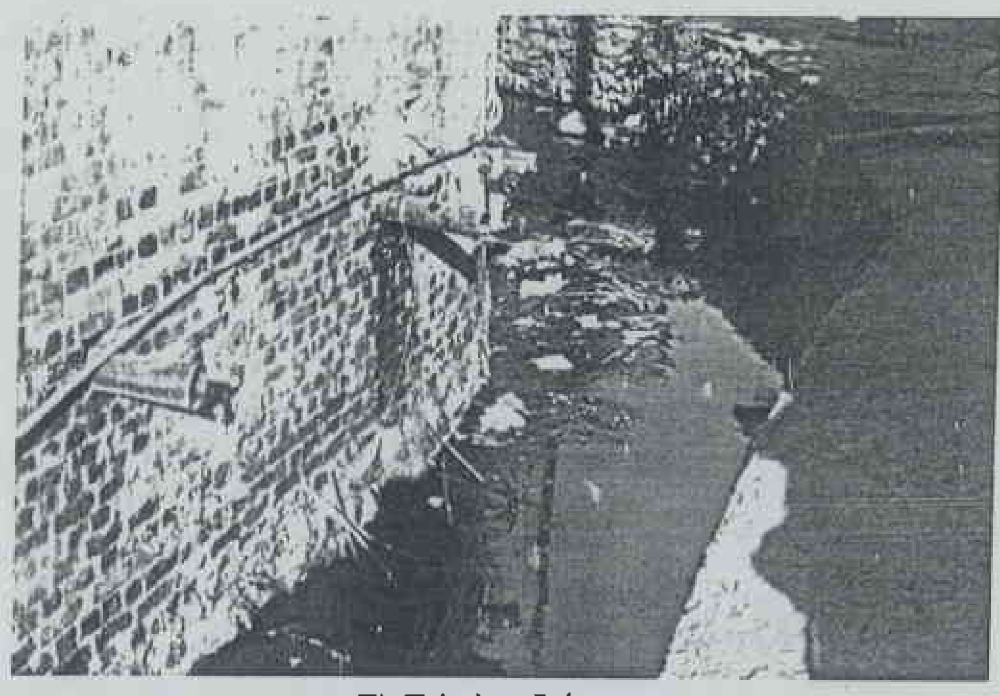
Intensive sand quarrying activity, the Manohara at Brambakhel



Gravel collection, the Balkhu, Kuleswor Ringroad

Economic uses of stream resources

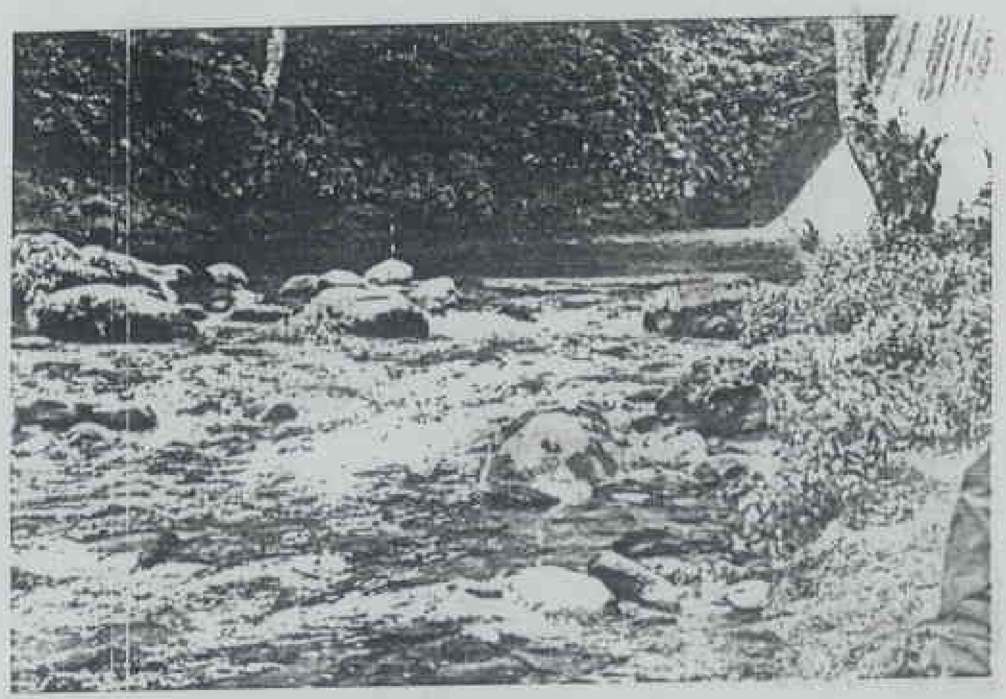
Water pumping for irrigating vegetable fields, the Hanumante, Imadol



The Tukucha at Baluwatar

Intensive human interference: domestic sewage effluent and refuse disposal

The Bagmati at Shantinagar



Just below the Sundarijal reservoir

The Bagmati river

With a wide river channel in the Tarai region