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Assessment of Water Quality of Manahara River, Kathmandu Valley by using Macroinvertebrates as Biological Indicator

A Dissertation
Submitted to Central Department of Environmental Science
for partial fulfillment of the requirement for the
Master's Degree in Environmental Science

Submitted by:
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LETTER OF RECOMMENDATION

This is to certify that **Mr. Gyan Kumar Chhipi Shrestha** has prepared this dissertation entitled "**Assessment of Water Quality of Manahara River, Kathmandu Valley by using Macroinvertebrates as Biological Indicator**" for partial fulfillment of the requirement for the completion of Master's Degree in Environmental Science and he has worked satisfactorily under my supervision and guidance.

This dissertation work embodies his own work and is in the form as required by Central Department of Environmental Science, Tribhuvan University.

I therefore recommend the dissertation for approval and acceptance.

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Prof. Dr. Umakant Ray Yadav

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Declaration by Student

I, Gyan Kumar Chhipi Shrestha, hereby declare that the work presented herein is genuine work done originally by me and has not been published or submitted elsewhere for the requirement of a degree program. Any literature data works done by others and cited within this dissertation has been given due acknowledgement and listed in the reference section.

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LETTER OF APPROVAL

The dissertation entitled "**Assessment of Water Quality of Manahara River, Kathmandu Valley by using Macroinvertebrates as Biological Indicator**" submitted by **Mr. Gyan Kumar Chhipi Shrestha** under the supervision of Prof. Dr. Umakant Ray Yadav, Head of Department, Central Department of Environmental Science has been accepted as partial fulfillment of the requirement for the completion of Master's Degree in Environmental Science.

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ABSTRACT

The Manahara river, one of the major tributaries of Bagmati river flowing from Manichud Lekh (ridge) and meets to the Bagmati river at Chyasal draining a length of 30.0 km and catchment area of 256 km^2. The present investigation was carried out from October 2005 to September 2006 at seven stations namely Salinadi, Sakhu, Brahmakhel, Bode, Sinamangal, Imadol and Chyasal respectively from upstream to downstream in the Manahara river. Important physico-chemical parameters, total coiforms and macroinvertebrates were studied monthly over the period of ten months from October 2005 to July 2006. The physico-chemical features such as Secchi disc transparency, mean depth, discharge, dissolved oxygen, oxygen saturation %, Biochemical oxygen demand, free carbondioxide, total alkalinity, bicarbonate, hardness, calcium, magnesium, chloride, ammoniacal nitrogen, nitrate nitrogen, ortho-phosphate, electrical conductivity, total dissolved solids, total coliforms and macroinvertebrates features vary significantly from stations 1 to 7 whereas the monthly variation of only the discharge, temperature, velocity, depth, pH of the river water and total density of macroinvertebrates was significant over the period of ten months. Compared to other stations, the river water was less polluted in monsoon season probably as the pollutants were diluted in the season. The water quality was found gradually being deteriorated from the station 1 to station 7 i.e. upstream to dowmstream which was indicated by the chemically determined water quality class using Bach index and Ministry of Public Transport and Public Works water quality index as well as biologically determined saprobic water quality class using Original NEPBIOS, NEPBIOS-BRS, Extended NEPBIOS and GRS index. The river was nearly in pristine condition with high species diversity of macroinvertebrates at station 1 (Salilnadi) and was deteriorated specially when it entered into urban area i.e. Bode (Madhyapur Thimi municipality) and more severe when it reached Sinamangal (Kathmandu Metropolitan City). The river water from stations 1 to 4 was found suitable for aquatic life including fishes as well as for drinking water but they should be treated to remove coliforms and suspended solids for drinking purpose.

The cause of the deterioration of water quality along the river from upstream to downstream may be the sewage outfall points in the river which were more in number in urban areas and also the sewage discharged into the river was untreated. The

quality of effluent which was entering into the river didn't comply the national effluent standards of Nepal. The legal measures are not utilized to control water pollution in the river in spite of several legal provisions. Among five wastewater treatment plants established in this watershed, two plants at Thimi and Sakhu are fully operational and one at Balkumari is partially operational. Thus about 8 % wastewater is being treated by these plants and remainings are discharged directly or indirectly into the Manahara river enhancing the water pollution. The wastewater treatment plants at Hanumanghat, Sallaghari and Balkumari should be repaired or reinstalled and new such plants should be constructed in other settlements for the treatment of sewage before discharge into the river. Moreover, for the sustainability of the plants, the effluent charge should be collected from each household.

The GRS index was found to be more appropriate than other biotic scoring systems for bioassessment of water quality. There is highly positive significant correlation of about 0.90 between chemically determined water quality class and biologically determined saprobic water quality class specially by using newly developed GRS index. Since the coefficient of determination is 0.80, the change in chemical water quality class is explained more than 80 % by the change in saporbic water quality class using GRS index. Thus, the water quality can be assessed by using macroinvertebrates as bioindicators and for more precise biological assessment, the GRS index should increase its taxa list and be refined the indicator value to genus/species level.

ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
As	Arsenic
ASPT	Average Score Per Taxon
BBI	Belgian Biotic Index
BMWP	Biological Monitoring Working Party
BOD_5	Biological Oxygen Demand (in five days incubation)
$CaCO_3$	Calcium carbonate
CBI	Chandler Biotic Index
CBS	Central Bureau of statistics
CBS	Central Bureau of Statistics
Cd	Cadmium
CEDA	Centre for Economic Development and Administration
cfu	colony forming unit
CIVD	Centre for Integrated Urban development
Cl	Chloride
CO_2	Carbondioxide
CO_3^{--}	Carbonate
COD	Chemical Oxygen Demand
Cr	Chromium
d.f.	degrees of freedom
DHM	Department of Hydrology and Meteorology
DO	Dissolved Oxygen
ECOSAN	Ecological Sanitation
EIA	Environment Impact Assessment
ENPHO	Environment and Public Health Organisation
EPA	Environment Protection Act
EPR	Environment Protection Regulation
FAO	Food and Agricultural Organization
FDD	Fisheries Development Division
Fe	Iron
GON	Government of Nepal
GRS	Ganga River System

GWRDP	Ground Water Resource Development Project
HCO_3^-	Bicarbonate
Hg	Mercury
HMG	His Majesty's Government
i.e.	that is
IB	Indices Biotiques
IEE	Initial Environment Examination
MFSC	Ministry of Forests and Soil Conservation
mg/L	Milligrams/Litres
µS/L	MicroSimens/Litres
MLD	Million Litres per Day
Mn	Ministry of Environment, Science and Technogy
MOPE	Ministry of Population and Environment
MPTW	Ministry of Public Transport and Public Works (Netherlands)
NEPBIOS	Nepalese Biotic Score
NEPBIOS-BRS	Nepalese Biotic Score – Bagmati River system
NEWAH	Nepal Water for Health
NH_3	Ammonia
$NH_4 - N$	Ammonical Nitrogen
$NO_3 - N$	Nitrate – Nitrogen
NO_3	Nitrate
NSF	National Sanitation Foundation
OH^-	Hydroxide
P	Phosphorus
PO_4	Ortho – phosphate
RONAST	Royal Nepal Academy of Science and Technology
SWMRMC	Solid Waste Management and Resource Mobilization Centre
SWQC	Saprobic Water Quality Class
TBI	Trent Biotic Index
TDS	Total Dissolved Solids
UK	United Kingdom
UNEP	United Nations Environment Program

UNESCO	United Nations Educational, Scientific and cultural organization
WECS	Water and Energy commission Secretariat
WHO	World Health Organization
WQI	Water Quality Index

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CHAPTER ONE

1. INTRODUCTION

1.1 Background

Water is marvelous substance - flowing, swirling, seeping, constantly moving from sea to land and back again. It shapes the earth's surface and moderates our climate. Water is one of the most essentials of life. It is the medium in which all living processes occur (Cunningham, 2003). Just like 70 % earth's surface is covered with water, 70 % of human body is constituted of water (Islam, 2006).

Water Quality refers to the set of concentrations, speciation and physical partitions of inorganic or organic substances including the composition and state of aquatic biota in the water body. However, water quality assessment is defined as the overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health and the health of the aquatic system itself (UNESCO, 1996).

Water is integral part of the environment and is of vital importance to all socio – economic sectors. Human and economic development is not possible without a safe, reliable water supply (Gustard *et al.*, 2002). Clean drinking water is necessary to prevent communicable diseases and to maintain a healthy life. For many of the world's poorest people, one of the greatest environmental threats to health remains the continued use of polluted water. In 2002 the United Nations estimated that at least 1.1 billion people lacked access to safe drinking water and 2.4 billion didn't have adequate sanitation. The deficiencies result in hundreds of millions of cases of water related illness and more than 5 million deaths every year (UNESCO, 2003; WHO and UNICEF, 2004; Cunningham, 2003).

The freshwater is given high priority by the international community for its sustainable utilization and conservation. UN, 1992 mentioned in the chapter 18 of Agenda 21 that freshwater resources are an indispensable part of all terrestrial ecosystems. Thus, these resources should be assessed and protected and national goals should be set for freshwater use, quality, protection and improvement. It emphasized

on the need of research, data storage, modeling and wide dissemination of information connected to freshwater issues. Further recommendations to support implementation of chapter 18 were taken by the Commission on Sustainable Development at its second session in 1994 and sixth session in 1998; by the United Nations General Assembly at its nineteenth special session to review the implementation of Agenda 21 in 1997 and by the World Summit on Sustainable Development in 2002 through its Plan and Implementation. The Commission on Sustainable Development, at its twelfth session in 2004 reviewed and assessed implementation of three thematic issues, including water and sanitation. Most recently, in 2005 at its thirteenth session, the Commission explored policy options for furthering implementation on the issues of water and sanitation as well as on human settlements as reflected in its decision (UN, 2006).

Moreover, United Nations launched the "Water for life" Decade on 22 March 2005, on World Water Day. The Decade aims to promote efforts to fulfill international commitments made on water and water-related issues by 2015. The year 2003 was earlier chosen by the General Assembly as the International Year of Freshwater (UN, 2006). Similarly, Millennium Development Declaration 2000 called the world to achieve Millennium Development Goals in which Nepal is a signatory. These include the water related Millennium Development Target of halving by 2015, the proportion of people without access to safe drinking water in 1990 (signed at Stockholm in 2000) and halving by 2015, the proportion of people without access to hygienic sanitation in 1990 (signed at Johannesburg in September 2002) (WAN, 2004).

There are challenges in future of freshwater. With a global population of 8 billion people – a 2 billion increase and a business – as – usual scenario, an overall increase in water withdrawls of 22 % over 1995 levels is expected by 2025. This includes increases of 17 % in the demand for water for irrigation, 20 % in the demand for water for industry, and 70 % in the demand for water by municipalities (Rosegrant *et al.* 2002; MEA, 2005).

1.2 Freshwater environment

Freshwater is distributed in solid, liquid and gaseous form in the earth. Ice and snow, fresh groundwater, fresh lakes, rivers, streams, soil moisture, atmospheric moisture

are the sources of freshwater (Cunningham, 2003). All freshwater bodies are inter-connected, from the atmosphere to the sea, via the hydrological cycle constituting a continuum for water (UNESCO, 1996). On the earth, 2.4 percent of all water is freshwater and 13 % of the freshwater is in liquid state. The easily accessible water in lakes, rivers and streams represents only 3 percent of all liquid freshwater (Cunningham, 2003). The freshwater environment can broadly be classified as lotic environment having running water bodies such as rivers, streams and springs and lenic environment having standing water bodies such as lakes, ponds (Odum, 1996). Rivers are the most important freshwater resources for man. Social, economic and political development has, in the past, been largely related to the availability and distribution of freshwater contained in riverine systems (UNESCO, 1996).

1.3 River and riverine ecosystem

1.3.1 Rivers

Rivers are characterized by unidirectional current with a relatively high, average flow velocity ranging from 0.1 to 1 ms^{-1}. The river flow is highly variable in time, depending on the climate situation and the drainage pattern. They are complex system of flowing waters draining specific land surfaces called as river basins or watersheds (UNESCO, 1996). Touching all parts of the natural environment and nearly all aspects of human culture, streams and rivers act as centres of organization within landscapes. They provide natural resources such as fish and clean water, transportation, energy, diffusion of wastes, and recreation (Naiman *et al.* 2001).

A size classification of rivers based on discharge, drainage area and river width is given in table 1. The distinctions are arbitrary and no indication of the annual variability in discharge is given.

Table 1: Classification of rivers based on discharge, drainage area and river width

A River size	Average discharge ($m3\ s^{-1}$)	Drainage area (km^2)	River width (m)	Stream Order
Very large rivers	> 10,000	> 10	> 1,500	> 10
Large rivers	1,000-10,000	100,000-10^6	800-1,500	7 to 11
Rivers	100-1,000	10,000-100,000	200-800	6 to 9
Small rivers	10-100	1,000-10,000	40-200	4 to 7
Streams	1-10	100-1,000	8-40	3 to 6
Small streams	0.1-1.0	10-100	1-8	2 to 5
Brooks	< 0.1	< 0.1	< 1	1 to 3

Source: UNESCO, 1996

The water quality of every stream differs from the next and will itself vary with time-sometimes over minutes. This is because the final composition depends on the interplay of several variabes. First there is initial composition and amount of rain and snow and how the water passes through the cathchment. It may run rapidly off hard rocks or soak slowly through permeable soil. Secondly, there are many thousands of substances derived from the local geology, soil, and ecosystems, which may become dissolved. And lastly, the catchment may be altered by human populations: forest removal, afforestation, cultivation and fertilization of land, the building of settlements, industrial use and the disposal of wastes (Moss, 1998).

The misuse of water resources and poor water management practices have resulted in depleted supplies, falling water tables, shrinking inland lakes, and stream flows diminished to ecologically unsustainable levels. In addition, water pollution, originating mostly from human activity, is occurring even more frequently, decreasing the amount of water suitable for many uses (Gustard et. al. 2002).

1.3.2 Riverine Ecosystems

The dynamic and hierarchical nature of lotic ecosystems i.e. river ecosystems can be conceptualized in a four-dimensional framework. The longitudinal dimension is constituted by upstream – downstream interactions. The lateral dimension includes

interactions between the channel and riparian/flood plain systems. Similarly, significant interactions also occur between the channel and contiguous groundwater, the vertical dimension. The fourth dimension, time, provides the temporal scale. Lotic ecosystems have developed in response to dynamic patterns and processes occurring along these four dimensions (Ward, 1989; Amoros and Bornette, 2002). Various lotic ecology concepts are developed and Ward *et al.* 2002 considered some of them under the Theoretical frameworks: Gradient analysis, Disturbance, Ecotones and Hierarchy. They are explained below:

A. Gradient analysis

The term gradient analysis was first applied to changes in mountain vegetation along an altitudinal continuum (Whittaker, 1965). Given that unidirectional flow is the defining feature of rivers, it is natural that examining gradients from headwaters to the lower reaches has been a dominant theme in Lotic ecology. Gradient analysis encorporates Stream Zonation Concept (Illies and Botosaneanu, 1963), River continuum Concept (Vannote *et al.*1980) and Hyporheic corridor concept (Stanford and Ward 1993) (After Ward *et al.* 2002).

B. Disturbance:

The role of disturbance, a topic of long- standing interest in ecology, has undergone a paradigm shift (Pickett and White 1985). Historically, disturbance was viewed as a deviation from the equilibrium conditions prevailing in nature, whereas disturbance is now generally recognized as an agent responsible for sustaining the ecological integrity of ecosystems – such as fire, hurricanes and tidal action. It is, in fact lack of disturbance that suppresses biodiversity, and this is perhaps most apparent in highly managed rivers. This theoritical framework encorporates Serial Discontinuity Concept (Ward and Stanford 1995), Flood Pulse Concept (Junk *et al.* 1989) and Telescoping ecosystem model (Fisher *et al.* 1998) (After Ward *et al.* 2002).

C. Ecotones

Clements (1905) regarded ecotones as tension zones between adjacent communities. Ecotones are now viewed as semi – permeable boundaries between relatively homogenous patches, transition zones where the rates of change in ecological patterns or processes are increased relative to the surroundings (Wiens, 1992). This thereotical

framework encorporates Aquatic-terrestrial ecotone concept (Naiman and Decamps,1990).

D. Hierarchy:

Recognition that ecological phenomena manifest across a diverse array of scales led to the development of the nested hierarchical model (Allen and Starr, 1982). According to Ward *et al.* 2002, perhaps its most important aspect is recognizing that phenomena structuring one hierarchical level may or may not be operative at another level. This was well exemplified by the investigation of Arscott *et al.* 2000 of the spatio – temporal heterogeneity at three hierarchical levels (corridor, floodplain and habitat scales) in six geomorphic reaches along a dynamic alluvial river system. This work clearly demonstrated that the patterns of variation were scale– and variable–dependent. This theoritical framework encorporates Catchment hierarchy concept (Frissel *et al.* 1986)

E. Connectivity:

The concept of connectivity originally referred to gene flow between sub populations of a meta population (Merriam, 1984). Connectivity is a relatively new concept in ecology and has only recently caught the attention of lotic ecologists. It encorporates Hydrological connectivity concept (Amoros & Roux, 1988).

1.4 Freshwater environment in Nepal

Water is one of the principal natural resources supporting the economy of Nepal (WECS, 2002). Nepal is rich in water resources. It doesn't constitute the marine and estuarine water and all the natural water available in Nepal can be categorized as freshwater. The freshwater is abundantly present in Nepal which is distributed in various water resources as shown in table 2.

Table 2: Surface freshwater resources of Nepal

Freshwater resources	Estimated area (ha)	Percent
Rivers	395,000	97.16
Lakes	5,000	1.23
Reservoirs	1,380	0.34
Village ponds	5,183	1.27
Total	406,563	100

Soure: DOAD/FDD, 1992, MFSC, 2002

The table 2 shows that river constitutes more than 97 % of the surface freshwater resources indicating that rivers are the important source of freshwater resource in Nepal.

1.5 River system in Nepal

There are over 6,000 rivers and rivulets 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 (Pradhan, 1998). The total drainage area of all rivers that flow through Nepal is about 194,471 km^2, out of which 76% is contained within the country. Drainage areas of 33 of Nepal's rivers are greater than 1,000 Km^2 (WECS, 2002).

In Nepal, there exist three types of rivers based on the nature of their source and discharge. a) The first category are perennial rivers that originate in the Himalayas and carry snow–fed flows with significant discharge, even in the dry season. These include the Koshi, Gandaki, Karnali, and Mahakali river systems. b) The second category are the Mechi, Kankai, Kamala, Bagmati, West Rapti and Babai rivers which originate in the Midlands or Mahabharat Range of mountains and are fed by precipitation as well as groundwater regeneration, including springs. Although these rivers are also perennial, they are commonly characterized by a wide seasonal fluctuation in discharge. c) The third category of river systems includes a large number of small rivers in the Terai (Southern plains), which originate from the Southern Siwalik Range of hills. These rivers are seasonal with little flow during the dry season, but characterized by flash floods during the monsoon (Sharma, 1977; WECS, 2002).

However, there exist four major river systems in Nepal based on the catchment boundary, that drain out the country. They are Saptakoshi river system in the east, Sapta Gandaki System in the central, Karnali system in the west and Mahakali system in the far west. Out of the four, the three: Saptakoshi, Sapta Gandaki and Karnali cross Himalayas and originate from the Tibetan plateau. Besides these, except Brahmaputra and Indus no other river cross Himalayas (Sharma, 1977).

1.6 The Bagmati River basin

The Bagmati river at present starts from the Southern slope of Shivapuri lekh (ridge) at an elevation of about 2650 meters (HMG 1969), north of Kathmandu basin and flows straight to South-West cutting the Mahabharat range. It appears that the present nature of rivers came into existence in Pleistocene times when the Kathmandu lake disappeared (Sharma, 1977). In the upstream region near Sundarijal, two streams: the Nagmati and the Syalmati come to join this rivers. The valley basin begins some kilometres below Sundarijal over which it flows to the south, turns to the west and again runs to the south and the west and then finally to the sout-west. In valley basin, the Manahara river with its tributaries such as the Salinadi, the Ghatte Khola, the Manamati, the Mahadev Khola, the Hanumante and the Kodku, joins the Bagmati river at Sankhamul Dovan. Before the Bagmati turning to the south at Teku, joins with 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 Chobar gorge (Pradhan, 1998). Bagmati first flows to southwest from Kathmandu upto Jhanalkot from there to Gangate in south and later on south east and makes U bend at Betehani. Up to Hariharpurgarhi to south easterly direction, and finally to the south. The drainage area is 2720 sq. km. The average discharge is 161.6 m^3/s when the maximum happens to be 2810 m^3/s (Sharma, 1977).

1.7 Water quality assessment using chemical methods

Water quality index is developed to assess the water quality of water systems. A water quality index (WQI) as defined by Lohani, 1981 is a rating reflecting the composite influence on overall quality of a number of individual quality characteristics. It is a tool that compares large amounts of data to standards and consolidates the information into an index score. The standards can come from the state, federal on tribal level. Ott, 1978 described six possible uses of indices: resource allocation (in allocating funds and determining priorities), location ranking, standards enforcements, trend analysis, public information and scientific research. The index also looks at the water body as a whole. This means that variations in water quality which are highly localized may not be immediately evident. Another change not necessarily reflected in the index is that to the habitat of fish as water quality on which the index is based, does not always account for habitat problems such as low water levels, high stream velocities or disruption of gravels. These factors would be incorporated into an ecosystem index, the development of which remain a challenge for the future (After Shrestha, 2005).

There exists number of chemical indices for water quality assessment such as River classification based on dissolved oxygen absorption test (now known as BOD_5) setup by Royal Commission on Sewage Disposal in 1898 in UK (After Hynes, 1978); Horton's Water quality index based on sewage treatment, dissolved oxygen, pH, Coliform density, specific conductance, carbon chloroform extract, alkalinity and chloride (Horton, 1965); Water quality index using Delphi method developed by Rand Corporation including dissolved oxygen, faecal coliform, pH, BOD_5, nitrates, phosphates, temperature, turbidity, total solids, hardness, carbon chloroform extract, phenol, radioactivity (β particle), conductivity, pesticide and toxic elements (After Lohani, 1981) and water quality index developed by Brown *et al.* 1970 considering 9 different parameters such as oxygen saturation, total number of coliforms, pH, BOD_5, NO_3, total phosphate, temperature, turbidity and total suspended matter.

The National Sanitation Foundation (NSF) developed WQI by taking opinions of 142 water quality experts from throughout the US in 1970 by considering eight individual variables (DO, faecal coliforms, pH, BOD_5, nitrates, phosphates, temperature,

turbidity and total solids) and two group variables (toxic substances and pesticides) as optional for users (Brown et al, 1970; Landwehr *et al.* 1976); WQI developed by Prati *et al.* 1971 incorporating 13 parameters (pH, DO, BOD, COD, permanganate value, suspended solids, NH_3, Cl, Fe, Mn, alkyl benzene sulphonates and carbon chloroform extract) of equal weight; WQI developed by Inhaber, 1974 dealing with industrial and domestic pollution in river water. Inhaber, 1974 has described a system based on two distinct sub indices. The first deals with industrial and domestic pollution in river water and is a pollutant source sub – index based on effluents from point sources. Here the pollutant variables are measured in effluents from five sources (municipal wastes and the petroleum – refinery, chlor – alkali, fish – processing, and paper industries). The second sub – index deals with ambient water quality and is in turn comprised of three sub – indices: (a) a trace metals sub – index based on cadmium, lithium, copper, zinc and the hardness of water; (b) a turbidity sub – index; and (c) a commercial fish catch sub index based on the weight and mercury content of fish. Altogether there are eight parameters in the second sub – index. The two sub – indices are given equal weighting and are averaged by successive root mean square operation to give the WQI which ranges from zero for the best water quality, to increasing numbers for progressively deteriorating water quality.

Harkins, 1974 described another system based on the rank order of observations. It is an application of Kendall's non-parametric classification procedure. The values for each parameter are given numerical rankings which are then related to the ranking of a selected 'control value' (usually a water quality standard or recommended limit) for that parameter.

Establishment of the water quality rating curves and associated weightings enabled a systematic study of six different methods of computing WQI (Botton, 1978). The six methods are unweighted arithmetic, solway and geometric index. The solway River Purification Board of UK has been using the weighted Solway index for several years and has found that it provides a satisfactory valuation of the middle and poor ranges of water quality. The index tends to be less than the numerical assessment of high quality water but, with usage, it has been possible to interpret the index in this situation. Similarly, LAWA, 1980 has developed scores in reference to saprobic

water quality class and saprobic index for the chemical parameters like BOD_5, NH_4 – N and oxygen (After Doetsch, 1987).

Bach, 1980 developed Bach waer quality index using eight physico-chemical parameters such as temperature, oxygen saturatin, BOD, pH, NO_3-N, PO_4-P, NH_4-N and electrical conductivity the easily measuriable parameters and which is extensively used (Pradhan, 1998). Similarly, Ministry of Public Transport and Public Work, 1989 developed Netherlands water quality index based on oxygen saturation, BOD and NH_4-N which is simple for application. Both of thes methods are applied in the present study (Poudel, 2005).

1.8 Water Quality assessment using biological methods

Organisms studied in situ can show the integrated effects of all impacts on the water body, and can be used to compare relative changes in water quality from site to site, or over a period of time (UNESCO, 1996). Community – based studies of macro-invertebrates form the basic of most biological studies of water quality chiefly for three reasons: first, macro invertebrates 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 (Cairns, *et al.* 1993 after Pradhan, 1998).

The history of surface water quality assessment based on biological methods started more than a century ago with Kolenati, 1848; Hassal, 1850 and Cohn, 1853 who observed that occur in polluted water are different from organisms that occur in clean water. Hundreds of methods for biological water quality measurement have been developed since that period (Schwoerbel, 1970; Sladecek, 1973a; 1973b; Pittwell, 1976; Persoone and De Pauw, 1979; Illies and Schmitz, 1980; Woodiwiss, 1980; Wright *et al.* 1984, 1988, 1989, 1993). Basically, there are three approaches developed for biological assessment of water quality which are as follows (Sharma, 1996). a) Saprobic approach b) Community structure approach c) Biotic approach

a) Saprobic approach

At the very beginning of the twentieth century the effect of point source pollution from sewage discharges on aquatic fauna and flora downstream of urbanized areas became evident. Two German scientists Kolkwitz and Marsson, 1902; 1908; 1909 and Kolkwitz, 1935; 1950 were the first to exploit these effects and present a practical system for water quality assessment using biota. Their system known as the saprobic system, has been used mainly in central Europe. The system was revised by Liebmann in 1951 and 1962, and valuable improvements were made by Sramek-Husek, 1956 (UNESCO, 1996; Sharma, 1996). The main advantage of saprobic approach is that it includes a wide range of taxa and communities and is thus applicable to all types of river (De Pauw and Hawkes, 1993 after Sharma, 1996). Specific criticism of the system is the requirements of more time and sound biological knowledge.

Kolkwitz and Marsson (1902, 1908, 1909) jointly introduced the concepts of "Biological Self Purification" with three distinct zones of decreasing pollution. These zones are termed as: Polysaprobic, Mesosaprobic and Oligosaprobic zone. Each zone affords optimal conditions for certain species and the communities of the organisms in turn behave as "biological indicators of organic pollution". Kolkwitz and Marsson (1908, 1909) further divided the mesosaprobic zones as α – mesosaprobic and β - saprobic giving four zones as given below and developed a list of 360 indicator plants and 500 indicator animals (after UNESCO, 1996; Sharma, 1996).

i) Oligosaprobic zone (no pollution or very slightly pollution)

ii) β - saprobic zone (moderate pollution)

iii) α – mesosaprobic zone (severe pollution)

iv) Polysaprobic zone (extremely severe pollution)

Similarly, the saprobity system is extended by subdivision of zones of greater pollution (after Shadecek, 1961).The success of this system lies in the precise taxonomic investigations to the species level. As the taxonomy of benthic macroinvertebrates is relatively well known in central Europe, it has enabled the scientists to use the saprobic system leading to the development of Saprobic Tables. According to UNESCO, 1996 and Sharma, 1996, Pantle and Buck, 1955a, 1955b were the first to design the saprobic Index. The saprobic 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 β - mesosaprobic, 3 for α – mesosaprobic and 4 for poly-saprobic (After Pradhan, 1998).

According to UNESCO, 1996, saprobic index has been modified by Liebmann, 1962. The frequency of occurrence of each species at the sampling point, as well as the saprobic value of that indicator species are expressed numerically. The frequently rating or abundance(a) are 1 for " random occurrence", 3 for " frequent occurrence", 5 for " massive development and the preferred saprobic zones of the species are indicated by the numerical values, S with 1 for oligosaprobic, 2 for β - mesosaprobic, 3 for α – mesosaprobic and 4 for polysaprobic. For any given species i, the product of abundance a_i and saprobic zone preference s_i expresses the saprobic value S_i for that species, i.e. $S_i = a_i s_i$. The sum of saprobic values for all the indicator species determined at the sampling point divided by the sum of all the frequency values for the indicator species gives the saprobic Index (S) which can be calculated by:

$$S = \sum_{i=1}^{n}(s_i.a_i) \Big/ \sum_{i=1}^{n}(a_i)$$

The Saprobic Index S, a number between 1 and 4, is the "weighted mean" of all individual indices and indicates the saprobic zone as follows:

S = 1.0 - < 1.5 oligosaprobic

S = 1.5 - < 2.5 β-mesosaprobic

S = 2.5 - < 3.5 α-mesosaprobic

S = 3.5 - 4.0 polysaprobic

The saprobic index has been modified in many ways since its inception by Pantle and Buck 1955 a, 1955 b. For general use of indicators organism, Zehinka and Marvan, 1961 have added a saprobic valency and indicator weight to the original index of Pantle and Buck 1955a/b. The saprobic valency has expressed the relative frequency of the species in different degrees of saprobility on a scale that totaled 10 (after Pradhan, 1998). Further modifications of the system was done by Sladecek, 1973a; 1973b. Similarly, the revision of the work with new saprobic list containing easily determinable species and altered indicative weight was done in Germany (Friedrich, 1990). This revised system which has been abbreviated as DIN is now in use in Germany as a German Standard Method) (after Sharma, 1996). To make saprobic

water quality assessment more precise, saprobic list of indicator organisms has been revised in detail in Austria in " Fauna Aquatica Austria" edited by Moog, 1995. The catalogue also provides additional information regarding functional feeding group and expected and longitudinal zonal distribution of the taxa (after Pradhan, 1998). In Austria, the biological river quality assessment follows the principles of the traditional saprobic system which has been in recent years thoroughly revised. The clear guidelines for an ecologically oriented bioassay of the river quality of this has been provided by the Austrian Standards M 6232 (ÖNORM M 6232, 1995). In these guidelines, environmental factors such as river description, discharge regime, habitat structures and chemical characteristics; periphytic assemblages such as sewage bacteria, diatoms, saprobity index (excluding diatoms) and trophic considerations; and zoobenthos such as saprobity index and assessment of longitudinal zonation are taken into account.

b) Community structure approach

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 structures such as "richness" (number of species present), "evenness" (uniformity in the distribution of individuals among the species) and "abundance" (total number of individuals of each species present). Diversity index is based on the assumption that undisturbed environment will be characterized by a high diversity or richness, an even distribution of individuals among the species and moderate to high counts of individuals (Ghetti and Bonazzi, 1977; Mason *et al.* 1985). Diversity indices are probably best applied to situations of toxic or physical pollution which impose general stress (Hawkes, 1977). Abundance or diversity indices are most suitable for use with benthic organisms since plankton are mobile and may reflect the situation elsewhere in the water body rather than at the monitoring site such as Simpson index, Species deficit index, Margalef index, Shannon index, Evenness index and Similarity indices (UNESCO, 1996).

c) Biotic Approach

Alternative approach to the saprobic Index have been developed by Cairns *et al.* 1968; Woodiwiss, 1964; Chandler, 1970 and others. The biotic approach to biological assessment, as defined by Tolkamp, 1985 a/b is one which combines diversity on the

basis of certain taxonomic groups with the pollution indication of individual species or higher taxa or groups into a single index or score. These methods are based on the presence or absence of certain "indicator" groups and/or "indicator" species, at the sampling point. As with the saprobic Index, they are best suited to use in waters polluted with organic matter, particularly sewage, since the indicator organisms are usually sensitive to decreases in oxygen concentrations. However, a similar approach has recently been developed for the biological monitoring of acidification in streams and lakes using an "Acidification Index" based on the tolerance of invertebrates to acidification (Raddum *et al.* 1988; Fjellheim and Raddum, 1990) (UNESCO, 1996).

Numerous biotic indices methods have been developed for different regions in Europe and abroad such as Trent Biotic Index (TBI) originally developed by Woodiwiss, 1964 for assessing pollution in the River Trent in England and forms the basis for many similar types of index; Chandler Biotic Index (Chandler,1970) developed in the UK and Biological Monitoring Working Party (BMWP) founded by the Department of Environment, Standing Technical Advisory Committee on Water Quality (STACWQ) in 1976 developed a standardized biotic system for assessing the biological quality of rivers in England, Scotland and Wales (ISO – BMWP, 1979).

The other biotic indices are Indices Biotiques (IB) developed by Tuffery and Verneaux, 1968 for use in France and the Biologique de Qualite Generale (IBG) introduced by Verneaux *et al.* 1982, as a new method for assessing the quality of rivers and streams in France. The Belgian Biotic Index (BBI) combines the IB from France with the sampling method used for the Trent Biotic Index in the UK (De Pauw and Vanhooren, 1983); The Biotic Index for South African streams and rivers developed by Chutter, 1972 which although based on TBI, this approach is unique in the sense that change in score is done with respect to dominance share and every individual organism contributed to the index value (Metcalfe-Smith, 1994) (after UNESCO, 1996; Sharma, 1996; Pradhan, 1998).

However, in Nepal region four systems Orignal NEPBIOS (Sharma, 1996); NEPBIOS-BRS (Pradhan, 1998); GRS index (Nesemann, 2006) and Extended NEPBIOS (Sharma *et al.*, 2007 and obtained the research paper through personal communication) are developed for assessing river water quality using benthic

macroinverterbrates which gives equivalent saprobic water quality classes. Thus determined saprobic water quality classes have characteristics as mentioned below (Moog, 1991; Pradhan, 1998). These four biological assessment methods were used in the present study.

Water quality class I

Saprobity level: Oligosaprobic

Degree of pollution: No to very slight pollution

Water quality mapping color: Blue

This saprobity level represents:

i. Clean water with only very little amount of organic matter and only very little concentration of nutrients.

ii. Clear water with exception of glacier fed brooks (turbidity caused by weathering processes)

iii. Waters are well oxygenated with oxygen saturation about 100 %.

iv. No reduction phenomenon exist at all. Even fine sediments (silt, mud and sand) are of light or brownish colour and of high mineralogenic content.

v. 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 insects larvae (in medium and higher reaches several species of Plecoptera occur). Net spinning Trichoptera extremely scarce.

vi. Highly diverse insecta fauna of only few specimens.

vii. 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.

viii. Worms are mainly restricted to Planarians and Lumbriculidae (mainly Stylodrilus) and Haplotaxidae..

ix. Fish fauna in Europe and North American continent is dominated by salmonids.

x. River type: Springs, spring brooks, summer cold upper courses.

xi. Suitable water for all uses, especially drinking water supply, fishery, bathing and recreation.

Chemical Water quality characteristics of rivers/streams of Bagmati basin, Nepal:

	DO (mg/l)	O_2–sat. (%)	BOD_5 (mg/l)	PO_4–P (mg/l)	NH_4 – N (mg/l)	Chloride (mg/l)	Cond. (µS/cm)
Min-max	11.2-13.0	98-108	0.1-1.4	0.03-0.05	0.02-0.09	2.8-3.9	19-38
Mean	11.8	103	0.5	0.04	0.04	3.2	28

(Pradhan, 1998)

Water quality class I – II

Saprobity level: Oligosaprobic to beta-mesosaprobic

Degree of pollution: Little pollution

Water quality mapping color: Blue-green

This saprobic level represents:

i. Clean water with only very little amount of organic matter and only little concentration of nutrients.

ii. Clear water with exception of glacier fed brooks (turbidity caused by weathering processes).

iii. Oxygen saturation about 100 %.

iv. No reduction phenomenon exist at all. Even fine sediments (silt, mud and sand) are of light or brownish colour and of high mineralogic contents.

v. 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 insects larvae (Plecoptera, Ephemeroptera, Trichoptera, Water beetles). Net spinning Trichoptera may occur.

vi. Highly diverse insecta fauna of medium abundance.

vii. 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.

viii. Worms are mainly restricted to Planarians and Lumbriculidae (mainly Stylodrilus) and Haplotaxidae.

ix. Fish fauna?

x. River type: Springs, spring brooks, summer cold upper and medium courses.

xi. Suitable for all uses, especially drinking water supply for native people (accustomed to use), fishery, bathing and recreation.

Chemical Water quality characteristics of rivers/streams of Bagmati basin, Nepal:

	DO (mg/l)	O_2–sat. (%)	BOD_5 (mg/l)	PO_4–P (mg/l)	NH_4 – N (mg/l)	Chloride (mg/l)	Cond. (µS/cm)
Min-max	7.7-10.2	68-104	0.2-1.5	0.05-0.20	0.04-0.16	3.1-7.8	35-359
Mean	9.0	83	1.1	0.09	0.07	4.9	153

(Pradhan, 1998)

Water quality class II

Saprobity level: beta-mesosaprobic

Degree of pollution: moderate pollution

Water quality mapping color: Green

The beta-mesosaprobic level indicates:

i. Moderately polluted water with a higher amount of organic matter and higher concentration of nutrients.

ii. Clear with exception of glacier fed 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.

iii. Good oxygen saturation. Oversaturation and depletion may occur respectively.

iv. Only little reduction phenomenon 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.

v. 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.

vi. Highly diverse insecta fauna of high abundance.

vii. Growing abundance and diversity of chironomids: subfamilies Diamesinae and Orthocladiinae prevail in lotic sites, Tanytarsini and Chironomini in lentic sections.

viii. Although worms of any family occur, the oligochaete fauna consists mainly of Lumbriculidae (mainly Stylodrilus) and certain Naididae.

ix. Fish fauna?

x. River types: Moderately polluted brooks, upper and medium courses and unaffected lower courses.

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

Chemical Water quality characteristics of rivers/streams of Bagmati basin, Nepal:

	DO (mg/l)	O_2–sat. (%)	BOD_5 (mg/l)	PO_4–P (mg/l)	NH_4 – N (mg/l)	Chloride (mg/l)	Cond. (µS/cm)
Min-max	7.5-10.2	66-103	1.1-4.1	0.04-0.51	0.05-1.60	4.2-20.2	52-258
Mean	8.7	81	2.6	0.10	0.22	8.9	154

(Pradhan, 1998)

Water quality class II – III

Saprobity level: beta-mesosaprobic to alpha-mesosaprobic

Degree of pollution: Critical pollution

Water quality mapping color: Green-yellow

This transitional zone has the characteristics:

i. The water is obviously polluted with a higher amount of organic matter and higher concentration of nutrients.

ii. 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.

iii. The oxygen content indicates oversaturation and depletion respectively which may cause fish kills or injuries to sensitive species.

iv. Putrefactic conditions may occur in very fine sediments at lentic sites. At the surface, the fine sediments of lotic sites (sites, 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 (don't confuse with black spots caused by blue-greens).

v. Filamentous algae (eg. 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.

vi. The benthic invertebrate fauna consist only of more or less tolerant group: 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.

vii. Moderately diverse insecta fauna of high abundance.

viii. 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 (eg. Polypedilum) prevail.

ix. The oligochaete fauna may consist of Lumbriculidae (non Stylodrilus), Naididae may be numerous and certain Tubificidae may occur in remarkable numbers.

x. Fish fauna?

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

xii. Conditioning for drinking water supply may be generally possible for native people (accustomed 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 fisheries 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.

Chemical Water quality characteristics of rivers/streams of Bagmati basin, Nepal:

	DO (mg/l)	O_2–sat. (%)	BOD_5 (mg/l)	PO_4–P (mg/l)	NH_4 – N (mg/l)	Chloride (mg/l)	Cond. (µS/cm)
Min-max	7.5-9.8	66-98	1.3-5.2	0.07-0.60	0.09-1.10	5.6-32.0	42-256
Mean	8.4	78	3.3	0.19	0.39	12.0	160

(Pradhan, 1998)

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:

i. The water is heavily polluted with a high amount of organic matter and high concentration of nutrients.

ii. 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 colours 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.).

iii. The oxygen content indicates oversaturation and heavy depletion respectively which periodically causes fish kills or injuries to sensitive species.

iv. 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.

v. Filamentous algae consist often of Stigeoclonium. Tolerant macropbytes may grow in high abundances, covering a big area of the river channel. Tolerant blue greens and tolerant diatoms (eg *Nitzschia palea*) may cover bigger areas in lentic zones. Sewage fungi (*Sphaerotilus, Fusarium, Leptomitus*) visibly grow in hard substrates or over benthic invertebrates which can be seen by naked eyes covering substrates and or animals

vi. 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.

vii. Poor fauna of high abundance.

viii. At specific sites a high abundance of chironomids may occur: besides tolerant species of the subfamily Orthocladiinae mainly Tanytarsini (mainly Micropsectra) and Chironomini prevail.

ix. The oligochaete fauna may consist of Lumbriculus, Naididae, Enchytraeidae and certain Tubificidae which may occur in remarkable numbers.

x. Fish fauna? Reproduction not always possible, periodical fish injuries.

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

xii. 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 endangers the risk of fish kills. The use of industrial water is possible with adequate treatment. Hydropower use cannot be recommended.

Chemical Water quality characteristics of rivers/streams of Bagmati basin, Nepal:

	DO (mg/l)	O_2–sat. (%)	BOD_5 (mg/l)	PO_4–P (mg/l)	NH_4 – N (mg/l)	Chloride (mg/l)	Cond. (µS/cm)
Min-max	4.1-8.6	36-86	2.9 - 25	0.05-1.28	0.10-12.6	7.8-43.2	109-277
Mean	5.9	65	11	0.48	4.9	16.4	192

(Pradhan, 1998)

Water quality class III-IV

Saprobity level: alpha – mesosaprobic to polysaprobic

Degree of pollution: very heavy pollution

Water quality mapping color: Yellow – red

This transitional zone indicates:

i. The water is very heavily polluted with a very high amount of organic matter and a very high concentration of nutrients.

ii. 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.

iii. The oxygen content indicates oversaturation and very heavy depletion respectively which does not enable a permanent fish live.

iv. 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 (ferrosulphide) at lentic sites and cover bigger areas at lotic sections. H_2S smell may be noticeable.

v. Algae mainly consist of Aufwuchs beneath the bacterial cover. Macrophytes cannot grow because of lacking light (turbidity). Sewage fungi grow in masses on hard substrates or cover benthic invertebrates. Sulfur bacteria may occur in visible spots (white to grayish cover).

vi. The microbentbic 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.

vii. Very poor fauna of partly high abundance.

viii. At specific sites (lentic sites) a high abundance of chironomids may occur: besides tolerant species of the Chironomini the Genus Chironomus prevails.

ix. The oligochaete fauna may consist of Enchytraeidae (*Lumbricillus*) and certain Tubificidae (*Tubifex, Limnodrilus*) which may occur in remarkable numbers.

x. Fish fauna? Reproduction not always possible, periodical fish injuries.

xi. River type: Very heavily polluted rivers where the assimilatory processes (production) are always lower than the reduction processes.

xii. The water is nearly unsuitable for every use with the exception of the introduction of sewage, because even the employment for irrigation is doubtful from hygienical point of view.

Chemical Water quality characteristics of rivers/streams of Bagmati basin, Nepal:

	DO (mg/l)	O_2–sat. (%)	BOD_5 (mg/l)	PO_4–P (mg/l)	NH_4 – N (mg/l)	Chloride (mg/l)	Cond. (µS/cm)
Min-max	1.2-6.5	11-71	4.6-78	0.51-1.30	1.0-12.6	12.7-49.2	150-534
Mean	4.1	47	29	0.91	4.9	33.3	291

(Pradhan, 1998)

Water quality class IV

Saprobity level: polysaprobic

Degree of pollution: extreme pollution

Water quality mapping color: Red

This saprobic zone describes:

i. The water is extremely polluted with a tremendous amount of organic matter and a very high concentration of nutrients.

ii. 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.

iii. The oxygen content indicates extreme oversaturation and depletion respectively which do not enable a permanent fish or water breathing benthic animal live.

iv. 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-Sulfide. 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.

v. Due to the enormous supply of anthropogenic "food" input, bacteria and other saprophytic microorganisms begin to increase rapidly. Organisms consist of bacteria, flagellates and free living, bacteriophagous ciliates, whereby the Colpidium-colpodae-assemblage is the most typical community of this 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 colonize in these river reaches because of anaerobic conditions at certain times or because of darkness. The benthic invertebrates are restricted to species using breathing-tubes and therefore being 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.

vi. With the exception of air breathing animals nearly no higher life.

vii. Chironomids may occur only scarcely: besides tolerant species of the Chironomini the Genus Chironomus prevails.

viii. The oligochaete fauna may consist of Enchytraeidae (*Lumbricillus*) and certain Tubificidae (*Tubifex, Limnodrilus*) which may occur in extremely low numbers.

ix. No fish fauna.

x. River type: Extremely heavy polluted rivers where the assimilatory processes (production) are always lower than the reduction processes.

xi. The water cannot be used with the exception of possible sewage inputs.

Chemical Water quality characteristics of rivers/streams of Bagmati basin, Nepal:

	DO (mg/l)	O_2–sat. (%)	BOD_5 (mg/l)	PO_4–P (mg/l)	NH_4 – N (mg/l)	Chloride (mg/l)	Cond. (µS/cm)
Min-max	0.5-2.9	5.0-39	13-187	0.12-4.23	4.6-40.6	32.3-102.0	174-1025
Mean	1.8	19	74	1.92	18.0	65.9	513

(Pradhan, 1998)

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Review of literatures

According to the published literatures, Kirkpatrick can be considered as the pioneer scholar in the field of freshwater environment of Nepal who described about some fishes (*Tor spp., Schizothorax spp., Barilius spp.* and *Anguilla spp.*) of Trishuli river in 1793. In the nineteenth century only two researchers, Hamilton, 1819 and Airkinson, 1882 studied the fishes of Nepal. Hamilton, 1819 described the occurrence of two groups of fishes (mugils and carps) in the Hill regions of Nepal. This is considered as the first scientific report of fish from Nepal. Further Hamilton, 1822 listed fish fauna of Nepal in "an account of the fish found in the river Ganges and its branches". Atkinson, 1882 investigated fishes of Kumaon, Garhwal, Nepal and Tibet (Ranjitkar, 2006).

The study on freshwater environment of Nepal was mainly carried out after middle of the 20th century. During early and middle of the 20th century, only few scholars such as Boulenger, 1907; Rengan 1907; Hora, 1937/1939 and Menon, 1949 studied the fishes of Nepal. Hora, 1937/1939 described the fishes of rivers and pools of Halchowk, Mugling, Nagarkot and Sundarijal (Ranjitkar, 2006). Hora, 1940 also studied Katli of the Nepalese barbus (*Lissochilus hexagonalepsis*) of Nepal. Menon, 1949 investigated the distribution of 52 fish species in the Koshi River of Nepal.

The study on different fields of freshwater environment (Physico-chemical parameters of water, maroinvertebrates, Plankton, and fishes) of Nepal was carried out by various researchers only after 1950. Brehm, 1953 is considered as the pioneer scholar in the field of freshwater zooplankton of Nepal. He studied the occurrence of three genera of zooplankton (*Diaptomus, Pseudodiaptomus* and *Cladocera*) in Kali Pokhari Pond of eastern Nepal. Hirano, 1955, 1965 made an extensive study on freshwater algae of Nepal. He collected algae from various water bodies of Gorkha, Tanahu and Syanjya districts of Nepal and identified 271 freshwater algal species. He reported 4 new cosmarium species and a new genus, *Chaetomnion* (Ranjitkar, 2006). Dewitt, 1960 made a checklist of 102 fish species of Nepal belonging to 20 families.

Loffler, 1968/1969 is considered as the pioneer scholar in the field of limnological studies of lentic environment in Nepal. He studied the morphometry, physico-chemical parameters of water and plankton of 24 high altitude (4500 m – 5600 m above the sea level) lakes and ponds. He observed predominant of nematodes in most of the lakes. Molluscs, Isopods, amphipods and fish or any carnivorous animals were totally absent. He concluded that the most significant factors were change of light, temperature and water level between dry and rainy season due to the influence of the monsoon. Further, Hickel, 1973 made an extensive study on physico-chemical parameters of water and phytoplanktons of four lakes of the Pokhara valley. He identified altogether 76 species of phytoplanktons in the lakes of the Pokhara valley and observed the dominancy of Melosira islandica. He also described the distribution of phytoplanktons in two ponds of the Kathmandu valley.

Ferrow and Swar, 1978; Ferrow, 1978/1979; 1981/1982 made the limnological investigations of lentic environment of the Pokhara valley in order to make a plan for the management of fish culture. Swar and Fernado, 1979a/b sampled Cladocera from both lakes and rivers of the Pokhara valley. They identified altogether 23 Cladoceran species of which 11 species were recorded as new species. Swar and Fernando, 1980 reported the occurrence of crustacean zooplanktons in Begnas and Rupa lakes. Swar and Gurung, 1988 studied the impact of cage culture of exotic carps in Begnas lake.

Swar, 1980 has attempted to provide information of the status of limnological studies in Nepal before 1980. The second study is NPC/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.

Shrestha, 1980 investigated the water quality in the Bagmati River including the biological indicators of pollution and reported that the Bagmati River had been polluted for some years and was characterized by high turbidity, eutrophication and growth of pathogens due to the discharge of untreated sewage in the Kathmandu Valley. Khadka *et al.* 1981, Yadav *et al.* 1982 and Miyoshi, 1987 analysed water sample from Dhobi Khola to record physical, chemical and biological quality to observe impact of Bansbari Tannery's effluent.

Yadav *et al.* 1982 investigated the benthic macro – fauna of Bansbari Khola and Dhobi Khola in Kathmandu valley. Altogether 26 taxa were recorded at different sites of the both streams. The major groups of bottom fauna recorded were *Tubifera sp.*, Tipulidae, Dolichopodiae and Chironomidae. These groups of the fauna were found to be patchily distributed at the bottom of the streams. The water of Bansbari Khola was found chemically more polluted than Dhobikhola. The genus *Tubifera* was found to be most tolerant to the chemical pollution caused by discharges of Bansbari Leather and shoe factory in Bansbari Khola.

Miyoshi, 1987 observed that a high pollution load was noted just below the effluent discharge site, and significant dilution occurred as it reached the Dhobi Khola. The Bansbari Tannery's effluent volume was 240 m^3/day and the concentration of pollutants was very high (NPC/IUCN 1991). Upadhyaya and Roy, 1982 studied chemical parameters in six rivers and rivulets – Manahara, Dhobi Khola, Nakhu Khola, Balkhu Khola, Bishnumati and Bagmati. A wide seasonal variation was noted in water chemistry. This is to be expected as the quantity of rainwater discharged into the river varies with the seasons, the highest discharges being in the monsoon months from June to September. As the Manahara river does not pass through the city, it was not polluted with industrial and municipal discharges. The total dissolved solids (TDS) values for this river were comparatively lower than those for other sites. The values of water chemistry parameters in the rainy season were lower than those during the winter and summer seasons. This was due to increased water volume & dilution ratio.

Khadka, 1983; Napit, 1988; Pradhananga *et al.* 1988 and Vaidya *et al.* 1988 studied water quality in Pashupati area (NPC/IUCN, 1991). Khadka, 1983 studied major ions in the Bagmati river near Pashupatinath temple on the day of Mahashivaratri festival and found that the concentration of major ions, specially Na and Cl, was higher in sample collected downstream of the temple than upstream. The ion imbalance resulted from many people bathing in the Bagmati at the temple site during the festival. Napit, 1988 investigated pollution of the Bagmati river in Pashupati area. The author found that physical characteristics such as colour, turbidity and suspended particles

exceeded desirable levels. However, the chemical parameters tested did not exceed the WHO standards.

Pradhananga *et al.* 1988 tested water samples of the Bagmati river at different sites in the Pashupati area and found parameters sucha s pH, Conductivity, DO, PO_4 and NH_3 - N within the permissible value for water supply, fisheries and industry. However, the values for suspended solids and BOD exceeded WHO standards. Vaidya *et al.* 1988 studied pollution of the Bagmati river in the Pashupati area on the basis of a diversity index for macro – invertebrate fauna and found the level of pollution rising from low at upstream sites to moderate and high at downstream sites. The higher population of pollution – tolerant species in each sampling site during the month of May to August indicated that the pollution level increased in summer. They speculated that the high degree of pollution could be due to municipal discharge and agricultural runoff.

The most comprehensive study including biological assessment of surface water quality was conducted by DISVI, 1988, in cooperation with RONAST. Water samples and biological samples were collected from ten sampling stations, seven stations along the Bagmati river from Sundarijal to Khokna and three stations in the major tributary Manahara, Dhobi Khola and Bishnumati before their inlets to the Bagmati. Samples were collected and analyzed on alternate months from January to July. RONAST continued the study until September. DISVI, 1988 classified the Bagmati river into four distinct zones according to water quality class as determined by the extended biotic index (EBI). Various chemical Parameters such as COD, BOD, DO, NH_3 – N, O - PO_4, NO_3 – N, NO_2 – N, pH, temperature and conductivity have also been examined to determine the river water quality with similar results to those using the EBI. The distinct zones are: zone of good ecological conditions (class I) from the source to Guheshwori temple; zone of slightly polluted conditions (Class II) from Pashupati to the inlet of the Dhobi Khola; zone of severe pollution (Class V – III) from the Patan Bridge to Chobar; and zone of pollution (class III) from Chobar to Khokna. The diversity of macro – invertebrates was higher in the unpolluted zone of the river than in the polluted zone. Only a few taxa were reported present in the polluted zone. The river water quality varied with seasonal variation. Pollution load was highest in Summer, while it decreased in winter and during the rainy season.

Among the three important tributaries studied, the Manahara river contributed less pollution load to the Bagmati river than the Dhobi Khola & Bishnumati rivers. The Manahara at Phulbary (Sankhamul dovan) had acceptable chemical water quality. However EBI was 9 indicating water quality class II i.e. slightly polluted. The discrepancy between the chemical and biological results is probably due to dredging activities that disturbs benthic community. The study reported a benthic community with a high number of groups, average 18 groups with the Ephemeroptera as dominant organisms and the presence of Trichoptera. In summary, the Bagmati River and its tributaries maintain good chemical and biological quality until they enter the urban areas where they receive untreated sewage.

DISVI, 1989 concluded that contamination of drinking water of city supply was mainly due to the infiltration of sewage into drinking water pipelines. It found the average value of total coliforms increased almost twenty times from the treatment plants to the distribution system with the numbers of samples without coliform organisms dropped from 77 % at the treatment plants to 30 % in the distribution system. On the other hand, it was speculated that the increase of total inorganic nitrogen (NH_3 – N, NO_3 – N, NO_2 – N), chlorides and phosphates was due to infiltration of polluted waters.

CEDA, 1989 studied the environmental problems due to urbanization in Kathmandu, Pokhara and Biratnagar. It investigated the chemical and bacteriological pollution of surface water, drinking water, sewage and effluent from industries. The level of total coliform and faecal coliform in the Bagmati, Bishnumati and Dhobi Khola rivers was found to be a staggering 720,000 cfu/100ml in each river of the chemical parameters tested, only the Chloride value in each river and COD in Bishnumati river proved to be higher than the WHO standard. Dissolved oxygen (DO) in the Bagmati and Bishnumati rivers was slightly lower than the desired level of 6 mg/L which suggests that at times of low flow these rivers may be susceptible to eutrophication or anaerobic condition. Water of the Dhobi Khola showed chromium (Cr) level of 0.10 mg/L, probably due to the discharge of Bansbari tannery effluent into the river. On the other hand, the result of test of industrial effluents of Bansbari Shoe factory, Balaju Industrial District, carpet factory and sewage of Bauddha, Balaju and Kalimati showed that number of coliform group of bacteria was high (> 4800 cfu/100ml). The

effluents were with high level of chemicals too. The highly toxic chromium was found up to 1600 ppm in the effluent from Bansbari shoe Factory, which was directly mixed to the Dhobi Khola without any treatment. Some effluent showed anaerobic condition, i.e. the dissolved oxygen was nil.

Shrestha, 1990 investigated water samples from the Bagmati River for organic pollution. The author found that the river had definite zones of pollution depending on proximity to urban areas and industry. The Bagmati was classified into six zones – a healthy zone, moderate upstream pollution zone, polluted zone, moderate downstream pollution zone, recovery zone and clear zone. The chief sources of pollution were identified as domestic wastes; garbage; faecal matter; finely divided organic matter in suspension; detergents; acid, alkalies and salts from hospitals, laboratory, tanneries and distillery; and petroleum products from laundries & automobile workshops. The Dhobi Khola and Tukucha contributed much in pollution of the Bagmati river.

NPC/IUCN, 1991 reviewed the previous studies on environmental pollution in Nepal including water pollution, air pollution, land pollution & noise pollution. The condition of Bagmati river and two of its tributaries, Dhobi Khola and Tukucha, has been studied. The capacity of these rivers to sustain aquatic life approached zero at points adjacent to and downstream of urban Kathmandu. At times, the adverse effects of direct discharge of sewage and untreated industrial effluents to the Bagmati river could be seen upto 10 km downstream of Kathmandu. On the other hand, higher bacteriological and chemical contamination was found in water from wells, tubewells and stone spouts, almost all the chemical parameters tested from these sources exceeded international standards. Industrial discharge, sewage seepage and poor hygienic practices around the wells were the major factors found to be contributing to the poor state of Kathmandu groundwater.

The urban water supply and sanitation Rehabilitation project (UWSSRP), 1991 included a study to document the major environmental problems and their causes and the status of river quality. It reviewed the government responses to these problems and proposed monitoring schedules. Water samples from 35 locations, including the Manahara, Hanumante, Dhobi Khola, Tukucha and Bishnumati rivers were collected and analyzed in November 1999 and formed the basis upon which a future monitoring

program was proposed. German Water Quality Classes (1987) were used to categorise the Bagmati and its tributaries into five categories: a) Bagmati river between Sundarijal to Nayapati designated as unpolluted (Class I); b) Bagmati from Gokarneswor to Guheshwori designate as polluted (Class III); c) River water near Pashupati temple highly polluted (Class IV); d) Bagmati after mixing with Manahara upto Dhobi Khola confluence polluted (Class III); and e) Downstream from Thapathali to Chobar gorge extremely polluted (Class V) (Stanely, *et al.* 1994).

NPC/IUCN, 1992 conducted pollution control study of Balaju Industrial district (BID) as a component of National Conservation Strategy Implementation Project. There were 73 industrial production/processing units, out of which 60 were operating, 11 non – operating and two were under construction. It studied water pollution, air pollution, land pollution and noise pollution of BID. Water pollution was concluded to be the major environmental problem at BID. Although some changes in chemical concentration occurred in morning and afternoon, the study showed that effluent samples had high pH and COD values than the proposed tolerance limits for industrial effluents discharged into inland surface water established by the Nepal Bureau of Standards and Metrology (NBSM) (HMG/NBSM, 1987). The reason for high pH was most likely due to the alkaline nature of the water source and industries like Bottlers Nepal, Balaju Kapada and Crystal Woolen used caustic soda & soap for cleaning purposes. Similarly it was expected that the high COD values were caused by organic effluent from industries like Balaju Kapada, Kathmandu Milk Supply & others. Even though BOD was not measured, it was expected that effluent from these industries had high BOD concentrations.

Halcrow Fox and Associates, 1992 prepared the Kathmandu Valley Urban Development Plans and Programs and assessed the environmental policy. This study also collected primary data from Manahara, Hanumante, Bishnumati, Bagmati, Dhobi Khola and Tukucha rivers and compared all the parameters with WHO standards. The parameters analyzed were pH, TDS, DO, BOD, COD, NH_3 – N, NO_2 – N, Chloride, O – PO_4 – P, Total Coliforms, Chromium, Arsenic, and Copper. Important conclusions of the study are (Stanely *et al.* 1994):

a) The upper part of Bagmati river was unpolluted.

b) Manahara appeared to be relatively clean throughout.

c) From Pashupati area to Dhobi Khola confluence, the pollution increased moderately.
d) From Patan bridge to Chobar the water quality was severely polluted.
e) During monsoon, the flow of the Bagmati River effectively assimilates and dilutes all pollution.
f) Hanumante received effluent from Bhaktapur but, except for phosphate and coliforms, all other usual parameters were within acceptable limits.

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 landuse. 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 continous habitat degradation in the downstream Karnali in the Terai due to the construction of dam or impoundment in the upstream Karnali (after Pradhan, 1998).

Stanely, *et al.* 1994 carried out the extensive study on the Bagmati basin to assist HMG Nepal with the pre – feasibility identification and assessment of practical measures and investments that can improve the environmental quality of water resources in the Bagmati River Basin. The study incorporated the analysis of physico – chemical and biological characteristics of water at 16 locations including one at each Manahara and Hanumante river. They calculated water quality index on the basis of oxygen saturation, BOD and NH_3 – N following the recommendations from Ministry of Transport and Public works, Netherlands (Hong kong Environmental Protection Department Publication, 1988). The study showed that the Bagmati, Bishnumati, Dhobi Khola and Tukucha rivers were extremely polluted. It confirmed that municipal sewage was the main source of pollution. This resulted in a very low dissolved oxygen (Sometimes zero), high BOD and high NH_3 – N concentrations. Heavy metal concentrations in the Bagmati and its tributaries were extremely low. Chromium in Dhobi Khola from the tannery was the main concern. Manahara just before confluence with Hanumante had "Excellent / Good" water quality condition throughout the year. However Hanumante just before confluence with Manahara had

"Bad" water quality condition which was restored as "good" by monsoon – as indicated by Water Quality Index.

On the other hand, the biological sampling showed 21 taxa belonging to 5 invertebrates group including insects nymph/larvae (13 taxa), oligochaete worms (3 taxa), leeches (3 taxa), snails (2 taxa) and bivalves (1 taxon). On the basis of these, the dominant benthic macro – invertebrates were mapped. Four main regimes of benthic macro – invertebrate groups are delineated in the Bagmati river system:

a) The first macro – invertebrate group, comprising a diverse range of stoneflies, mayflies and bivalves, was confined to the upstream reaches the Bishnumati and Nakhu Khola.
b) The second macro – invertebrate group, dominated by the presence of blood worms (midge larvae) and beetles (Coleopteran), was confined to the upstream stretch of the Bagmati River and Manahara river.
c) The third group of benthic macro – invertebrates was dominated by blood worms and oligochaets and occupied most parts of the Bagmati River as well as in the Hanumante river, Dhobi Khola and Tukucha Khola.
d) The fourth macro – invertebrates group was only represented by one sampling location which was located downstream of the Bansbari Shoe Factory in the Dhobi Khola. At this site, only one insect larval taxon, the blood worm was recorded.

Similarly, on the basis of ecological indicators such as Phytoplankton, Zooplankton, Periphyton and Macrophytes, the Bagmati has been divided into five zones:

a) Healthy zone or Trout zone (Zone 0) that occurred upstream of Sundarijal.
b) Moderately polluted zone (Zone 1) that lied downstream of Sundarijal to Min Bhawan.
c) Polluted zone or catfish zone (Zone 2) near the urban centre of Kathmandu and Patan.
d) Recovery zone or Murrel zone (Zone 3) that occurred near Dakshinkali.
e) Clean zone (Zone 4) that occurred downstream of Pharping.

The Hydrology Division of HMG Nepal, 1996 has since 1992 initiated an attempt to collect Water Quality samples of some of the main rivers in the Kathmandu Valley, as

well as in other parts of the country with a view of monitoring river water quality. The study showed that Bagmati, Bishnumati, Dhobi Khola, Manahara & Hanumante rivers are all polluted.

ENPHO, 1997 assessed the water quality of Shivapuri Watershed as the Phase II of Shivapuri Integrated Watershed Development Project (SIWDP) from 1992 to 1997 to follow up the Phase I i.e. Shivapuri Watershed Mangement and Fuelwood Plantation Project (SWMFPP) (1985 – 1992). It studied eleven streams and two reservoirs in the headwater region of the rivers in terms of physico-chemical, microbiological and biological parameters/benthic macroinvertebrates (Extended Biotic Index). The result is that, with a high diversity of macroinvertabrates, the upstream region of the streams has shown the best water quality in terms of both biological and chemical parameters. In most of the streams and most of times, the Water Quality Class is I "Unpolluted" or Class II "Slightly polluted".But bacteriologically, waters of all the streams except a sample in 2nd sampling of July in Bishnumati Dwar were contaminated with faecal coliform and water of all the streams contained faecal *streptococcus*.

Ground Water Resources Development Board, 1997 showed that the shallow aquifer in the Kathmandu Valley is extensively polluted by sewage. Overall faecal contamination was present in almost 60 % of groundwater samples from dugwells and shallow tubewells in the shallow aquifer. The most significant pollution of the shallow aquifer was beneath the old cities of Bhaktapur, Kathmandu and Patan. The sources of contamination are presumed to be infiltration from leaking sewer pipes & septic tanks. The study indicates the posiibility of contaminants infiltrating from the polluted rivers to the shallow aquifer and recommends for further investigation.

Groundwater Resource Development Project (GWRDP), 2001 conducted a study during premonsoon of the year in 17 locations where 10 stations were on Bagmati and 7 stations were on its main tributaries. It concluded that water quality becomes worse. From bacteriological point of view, the water quality along the Bagmati river and that of tributaries was heavily polluted as indicated by very high concentration of total coliform bacteria. The concentration of toxic metallic ions like As, Cr, Cd, Hg, possess no significant threat. Pollution increases as river enters urban area & gets improved as it flows further away from the urban areas. Among the six major

tributaries, Manahara has highest discharge. GWRDP, 2003a; 2003b; 2004 reported the similar results. The rivers were heavily polluted bacteriologically.

Sharma, 1996 developed the biological method for water quality assessment for Nepal named as Nepalese Biotic Score (NEPBIOS) method which combines the significance of two traditional systems: the central European saprobic system and the score method proposed by Biological Monitoring Working Party (i.e. BMWP/ ASPT method). In the NEPBIOS, a total of 103 families are listed as shown in Appendix XXII. Eighty two families are scored and twenty one families are left unscored. Of the unscored families, Baetidae and Chironomidae are scored to selected generic and species level respectively. Some genera of Ephemerellidae, Heptageniidae, Hydraenidae and Perlidae are rescored besides family level scoring. The average scores per taxon based on Nepalese Biotic Score (NEPBIOS/ASPT) values are calculated by summing the individual taxon i.e. to family or generic or species level as defined in the score list present in a sample and divided by the number of scoring taxa. In other words, NEPBIOS is the total individual score summed up and ASPT is average score per taxon, previous when divided by the later gives NEPBIOS/ASPT. Once NEPBIOS/ASPT is calculated, it is transformed to equivalent seven saprobic water quality classes as given in table 3.

Table 3: NEPBIOS/ASPT transformation scale

NEPBIOS/ASPT	Equivalent Saprobic Water Quality classes
8.00 – 10.00	I
7.00 – 7.99	I – II
5.50 – 6.99	II
4.00 – 5.49	II – III
2.50 – 3.99	III
1.01 – 2.49	III – IV
1	IV

(Source: Sharma, 1996)

Pradhan, 1998 proposed Nepalese Biotic Score-Bagmati Biotic Score (NEPBIOS-BBS) by studying the Bagmati river of Nepal. To make Saprobic Water Quality class

more precise out of 71 total families, 54 families are given score in the family level, 12 families are given in genera and species level and the rest 5 families are unscored due to less number of occurrences in the sampling sites. The author strengthened NEPBIOS with 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. While comparing this scores between NEPBIOS and NEPBIOS-BRS, out of 82 scored families of NEPBIOS, 17 families got the same score while the rest of the families got different scores.

Nesemann, 2006 developed GRS (Ganga River System) index based on results of fieldwork in the years from 2000 to 2006 in Nepal and India covering all biocentric regions from the water bodies of the Trans – Himalayan zone in Mustang, Nepal (elevation of 3900 meter above sea level) to the tidal zone of Hugli River in the Gangetic delta, India. It includes a total number of 171 families of Porifera, Cnidaria, Platyhelminthes, Nemertini, Nematomorpha, Arthropoda, Annelida, Mollusca and Bryozoa. The catalogue of GRS – index contains 420 taxa with indicator value which are classified according to their sensivity to organic load, pollution and to their saprobial distribution. Thus developed GRS index was tested in several rivers and streams of the Nepalese Middle streams in the Dhulikhel and Bhaktapur area including the Manahara river. It is recommended to use GRS index in Nepal, Northern India, Bangladesh and Bhutan as it gave more exact results than the original NEPBIOS. He applied GRS index at disturbed and undisturbed sites of Manahara river near Bodegau which were found as water quality class III for the both.

Most of the above studies were concentrated on the main stretch of the Bagmati river and on its tributaries just before entering into the Bagmati river. These studies have given less importance to the whole stretch of the Manahara river.

Many dissertation works have been carried out to study the relationship between benthic macroinvertebrates and physico-chemical parameters in Manahara river. Adhikari, 1992; Rai, 1992; Singh, 1992; Subba, 1993; Rai 1994; Karki, 1995; Tamrakar, 1996; Shrestha, 1996; Khadka, 1996; Kadel,1997 studied the distribution and abundance of benthic macroinvertebrates in relation to physico-chemical parameters in Manahara river. Most of the researchers found 8 orders/groups such as

Diptera, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Plectoptera, Coleoptera and Oligochaeta at different sites of the Manahara river. Species diversity was found high at unpolluted sites which lied at upstream part whereas species diversity was found low at polluted sites that lied at downstream region of the Manahara river. These researches studied the macroinvertebrates upto order level only. They lack the use of benthic macroinvertebrates for the assessment of water quality of Manahara river.

Kafle, 2006 studied the effluent from two industries namely beverage industry and Carpet industry and their subsequent effect on water quality of Manahara river. It revealed that effluents from both industries are polluting the river waters and not complying with existing legal standard. The river was progressively polluted from upstream to downstream. But biological aspect is totally neglected.

Hence, the complete assessment of water quality of Manahara river including freshwater ecology and use of benthic macroinvertebrates as bioindicators for river water quality monitoring are essential for the successful river basin planning and management.

2.2 Rationale of the study

The Manahara river serves as recharging zone for surrounding ground water. It recharges water in the dug wells and tube wells of Nepal Water Supply Corporation (NWSC) at Bode and Lokanthali. The dug wells on the bank of Manahara river at Bode, supply 24 million litres daily (MLD) water to Madhyapur Thimi Municipality, Bhaktapur Municipality and Baneshwor area of Kathmandu Metropolitan City (Field survey, 2005) Similarly, the Manahara river is an important source of irrigation for agricultural field on both sides of the river from Sakhu, the upstream region to Narephaant, the downstream region. Particularly, the Madhyapur Thimi (Bode, Nagadesh and Lokanthali near the river) lying on the left bank of the river, is the fertile land which supply vegetables to the core residents of the Kathmandu valley. If the Manahara river is polluted, drinking water supply of NWSC will be contaminated, the quality & quantity of vegetable and other agri-production will be affected. Moreover, thousands of people from the surrounding have been using the water for

washing and bathing purposes as well as by the children for recreational swimming. The Manahara river has religious importance too. The Salinadi, the upstream part of the Manahara river is the sacred place of Hindu which is visted by Hindu people annually which should be preserved from any kind of pollution. Thus, the Manahara river has high socio–economic, cultural and environmental importance.

During the past years, the quality of the water is continuously degrading. The water quality of Manahara river was found good throughout the years in whole Manahara Stretch by Upadhyaya *et al.* 1982; DISVI, 1988 and Halcrow Fox and Associates, 1992. However, Stanely *et al.*1994 found that the river was clean just before confluence with Hanumante river only. GWRDP, 2001; 2003a; 2003b and 2004 concluded that the water quality of Manahara became worse. Similar results are shown by several dissertation works carried in 1990s by Adhikari,1992; Rai,1992; Singh,1992; Subba,1993; Rai,1994; Karki,1995; Tamrakar,1996; Shrestha,1996; Khadka,1996; Kadel,1997; Kafle, 2006 on the Manahara river. But the integrated study by using chemical method and biolocical method in watershed approach are lacking. In addition, several biological assessment methods based on benthic macroinvertebrates are developed in Nepal and none of each is tested regularly in monthly basis in a complete stretch of a river/stream. Thus, the causes of the pollution and its control measures are to be identified for conserving river ecosystem as well as a simple scientific monitoring method for water quality monitoring of a river is to be identifed which will be helpful for planners and policy makers for successful river basin planning.

CHAPTER THREE

3. OBJECTIVES

3.1 Objectives of the study

General objective

To assess water quality of Manahara river based on physico-chemical parameters and biological components and use benthic macroinvertebrates as biological indicator for river water quality assessement.

Specific objectives

i) To analyze important physico-chemical parameters such as temperature, Secchi disc transparency, mean depth, velocity, discharge, pH, dissolved oxygen, Biochemical Oxygen Demand, free carbondioxide, total alkalinity, bicarbonate, hardness, calcium, magnesium, chloride, ammoniacal nitrogen, nitrate nitrogen, ortho-phosphate, electrical conductivity and total dissolved solids and biological components such as total coliforms and macro-invertebrates (density, Shannon diversity index, evenness index and index of dominance) of the river.

ii) To study the monthly and spatial variation of physico-chemical parameters and biological components of the river ecosystem.

iii) To assess the effectiveness of the biological assessment methods based on benthic macroinvertebrates for water quality assessment developed in Nepal.

iv) To prepare water quality map of Manahara river using chemical index as well as biological index based on macroinvertebrates.

v) To study the existing legislation in Nepal for the control of water pollution.

3.2 Limitations of the study

The limitations of the present study are mentioned as follows.

a. Most of the macroinvertebrates were identified upto family level because of the lack of idenfication keys of this region/Nepal and technical manpower.

b. There is the limitation of time in the present study.

CHAPTER FOUR

4. STUDY AREA

4.1 Geography

The Kathmandu valley lies in the central hill region of Nepal. The valley with bowl shape is 899 sq. km (Rimal *et al.* 2006). The valley comprises of three districts, viz. Bhaktapur, Kathmandu and Lalitpur. The floor of the valley lies at an average elevation of 1250 m from the mean sea level from which mountains rise steeply on all sides above 1800 m, the highest being the Phulchowki ridge with elevation of 2831 m in the east (Pradhan, 1998). The Manahara watershed is located in the east of the Kathmandu valley having the drainage area of 256 sq.kms which is shown in figure 1. The Manahara river originates from Manichud Lekh (ridge) at an elevation of 2352 m and having a length of 30 km. (Survey Department, 1995).

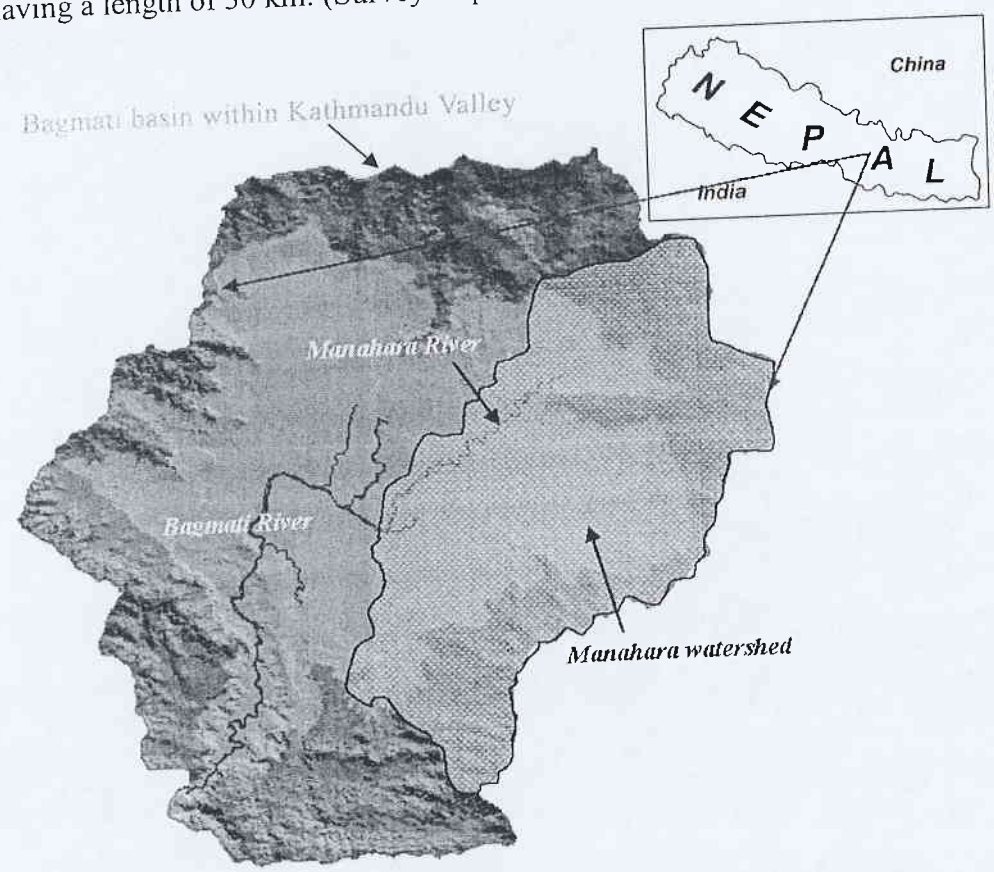


Figure 1: Location map of the study area in relation to the Bagmati basin with Kathmandy valley

The drainage basin of the Manahara river is presented in figure 2. It contains three subwatersheds namely Upper Manahara, Hanumante and Kodku subwatershed as shown in figure 2.

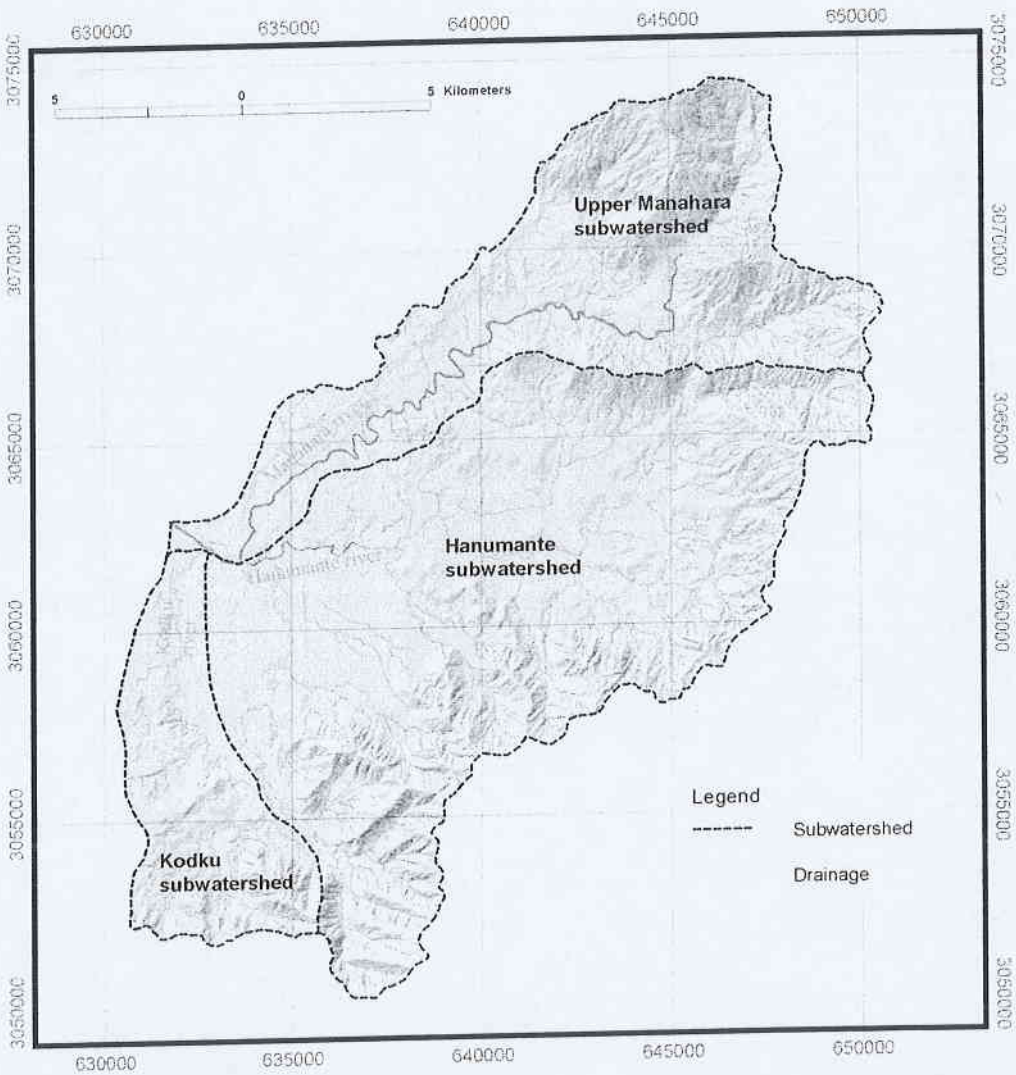
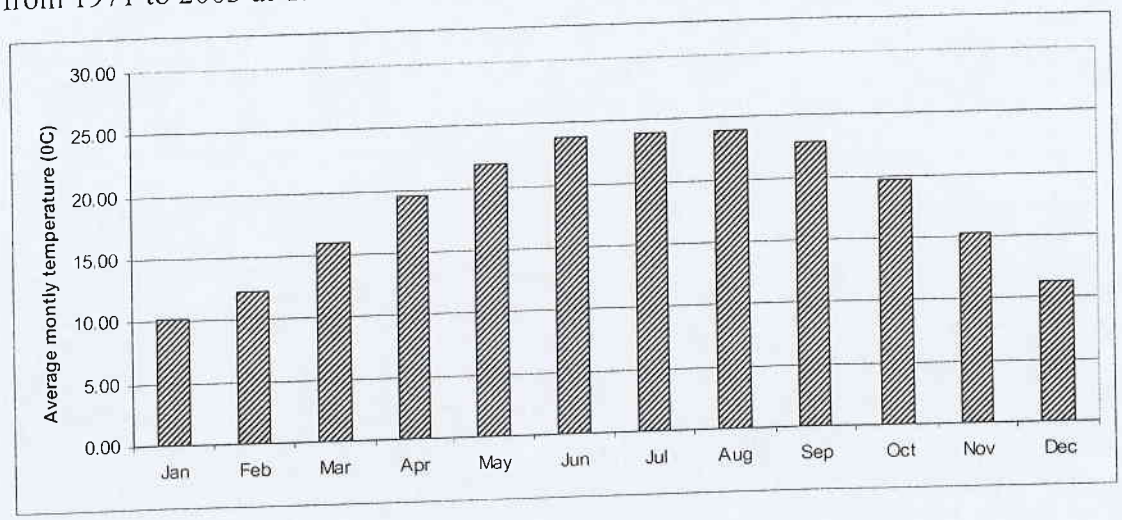


Figure 2: Drainage basin ot the Manahara river

3.2 Climate

The Kathmandu valley containing the Manahara watershed lies in temperate climatic zone. But the altitudinal variation between the valley floor and ridge give rise to different type of climate: warm temperate climate at the valley floor and cool temperate climate at the ridges (Pradhan, 1998). The mean monthly maximum temperature occurs in the month of July. The mean air temperature rises during the pre-monsoon, reaches maximum in July-August (Monsoon), declines in the post-monsoon period and further declines to a minimum value in the month of January

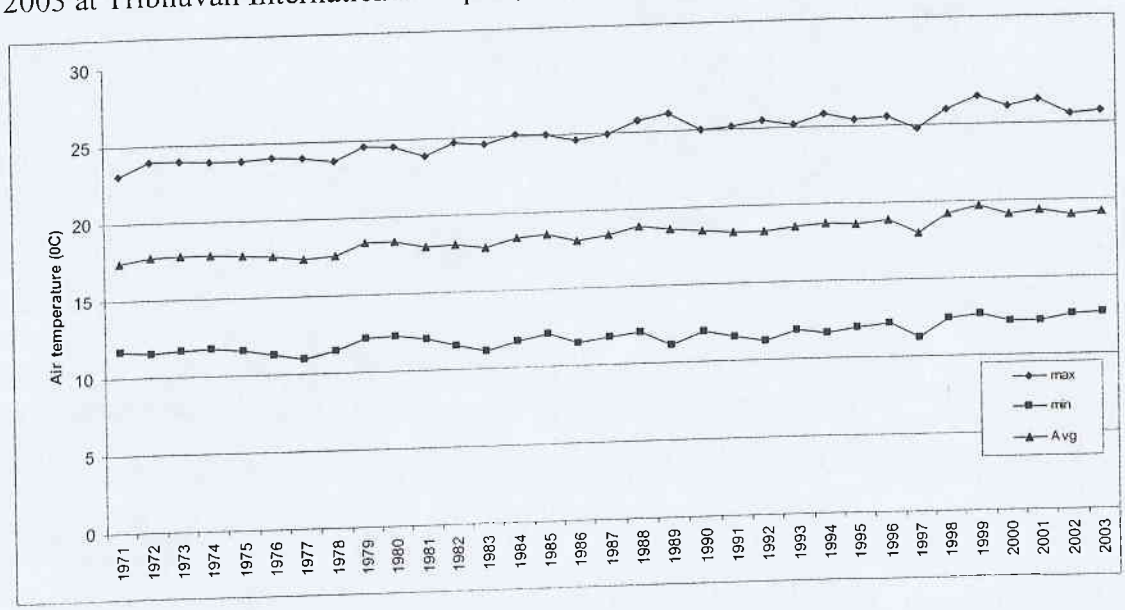
(winter) as shown in figure 3 which is the average monthly temperature of 33 years from 1971 to 2003 at Tribhuvan International Airport, Kathmandu(DHM, 2006).



(Source: DHM, 2006)

Figure 3: Avergae monthly temperature of Manahara watershed during 1971-2003

The trend of annual minimum, maximum and average temperature of the Manahara watershed (in Kathmandu International Airport) in the past 33 years from 1971 to 2003 at Tribhuvan International Airport, Kathmandu has been presented figure 4.

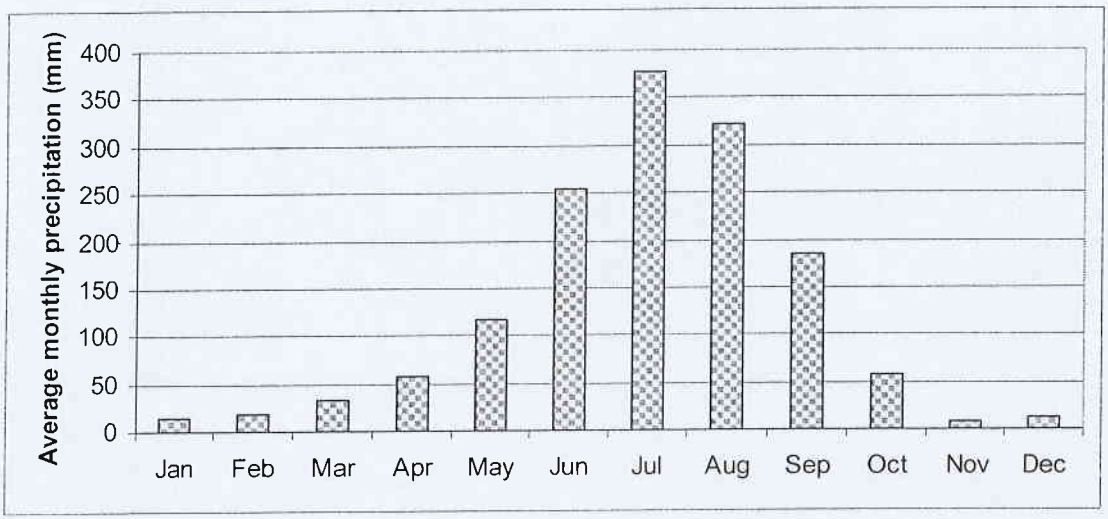


(Source: DHM, 2006)

Figure 4: Trend of air temperature of the Manahara watershed from 1971-2003

The figure 4 shows that annual mean temperature fluctuated and shows increasing trend of temperature in recent years.

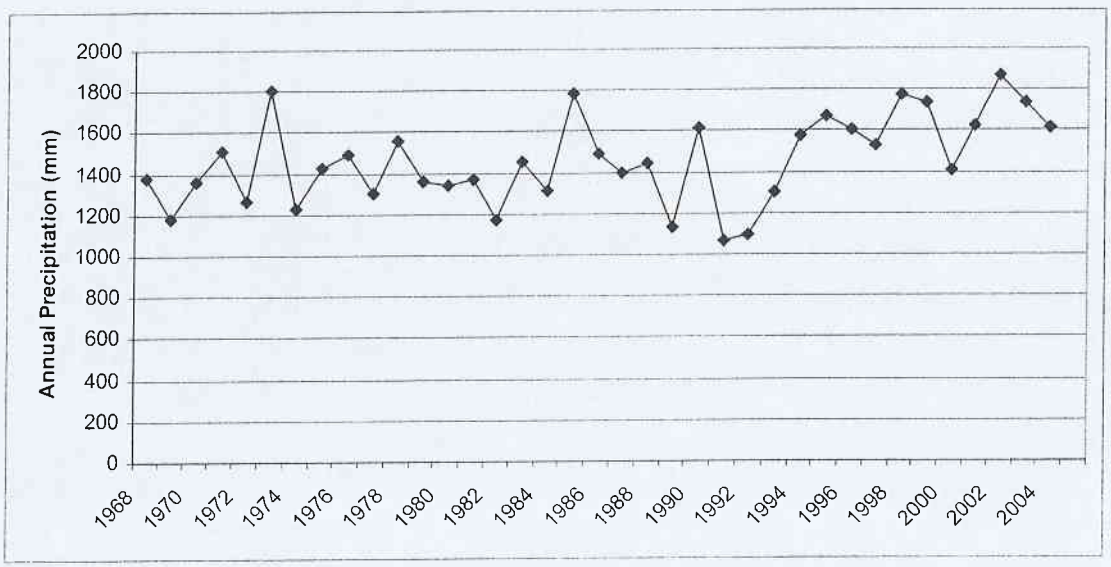
The Manahara watershed received average annual rainfall of 1452 mm in the past 37 years from 1968 to 2004 (DHM, 2006). The south-east monsoon is the main rain being wind which delivers about three-fourth of the total rainfall during June to September. While winter months remain mostly dry, occasional precipitation occurs in the form of winter rains (Pradhan, 1998). The average monthly precipitation received in the watershed (Kathmandu International Airport) in the past 37 years from 1968 to 2004 is graphically presented in figure 5 (DHM, 2006).



(Source: DHM, 2006)

Figure 5: Average monthly precipitation in the Manahara watershed during 1968 – 2004

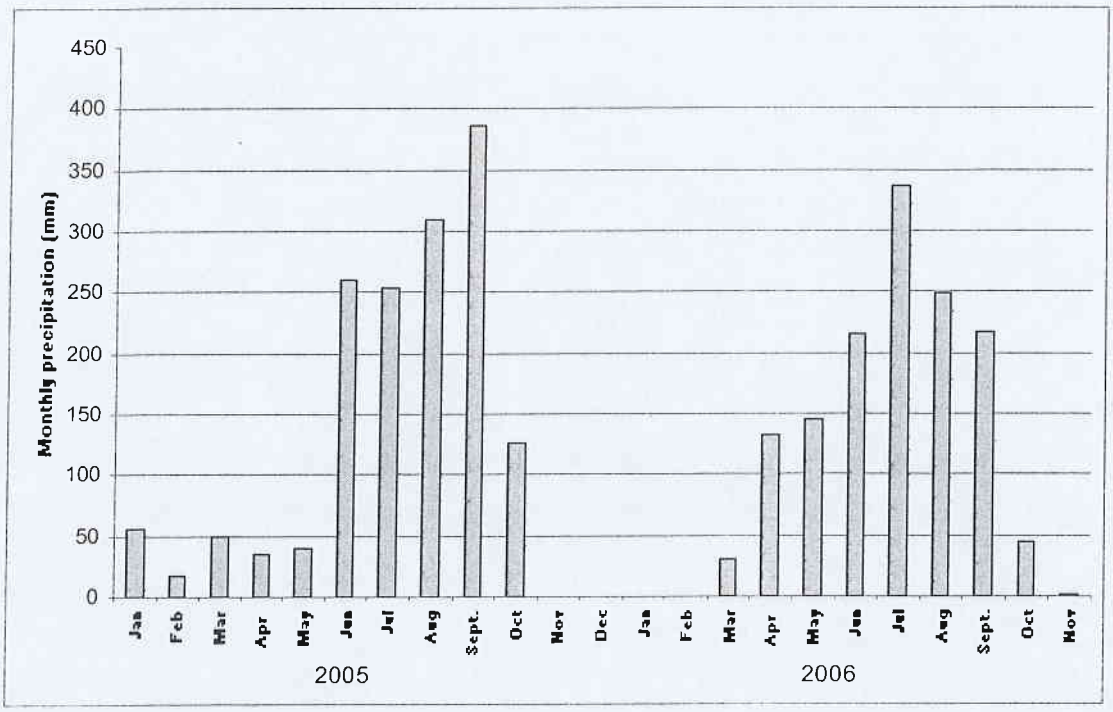
The trend of annual precipitation in the watershed is shown in the figure 6. The precipitation trend shows the fluctuation of annual precipitation.



(DHM, 2006)

Figure 6: Annual precipitation in the Manahara watershed from 1968 – 2004

The monthly precipitation recorded in the Manahara watershed during the present investigation period is presented in figure 7. It showed that threre was no precipitation for four months from November 2005 to February 2006 In the watershed.



(DHM, 2006)

Figure 7: Monthly precipitation in the Manahara watershed during the investigation period (2005 and 2006)

3.3 Landuse

The landuse pattern shows the extent of human activities and the use of the natural resources. From environmental point of view, urban growth is the key aspect of the landuse. Kathmandu has grown rapidly in a fairly unregulated manner from a small city located in the tar (elevated plateau) between the Bagmati, Bishnumati and Dhobikhola. Kathmandu has spread out over a large area (Stanley *et al.* 1994). The landuse pattern of 1995 is presented in the figure 8 and table 4 and that of 2002 is prewented in figure 9 and table 5.

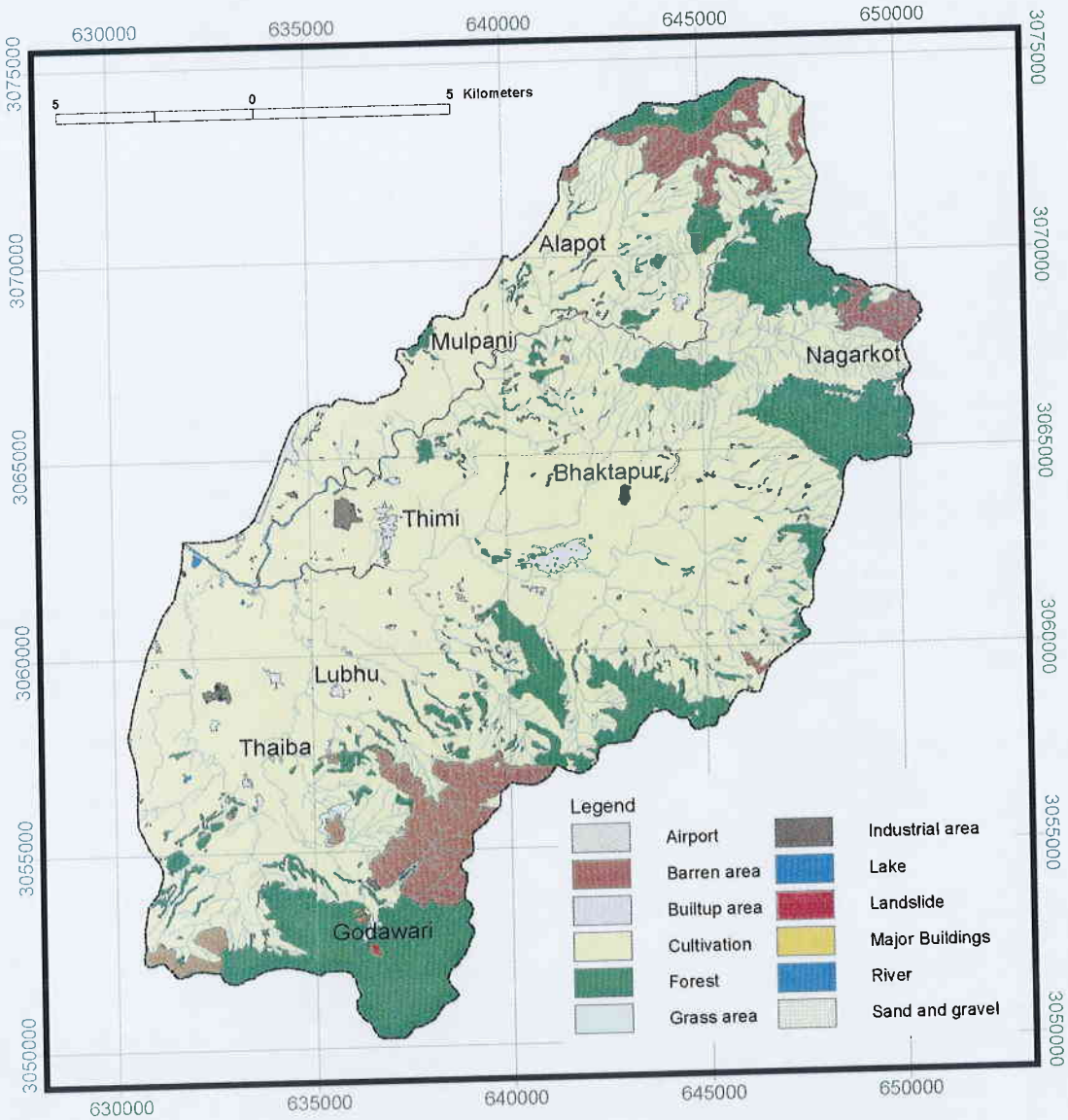


Figure 8: Landuse map of Manahara watershed in 1995
(Source: Survey Department, 1995 for base maps)

Table 1: Landuse pattern of Manahara watershed in 1995

Landuse type	Area (sq.km)	Percentage (%)
Airport	0.46	0.18
Barren area	16.78	6.56
Builtup area	2.05	0.80
Cultivation	189.64	74.17
Forest	44.15	17.27
Grass area	0.39	0.15
Industrial area	0.81	0.32
Lake	0.20	0.08
Landslide	0.20	0.08
Major Buildings	0.07	0.03
River	0.55	0.21
Sand and gravel	0.37	0.15
Total	**255.68**	**100.00**

(Source: Survey Department, 1995 for base maps)

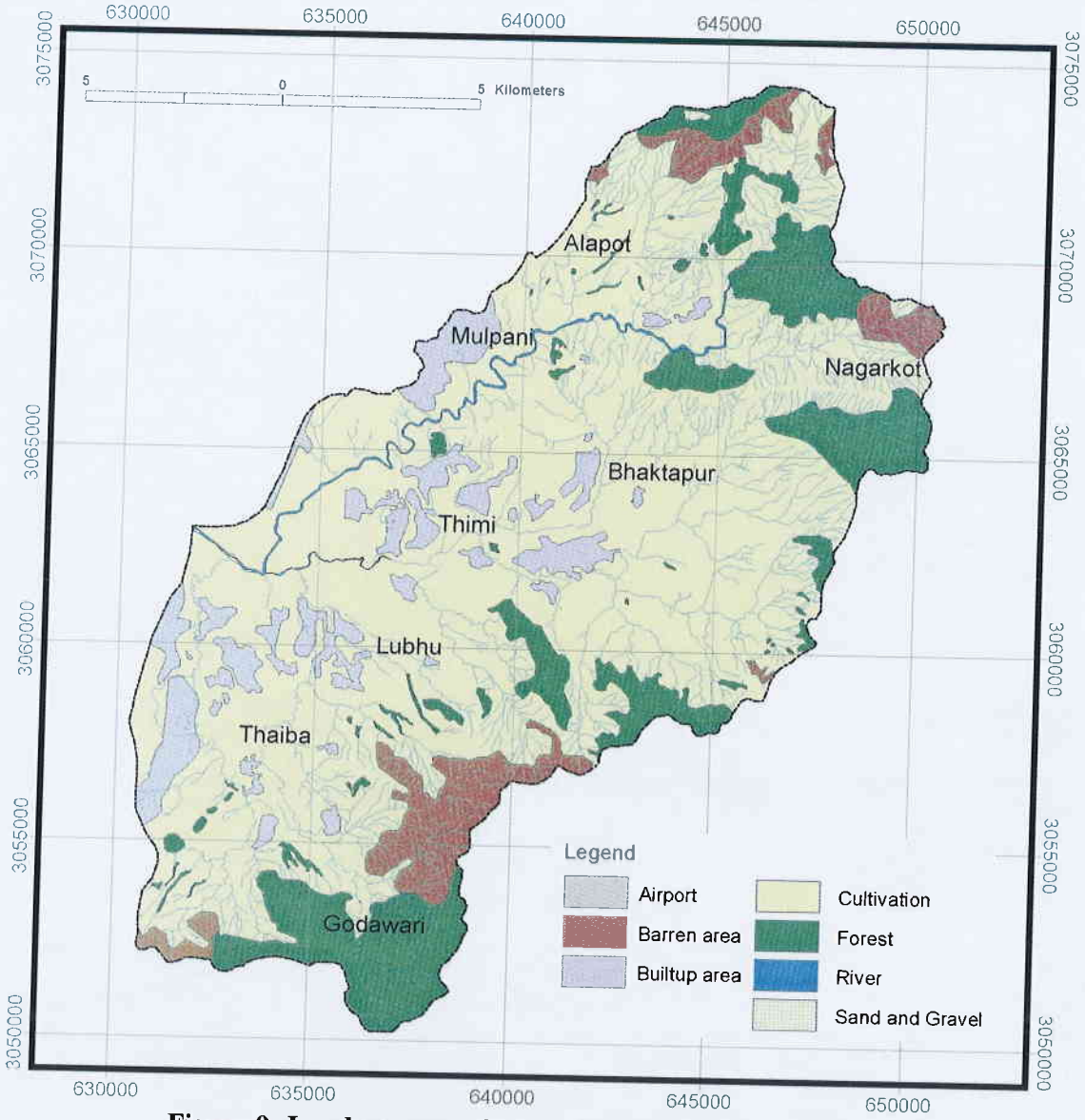


Figure 9: Landuse map of Manahara watershed in 2002

(Source: LAND SAT imagery 2002 and field verification)

Table 2: Landuse pattern of Manahara watershed in 2002

Landuse type	Area (sq.km)	Percentage (%)
Airport	0.48	0.19
Barren area	15.91	6.22
Builtup area	19.30	7.55
Cultivation	180.08	70.43
Forest	38.41	15.02
River	1.41	0.55
Sand and Gravel	0.10	0.04
Total	**255.68**	**100.00**

(Source: LAND SAT imagery 2002 and field verification)s

4.4 Demography

The Manahara watershed is constituted by entire Bhaktapur district, approximately half Lalitpur district and a part of Kathmandu district. The total population of the Manahara watershed is 378740 based on the population census of Nepal 2001 (CBS, 2002). Among them, 150998 people i.e. 39.87 % is urban and 227742 people i.e. 60.13 % is rural. The average population density of the watershed is 1945 persons/sq.km. The population distribution and density in different municipalities and VDCs is shown in table 6 and its political map is shown in figure 10.

Table 6: Population distribution and density of Human in different VDC and Municipalities of Manahara watershed

VDC/Municipalities	Area (sq.km)	Population	Population density (Person/sq.km)
Alapot	0.83	1628.07	1961.38
Badikhel	5.80	3185.88	549.39
Bageshwari	9.55	5004.87	524.10
Balkot	2.84	7454.00	2624.49
Bhadrabas	1.24	1586.61	1280.08
Bhaktapur Municipality	6.56	72543.00	11064.15
Bisankhunarayan	6.45	4197.32	650.94
Changunarayan	6.78	5858.00	863.60
Chapagaun	4.73	8099.69	1711.25
Chhaling	9.61	2674.00	278.22
Chitpol	5.07	5486.20	1082.53
Dadhikot	6.50	7244.00	1114.80
Dhapakhel	3.67	6345.00	1728.04
Duwakot	6.31	6290.00	997.50
Gagalphedi	9.31	4520.31	485.77
Godamchaur	3.13	4459.00	1426.50
Godawari	15.21	5774.44	379.77
Gothatar	3.43	6141.15	1792.56
Gundu	7.42	5750.02	774.82
Harisiddhi	3.10	5939.00	1915.84
Imadol	4.02	9615.00	2390.35
Indrayani	2.77	2958.00	1069.39
Jharuwarasi	3.81	3662.00	960.56
Jhaukhel	5.22	6678.00	1278.40
Jorpati	0.09	789.09	8562.35
Kathmandu MC	4.11	2921.65	711.45
Katunje	4.33	13043.00	3013.11
Lalitpur SMC	2.58	27782.57	10755.92
Lamatar	6.64	4545.38	684.75
Lapsiphedi	10.43	3288.29	315.32
Lubhu	6.40	7610.00	1188.36
Madhyapur Thimi Muni.	11.11	47751.00	4297.31
Mulpani	3.56	5416.85	1521.68
Nagarkot	9.43	4224.48	448.04
Nangkhel	6.05	4633.89	765.99

Pukhulachhi	1.38	2746.00	1984.94
Sankhu Bajrayogini	5.24	3880.00	740.64
Sankhusuntol	10.56	3817.58	361.60
Siddhipur	2.01	5566.00	2769.44
Sipadol	8.11	7004.00	863.60
Sirutar	1.37	4532.00	3315.45
Sudal	7.33	7052.52	962.77
Sunakothi	1.10	2250.96	2054.35
Tathali	8.70	5652.00	649.52
Thaiba	2.34	6308.00	2693.69
Thalidanchhi	3.97	6094.56	1536.94
Thecho	1.33	3288.05	2463.84
Tikathali	3.01	5449.00	1809.52
Total	**254.51**	**378740.44**	
Average			**1945.31**

(Source: CBS, 2002 and Suevey Department, 1995).

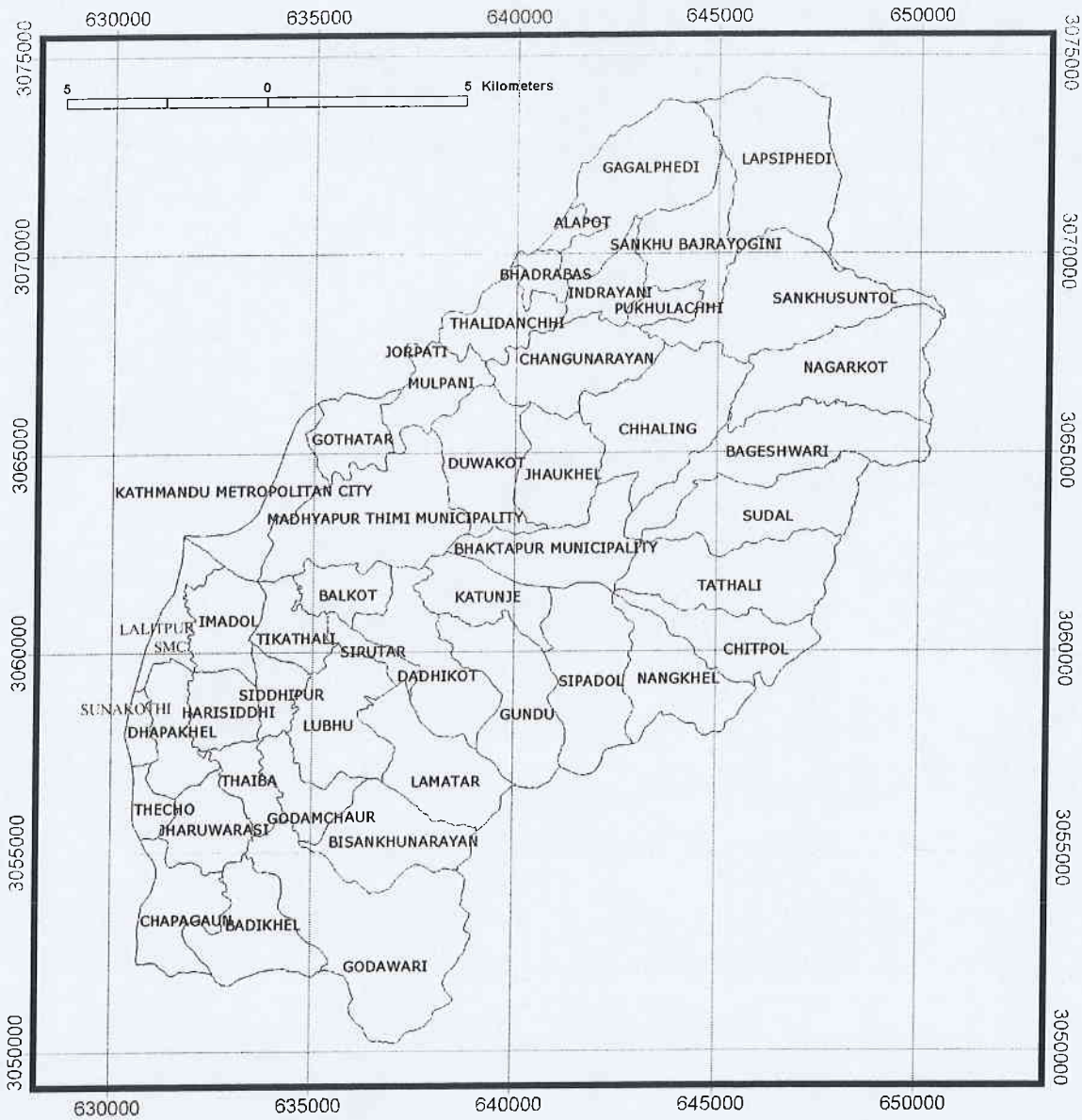


Figure 10: Political map of the Manahara watershed

CHAPTER 5

5. MATERIALS AND METHODS

5.1 Sampling stations

The sampling stations of Manahara river were selected on the basis of reconnaissance survey throughout the length of the river. The settlement area, confluence, wastewater discharge, substrate and water uses were considered to fix the sampling stations. A reference station at upstream i.e a point remote from all waste water discharges of concern was established. Other stations immediately downstream of confluence or in the affected area in the immediate vicinity of each significant waste water discharge were located (APHA, 1995). Altogether seven sampling stations were selected in the river. These stations are described below.

Station 1: Salinadi/Thulo khola

The sampling station 1 is located at Salinadi/Thulo khola, Sakhu at the headwater region of the Manahara river lying at 27^0 44' 14.8'' N latitude, 85^0 28' 22.0 E longitude and 1500.0 metres altidude (Plate 1). There is a forest on the left side of the river with a patch of agricultural field in between the river and the forest. However, there is agricultural field on the right side of the river. The substrate consists of mainly cobbles, gravels, sands and boulders. There is a small patch of *Alnus nepalensis* as riparian vegetation at the right bank. There is little human interference in this area. Instream human activities like bathing, washing and fishing were common. Sewerage discharge into the river was absent.

Station 2: Sakhu

The sampling station 2 is located at 27^0 43' 14.0'' N latitude, 85^0 28' 17.4 E longitude and 1459.8 metres altidude at Sakhu. The station is just downstream of the confluence of Salinadi and Naldum Khola (Ghatte Khola) (Ghatte Khola) (Plate 2). Its substrate mainly consists of gravels, cobbles and sands. The right and left flood plain is used for agricultural activities. Instream activities such as bathing, washing, cleansing and fishing as well as irrigation of agricultural land were common. Sewage discharge into the river was absent.

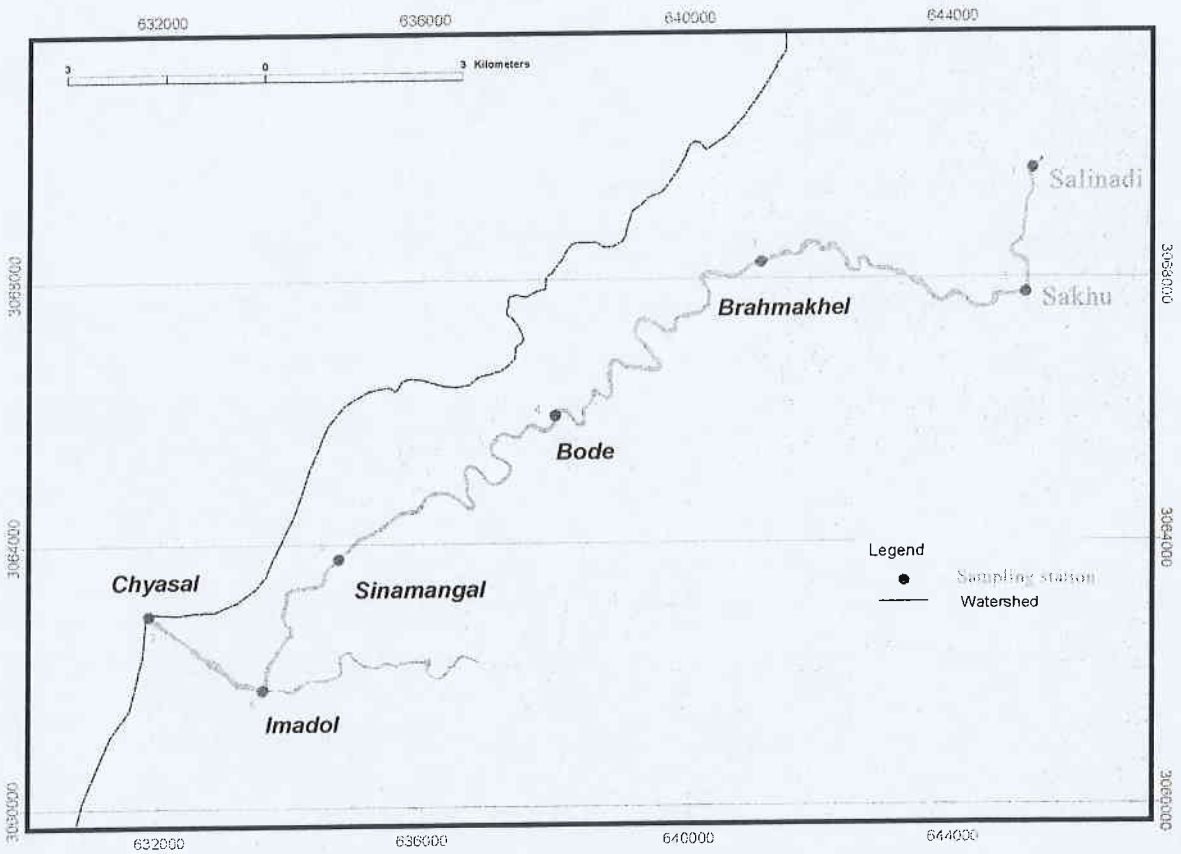


Figure 11: Sampling stations in the Manahara river

Station 3: Bramhakhel

The sampling station 3 is located at 27^0 43' 32.0'' latitude, 85^0 25' 51.8'' E longitude and 1438.2 metres altitude at Brahmakhel. The station is just downstream of the confluence of Manahara river and Mahadev Khola (Plate 3). Its substrate mainly consists of gravels, cobbles, sands and silt. The right and left flood plain is used for agricultural activities whereas sparse settlement with some houses has been started in right flood plain. Instream activities such as bathing, washing and cleansing as well as irrigation of agricultural land were common. Sewerage discharge into the river was almost absent.

Station 4: Bode/Mulpani

The sampling station 4 is located at 27^0 42' 17.1'' N latitude, 85^0 23' 56.4'' E longitude and 1416.9 metres altitude with Bode town at left bank and Mulpani village at right bank. The station is just upstream of the water abstraction zone (dug wells) of Nepal Water Supply Corporation (Plate 4). Its substrate mainly consists of sands, silts

and gravels. The right and left flood plain is used for agricultural activities. However, sparse settlement has been started in right and left flood plain. Instream activities such as bathing, washing and cleansing as well as irrigation of agricultural land were common. Sewerage discharge into the river was observed upstream and downstream of the sampling station.

Station 5: Sinamangal

The sampling station 5 is located at 27^0 41' 07.9'' N latitude, 85^0 21' 59.3'' E longitude and 1402.3 metres altitude at Sinamangal (Pepsi Cola). The station is just downstream of the Sinamangal-Sanothimi bridge (Plate 5). Its substrate mainly consists of sands and gravels. The right and left flood plain is used for agricultural activities with thin human settlement. Instream activities such as washing, cleansing and bathing, as well as irrigation of agricultural land were common. Discharge of sewage and industrial effluents into the river was observed in upstream of the sampling station.

Station 6: Imadol

The sampling station 6 is located at 27^0 40' 03.8'' N latitude, 85^0 21' 15.2 E longitude and 1380.4 metres altitude at Imadol. The station is just downstream of the confluence of Manahara river and Hanumante river (Plate 6). Its substrate mainly consists of sands, silts, gravels and a patch of black clay as the river bottom. A patch of right flood plain is used for agricultural activities whereas the left flood plain has dense settlement just near to the river bank. Instream activities such as washing and cleansing were occasionally observed during high flow. Sewage discharge into the river was observed in this sampling station.

Station 7: Chyasal

The sampling station 7 is located at 27^0 40' 41.0'' N latitude, 85^0 20' 12.0''E longitude and 1384.5 metres altitude at Chyasal. The station is just before the confluence of the Manahara river and Bagmati river (Plate 7). Its substrate mainly consists of sands and gravels. There is dense settlement at right and left flood plain of the river being the core urban area. Instream activities such as bathing, washing and cleansing were never observed. Sewage discharge into the river was observed in this sampling station.

5.2 Sampling frequency

The physico-chemical and macroinvertebrates study were carried in each month from October 2005 to July 2006 for 10 months and microbiological study were carried in each month from October 2005 to December 2005 for three months as regular sampling. A monthly sampling program is essential to detect seasonal changes in abundance of macroinvertebrates (Yadav *et al.* 1987). However, for the month of December 2005, the water sample was taken simultaneously at the same time on the same day i.e. at 9:00 am on December 22, 2005. In addition, the diurnal variation of water quality was studied on September 21, 2006 from 07:00 hours to 18:00 hours at station 4. During every sampling (for physico-chemical and microbiological study) at each sampling station, 3 samples of water and 10 samples of benthic macroinvertebrates were collected. Thus, altogether 234 water samples and 700 benthic macroinvertabrates samples were studied. In addition, the characteristics of the effluents entering to the river at two places were also studied.

5.3 Methods of sample collection, preservation and analysis

5.3.1 Water sample

5.3.1.1 Water sample collection and preservation:

In each sampling station, three water samples: A (near left bank), B (at middle of the river) and C (near right bank) were taken (UNESCO, 1996). From each sampling point (site), water sample was collected in a clean sampling bottle (plastic). Most of the physico-chemical parameters such as secchi disc transparency, depth, velocity, discharge, temperature, pH, dissolved oxygen, free carbondioxide, total alkalinity, hardness, calcium, magnesium, chloride, conductivity and total dissolved solids (TDS) were measured in the sampling site (field measurement). Water samples were collected and preserved for the analysis of BOD_5, NO_3-N, PO4-P and NH_3-N. Water sample for analysis of NH_3-N was preserved by adding conc. H_2SO_4 to pH less than 2 whereas water samples for analysis of BOD_5, PO_4-P and NO_3 -N need no chemical preservation. All samples were brought to laboratory as fast as possible and refrigerated (< 4°C but above freezing). The water samples for BOD_5 analysis were incubated on the same day whereas other parameters were analyzed within 48 hours (APHA, 1995).

5.3.1.2 Methods of analysis of Physico-chemical parameters

1. **Transparency (light penetration)**:

The Secchi disc transparency was measured in the field by lowering a secchi disc of 20 cm diameter in the water with the help of the string tied to it, until it just disappeared. The depth was noted by marking on the string. Then the Secchi disc was uplifted and noted the depth at which it reappeared again. For better results, measurements should be made during the middle of the sunny days. The secchi disc transparency was calculated by the following equation (Trivedi and Goel, 1986).

$$\text{Sechhi disc light penetration} = \frac{A+B}{2}$$

A = depth at which Secchi disc appears

B = depth at which Secchi disc disappears

2. Depth:

The depth of the river was measured by at every station by immersing a straight rod in the river which was then marked amd measured the length upto the mark. The depth was measured at many points across the river from one bank to another to get the mean depth.

3. Velocity:

For the measurement of stream velocity, a float (thermocole) was thrown on the water surface. The time't' required for a float to travel a known distance 'd' was observed and the average velocity was obtained by using the following equation (Trivedi and Goel, 1986)

$$\bar{v} = \frac{d}{1.2t}$$

The factor 1.2 accounts for the fact that surface velocities are normally about 1.2 times higher.

4. Discharge:

The total discharge (Q) is calculated by the method of mid-sections as follows (Subramanya, 1998):

$$Q = \sum_{i=1}^{N-1} \Delta Q_i$$

Where,

ΔQ_i = discharge in the i^{th} segment.

The figure 12 shown below is considered where the cross-section of a river is divided into N segments by N-1 verticals. The velocity averaged over the vertical at each section is known. Then,

$$Q = \sum \Delta Q_j + \Delta Q_1 + \Delta Q_{N-1}$$

Where,

$\Delta Q_1 = \bar{v}_1 \cdot \Delta A_1$; $\Delta Q_{N-1} = \bar{v}_{N-1} \cdot \Delta A_{N-1}$ and j = 2 to (N – 2)

a) Discharge except for 1^{st} and last segment;

$\Delta Q_j = \Delta A_j \times v_j$

= (depth at the j^{th} segment) x ($\frac{1}{2}$ width to the left + $\frac{1}{2}$ width to right)x (average velocity at j^{th} vertical)

$$= y_j \times \left(\frac{W_j}{2} + \frac{W_{j+1}}{2} \right) \times v_j$$

For j = 2 to (N – 2)

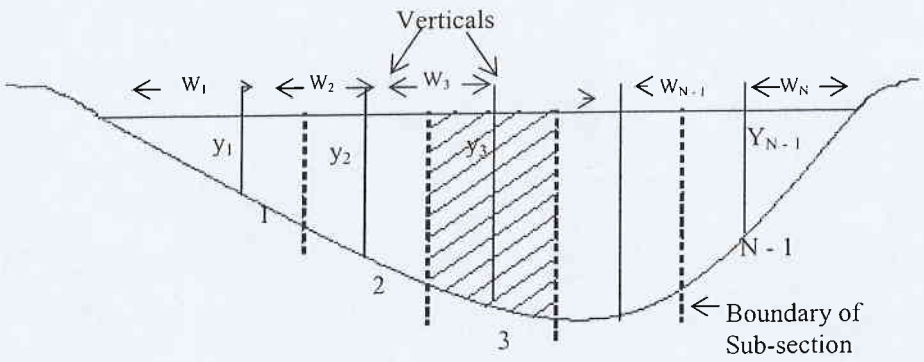


Figure 12: Stream section for area – velocity method for discharge calculation

For the first and last sections, the segments are taken to have triangular areas and the area is calculated as:

$$\Delta A_1 = \frac{\left(W_1 + \frac{W_2}{2}\right)}{2\,W_1} \times y_1$$

$$\Delta A_{N-1} = \frac{\left(W_N + \frac{W_{N-1}}{2}\right)^2}{2\,W_N} \times y_{N-1}$$

5. Temperature:

The temperature of water and air was measured by using a mercury-filled Celsius thermometer graduated to an accuracy of 0.1°C (APHA, 1995). The surface water was collected in a beaker. Soon after the collection of the water sample , the thermometer was dipped into the water sample and noted the reading. To minimize the error, the thermometer was always calibrated with another thermometer of known accuracy (Trivedi and Goel, 1986).

6. **pH**

For the measurement of pH (Potentia hydrogenii) of water, water sample was taken in a clean beaker and electrode (rinsed with distill water & blot dried) of pH meter of model HI 8314 portable pH meter (Hanna instruments, Manufacturers with accuracy of ± 0.01 at 20°C/68°F) was dipped into the water sample. Equilibrium between electrodes and water sample was established by stirring water sample to ensure homogeneity. It was stirred gently to minimize CO_2 entrainment. Then, the reading of pH meter was noted. On each sampling day, electrodes from storage solution was removed, rinsed with distill water, blot dried with a soft tissue paper and placed in buffer solutions (pH 4 and 9.2) and set the pH meter with the pH of buffer (APHA, 1995).

7. Conductivity :

For the measurement of conductivity of water, the calibrated (with standard potassium chloride solution of 0.01 N) conductivity meter of Model 4150 *9 with Accuracy of* ± 0.5 % ± 2 digits) was first brought into the conductivity mode. Then the electrode was washed and rinsed a few times with distilled water and then dipped in the beaker containing the sample water. The conductivity reading was noted down after the reading stabilized at the certain point.

8. Total dissolved solids(TDS):

Total dissolved solids are the residue left after evaporation of the filtered water sample. TDS in a water sample can be estimated by multiplying conductivity (in μS/cm) by an empirical factor. This factor may vary from 0.55 to 0.9, depending on the soluble components of the water and on the temperature of measurement. Relatively, high factors may be required for saline or boiler waters, whereas lower factors may apply where considerable hydroxide or free acid is present (APHA, 1995). For the measurement of TDS, the instrument (conductivity meter of Model 4150) was first brought into the TDS mode. The electrode was rinsed with distilled water. The electrode was dipped into the sample water contained in a clean beaker that gave TDS directly.

9. Total Suspended Solids (TSS) :

Total Suspended Solids are the solids retained on the filter paper. A well-mixed water sample (of 100 ml) was filtered through a weighed standard filter paper (Whatmann no. 44) and the residue retained on the filter paper was dried to a constant weight at 105°C. The increase in weight of the filter paper represent the TSS. If suspended material clogs the filter and prolongs filtration, the difference between the total solids and TDS may provide an estimate of the TSS. It is calculated by the following equation (APHA, 1995).

$$\text{TSS (mg/L)} = \frac{(A-B)x1000}{ml}$$

Where, A = Weight of filter paper + dried residue (mg)

B = Weight of filter paper (mg)

9. Alkalinity:

For the determination of alkalinity, 100 mL of water sample was taken and added 2 drops of phenolphthalein indicator. When the solution remained colourless, Phenolphthalein Alkalinity (PA) is zero. When the colour changed into pink after addition of phenolphthalein, it was titrated with 0.1 N HCl until the colour disappeared at end point. This is PA. Then 2-3 drops of methyl orange was added to the same sample and continued the titration further until the yellow colour changed into pink at end point. This is total alkalinity (TA) (APHA, 1995; Trivedi and Goel, 1986). They are calculated by the following equations:

$$\text{PA as } CaCO_3\text{, mg/L} = \frac{(\text{A x Normality) of HCl x 1000 x 50}}{\text{ml of sample}}$$

$$\text{TA as } CaCO_3, \text{ mg/L} = \frac{(\text{B x Normality}) \text{ of HCl x } 1000 \text{ x } 50}{\text{ml of sample}}$$

where, A = mL of HCl used with only phenolphthalein

B= mL of total HCl used with phenolphthalein and methyl orange

PA = Phenolphthalein alkalinity

TA = Total alkalinity

Concentration of carbonates, bicarbonates and hydroxyl ions can be determined from the table 7 using data of PA and TA.

Table 7: Values of hydroxyl ions, carbonates and bicarbonate from the values of phenolphthalein and total alkalinities

Result of titration	OH alkalinity as $CaCO_3$	CO_2 alkalinity as $CaCO_3$	HCO_3 alkalinity as $CaCO_3$
P = 0	0	0	T
P = ½ T	0	2P	T – 2P
P = ½ T	0	2P	0
P > ½ T	2P – T	2(T – P)	0
P = T	T	0	0

(Source: APHA, 1995; Trivedi and Goel, 1986)

Where, P = phenolphthalein alkalinity

T = Total alkalinity

10. Hardness

For the determination of hardness, 50 ml of water sample was taken in a clean beaker. If the water sample is having higher calcium, a smaller volume should be taken and diluted to 50 mL. Then 1 mL of buffer solution was added . If the water sample is having higher amounts of heavy metals, 1 ml of Na_2S should be added. Then, 100-200 mg of Erichrome Black T indicator was added, the solution turned wine red. The contents was titrated against the EDTA solution and the colour changed from wine red to blue at the end. The hardness is calculated by the following equation. (APHA, 1995; Trivedi and Goel, 1986).

$$\text{Hardness (EDTA) as mg } CaCO_3/L = \frac{\text{ml EDTA used x B x } 1000}{\text{ml sample}}$$

$$= \frac{\text{ml EDTA used x } 1000}{\text{ml sample}}$$

Where, B = mg $CaCO_3$ equivalent to 1.00 ml of 0.01 M EDTA = 1

When hardness numerically is greater than the sum of carbonate and bicarbonate alkalinity, that amount of hardness equivalent to the total alkalinity is called "Carbonate hardness"; the amount of hardness in excess of this is called "non-carbonate hardness". When the hardness numerically is equal to or less than the sum of carbonate and bicarbonate alkalinity, all hardness is carbonate hardness and non-carbonate hardness is absent (APHA, 1995).

11. Free Carbon dioxide (CO_2) :

For the determination of free carbondioxide content of water sample, 100 mL of water sample was taken in a conical flask and added few drops of phenolphthalein indicator. If the colour turns pink, free CO_2 is absent. When the water sample remained colourless, it was titrated against 0.05 N sodium hydroxide till pink colour appeared at the end point. It is calculated by the following equation (APHA, 1995).

$$\text{Free } CO_2, \text{ mg/L} = \frac{(\text{mL} \times \text{N}) \text{ of NaOH} \times 1000 \times 44}{\text{mL sample}}$$

Where, N = Normality

12. Chloride

To determine chloride, 50 mL of water sample was taken and added 2 ml of potassium chromate (K_2CrO_4) solution. It was titrated against 0.02 N silver nitrate until a persistent red tinge appeared. It is calculated by the following equation (Trivedi and Goel, 1986).

$$\text{Chloride (mg/L)} = \frac{(A - B) \times N \times 35450}{\text{ml sample}} \quad \text{(APHA, 1995)}$$

Where, A = ml titration for sample

B = ml titration for blank &

N = Normality of $Ag NO_3$

13. Calcium

For the determination of calcium, 50 mL water sample was taken. (If sample contains higher calcium, a small volume could be taken and diluted to 50 mL). 2 ml of NaOH

solution and 100 mg – 200 mg of murexide indicator was added that developed a pink colour. It was titrated against EDTA solution (0.01 M) where pink colour changed to purple at the end. It calculated by the following equation (APHA, 1995).

$$\text{Calcium, mg/L} = \frac{\text{ml of EDTA x B x 400.8}}{\text{mL sample}}$$

$$\text{Calcium hardness as mg } CaCO_3\text{/L} = \frac{\text{ml of EDTA x B x 1000}}{\text{mL sample}}$$

Where,

B = mg $CaCO_3$ equivalent to 1.00 ml EDTA of 0.01 M at the calcium indicator end point = 1

14. Magnesium

Magnesium can be estimated as the difference between hardness and calcium as Ca CO_3, if interfering metals are present in non interfering concentrations in the calcium titration. It is calculated by the following equation (APHA, 1995).

Mg (mg/L) = [Hardness (as mg $CaCO_3$/L) – Calcium hardness (as mg $CaCO_3$/L)] x 0.243

15. Dissolved Oxygen

Dissolved Oxygen (DO) was determined by the Wrinkler or iodometric method. The water sample was filled in a glass stoppered bottle (BOD bottle) avoiding any kind of bubbling and trapping of the air bubbles in the bottle after placing the stopper. 2mL of each $MnSO_4$ and alkaline KI solution was poured well below the surface from the walls. A precipitate appeared. The contents were shaken well in an '8'shape repeatedly. The bottle was kept for some time to settle down the precipitate. If the titration is to be prolonged for few days, the water sample at this stage with precipitate should be kept Then 2 mL of concentrated H_2SO_4 was added and shaken well to dissolve the precipitate. 50 mL of the contents was taken preventing any bubbling to avoid further mixing of oxygen. 2-3 drops of starch as indicator was added to it and titrated against sodium thiosulphate where colour changed from blue to colourless at the end. The dissolved oxygen is calculated by the following equation (APHA, 1995; Trivedi and Goel, 1986).

$$\text{Dissolved oxygen (mg/L)} = \frac{\text{(ml x N) of titrant x 8 x 1000}}{V_2 (V_1 - v) / V_1}$$

Where, V_1= volume of sample bottle after placing the stopper

V_2= volume of the part of the contents titrated

V= volume of $MnSO_4$ and KI added.

16. Biochemical Oxygen Demand

For the determination of BOD_5, dilution water was prepared in a container by aerating with air in distilled water for about 30 minutes. 1 mL of each phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride solutions for each litre of dilution water and mixed thoroughly. The water sample was neutralized to pH 6.5 – 7.5 by using NaOH or H_2SO_4. Dilutions were prepared in graduated cylinders so that the dilutions results in a residual DO of at least 1 mg/L and a DO uptake of at least 2 mg/L after 5 days incubation (APHA, 1995). For this purpose, the dilutions of water sample were prepared according to the expected BOD range as shown in table 8.

Table 8: Preparation of dilutions for various ranges of BOD in the sample

Range of BOD(mg/l) O_2	Dilution (%)	Sample volume in 1 litre of mixture
0 – 6	No dilution	1000
4 – 12	50	500
10 – 30	20	200
20 – 60	10	100
40 – 120	5	50
100 – 300	2	20
200 – 600	1	10
400 – 1200	0.5	5
1000 – 3000	0.2	2
2000 – 6000	0.1	1
Above 6000	0.05	0.5

Two sets of the BOD bottles were filled with the diluted water sample . One set of bottles was stoppered tightly, water sealed and incubated for 5 days at 20°C in BOD incubator of SANYO incubator Item no. 10 and DO was determined immediately for another set. DO was determined in the sample bottles immediately after the

completion of 5 days of incubation. Dilution water blank was used as a rough check on quality of dilution water (unsealed) and cleanliness of incubation bottles. Together with each batch of samples, a bottle of dilution water (unsealed) was incubated. Initial and final DO was determined. The DO uptake shouldn't be more than 0.2 mg/L and preferably not more than 0.1 mg/L. The BOD_5 is calculated by the following equation (APHA, 1995).

When dilution water is not seeded:

$$BOD_5\,(mg/L) = \frac{D_1 - D_2}{P}$$

$$BOD_5\,(mg/L) = \frac{[(D_1 - D_2) - (B_1 - B_2)\,f\,]}{P}$$

Where, D_1 = DO of diluted sample immediately after preparation, mg/L

D_2 = DO of diluted sample immediately after 5 days incubation at 20^0C, mg/L

B_1 = DO of seed control before incubation, mg/L

B_2 = DO of seed control after incubation, mg/L

P = Decimal volumetic fraction of sample used

f = Ratio of seed in diluted sample to seed in seed control

$$= \frac{\text{(\% seed in diluted sample)}}{\text{(\% seed in seed control)}}$$

If seed material is added directly to sample or to seed control bottles:

$$f = \frac{\text{(Volume of seed in diluted sample)}}{\text{(Volume of seed in seed control)}}$$

17. Chemical Oxygen Demand

Chemical oxygen demand (COD) was determined by open reflux method (APHA, 1995). 20 ml of water sample was taken in a COD flask. For the sample expected to have COD more than 50 mg/L, 10 ml of 0.25 N potassium dichromate solution was added. (In case the COD is expected below 50 mg/L, add 10 ml of 0.025 N $K_2Cr_2O_7$). A pinch of Ag_2SO_4 and $HgSO_4$ was added. If the water sample contains chlorides in higher amount, $HgSO_4$ is added in the ratio of 10:1, to the chlorides. COD can't be determined accurately if the water sample contains more than 2000 mg/L of chlorides. Then 30 ml of sulphuric acid was added. Refluxed at least for 2 hours on a water bath or a hot plate.Then the flasks were removed, cooled and added distilled water to make

the final volume to about 140 ml.To it, 2-3 drops of Ferrowin indicator was added, mixed thoroughly and titrated with 0.1 N Ferrous ammonium sulphate (with 0.01 N ferrous ammonium sulphate if 0.025 N K_2CrO_7 has been used). A blank was run with distilled water using same quantity of the chemicals.

$$\text{COD (mg/L)} = \frac{(b - a) \times N \text{ of Ferrous ammonium sulphate} \times 1000 \times 8}{\text{ml of sample}}$$

where, a = ml of titrant with sample

b = ml of titrant with blank N= Normality

18. Orthophosphates

Orthophosphate can be colorimetrically determined by stannous chloride method which is more suited for the range of 0.01 to 6 mg P/L. (APHA, 1995). The standard calibration curve containing concentration and absorbance was prepared as follows. For this, 4.388 gm of dried anhydrous potassium hydrogen phosphate (K_2HPO_4) was dissolved in distilled water and made the volume of 1 litre. This solution was diluted to 100 times to make the standard solution containing 10 mg P/L i.e 1 ml = 0.01 mg P. From the standard phosphate solution, various dilution at the interval of 0.1 mg P/L were made. Absorbance of these diluted standard solutions was determined employing the same procedure as for the sample. A standard calibration curve of absorbance versus concentration was prepared from this (Trivedi and Goel, 1986).

Sample measurement

50 ml of filtered water sample was taken in a volumetric flask. If the water sample contains colour and colloidal impurities, they can be removed by adding a spoonful of activated charcoal and then filtering the water sample . 2 mL of ammonium molybdate was added to the water sample which was followed by 5 drops of stannous chloride solution. A blue colour appeared. Reading was taken at 690 nm in spectrophotometer of Model 7225 using a distilled water blank with the same amount of chemicals. The readings were taken after 10 minutes but before 12 minutes of the addition of the latest reagent. Using the same specific interval for all determinations. The concentrations was found out with the help of the standard calibration curve (APHA, 1995 and Trivedi and Goel, 1986).

19. Nitrate - Nitrogen

Nitrate was determined by phenol disulfonic acid method. The standard calibration curve containing concentration and absorbance was prepared as follows. For this, 0.722 gm of potassium nitrate (KNO_3) was dissolved in distilled water and made up the volume of 1 litre. This solution contains 100mg N/L. It was diluted to 100 times to prepare a solution having 1 mg N/L. From this standard nitrate solution, different dilutions from 0.1mg N/L to 1.0 mg N/L at the interval of 0.1 was prepared. Absorbance of these diluted standard solutions was determined following the same procedure as for the sample. Using concentrations and their respective absorbance, a standard calibration curve was prepared (APHA, 1995 and Trivedi and Goel, 1986).

Sample measurement

50 ml of water sample containing not more than 1 mg/L of NO_3-N was taken in a conical flask. Then an equivalent amount of silver sulphate solution was added to remove chlorides. It was then heated slightly and the precipitate of silver chloride (AgCl) was filtered. Then the filtrate in the porcelain basin was evaporated to dryness. It was then cooled and the residue was dissolved in 2 mL phenol disulphonic acid and diluted to 50 mL. Then 6 mL of liquid ammonia was added which developed yellow colour. Similar process was done for blank distilled water. Then the absorbance was noted in spectrophotometer of Model 7225 at 410 nm (Trivedi and Goel, 1986).

19. Ammoniacal nitrogen

Nessler's method was used to determine the ammonia content of water is useful for ammoniacal nitrogen up to 5 ppm. For the determination of ammoniacal nitrogen, a little NaOH was added to 100 mL water sample to neutralize the acid used for storage and then added 1 mL 10% $ZnSO_4$.$7H_2O$ followed by 1 mL of 10 % NaOH. It was stirred and filtered. (Ca, Fe, Mg, S^{2-} were precipitated). The colourless middle fraction was collected and added 1 drop of 50 % EDTA (disodium salt) and mixed well. It was added with 2 ml of Nessler's reagent. [70 g KI + 160 g HgI_2 + 160 g NaOH (ice-cooled)] diluted to 500 ml). It was shaken well. Similar, process was done to blank distilled water. The resulting yellow colour was measured at 420 nm in spectrophotometer of Model 7225 (De, 2000).

5. 3.1.3 Water quality class using physico-cheimcal featuress

Using physico-chemical parameters two water quality indices namely Bach water quality index (Bach, 1980) and Netherlands water quality index developed by Ministry of Public Transport and Public Work, 1989 were used in the present study.

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 value for eight parameters are multiplied to get chemical index of that site (Pradhan, 1998).

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

where, CI = Chemical index

q_i = Transformed value of each parameter

w_i = relative weight of n^{th} parameter

q_i^{wi} = Value for each parameter is given in the appendix XXI.

Table 9: Weight assigned to each parameter (Bach, 1980)

Parameter	Unit	Importance value (w_i)
Temperature	°C	0.08
Oxygen saturation	%	0.20
BOD_5	mg/L	0.20
pH - value	-	0.10
NO_3 - N	mg/L	0.10
$O - PO^4 - P$	mg/L	0.10
$NH_4 - N$	mg/L	0.15
Electric conductance	µS/cm	0.07
Total weight		1.00

After index calculation for each sampling site, the classification of the index has been done on the basis of table 10..

Table 10: Water Quality classification based on chemical index (Bach 1980)

C I	Water Quality class	Water condition
>83	I	No or very low pollution
73 – 82	I–II	Low pollution
56 – 72	II	Moderate pollution
44 – 55	II–III	Critical pollution
27 – 43	III	Severe pollution
17 – 26	III–IV	Very severe pollution
< 17	IV	Excessive pollution

Similarly, in the Ministry of Public Transport and Public Works (MPTPW) Water Quality Index (WQI), three parameters were chosen to calculate WQI value. The chosen parameters with their numerical range and points and points awarded are given in the table 11:

Table 11: Chosen parameters for WQI

Points Awarded	O_2 – Saturation (%)	BOD_5 (mg/l)	Ammonia (NH_3 – N) (mg/l)
1	91 – 110	<3	<0.5
2	71 – 90	3.1 – 6	0.5 – 1
3	51 – 70	6.1 – 9	1.1 – 2
4	31 – 51	9.1 – 15	2.1 – 5
5	<30	>15	>5

(Source: Shakya, 2001)

Then summation of points awarded for the three parameters was calculated which describes the quality of water as represented in the table.

Table 12: Descriptor words for Water Quality Index

Class Interval	WQ Condition	Colour
3.0 – 4.5	Excellent	Blue
4.6 – 7.5	Good	Green
7.6 – 10.5	Fair	Yellow
10.6 – 13.6	Bad	Red
13.6 – 15	Very bad	Black

(Source: Shakya, 2001)

5.3.2 Macroinvertebrates

5.3.2.1 Sample collection, preservation and identification

Benthic macroinvertebrates were sampled by using bin sampler (box sampler) of area 30 cm x 30 cm. It consists of square box open at the top and bottom which was pushed into the substratum. The bottom was jaggedly toothed and the top is fitted with lateral handles so that it can be pushed easily into the substratum (Wilding, 1940; Hynes, 1979, Yadav *et al.* 1987). The samples were collected by stratified random

sampling so as to cover all types of microhabitats present within the river. The sampling station (area) was divided into different strata based on biotopes (microhabitats) such as stony substratum, mud, moss, sand, pool, rifle etc. The sampling units were allocated to each stratum proportionally to the area of stratum and the samples were taken randomly from each stratum (Yadav *et al.*1987). All the substratum along with benthic macroinvertebrates were lifted up immediately and kept in a bucket containing water. The stones were washed in the bucket using soft paint brush. The water and fine substratum (sand and silt) along with macroinvertebrates were sieved in the sieve-set containing the brass sieve of 600 μ mesh size at the top and 420 μ mesh size at bottom. They were washed several times. Each sample was placed with a little stream water in a separate container with the details of its sampling position and dates and then brought to the laboratory. Monthly 10 samples were taken from each of seven sampling stations for 10 months.

Samples were sorted in the laboratory soon after their collection from the field, usually on the same day. Sorting of the sample was found to be much easier and quicker when the animal were alive. For sorting, sample was poured in a white enameled tray containing a little water from where animals were removed by forceps or soft paint-brush even by observing through hand lens for some minute animals. If sand and gavels predominate, a floatation technique using super-saturated magnesium sulphate can be used to float-off the organisms (Anderson, 1959). The sorted macroinvetebrates were fixed in a vial containing 4 % formalin for about week. Then they were preserved in 70 % alcohol (APHA, 1995). Due to the lack of complete taxonomic identification keys of this region, the preserved species were identified by using the previously identified species and literatures on identification of species of this region such as of Indian and China.

5.3.2.2 Methods of macroinvertebrates analysis

The macroinvertebrates features were analyzed by using the following indices of species structures in communities.

a) Density

The density of macroinvertebrates (D) were calculated by using the following equation (Yadav *et al.* 1987)

$$D = \frac{Total\ no.\ of\ individuals}{Sampling\ area}$$

b) Shannon index of general diversity:

Shannon index of general diversity ($\overline{H}$) is calculated by using the following equation (Odum, 1996).

$$\overline{H} = -\sum\left(\left(\frac{ni}{N}\right)\log_e\left(\frac{ni}{N}\right)\right)$$

Where,

n_i = Number of individuals of a species

N = Total no. individuals of all species

c) Evenness index:

The evenness index (e) is calculated by using following equation (Odum, 1996).

$$e = \frac{\overline{H}}{\log S}$$

Where,

$\overline{H}$ = Shannon index

S = number of species.

d) Index of Dominance (c):

The index of Dominance (c) is calculated by using following equation (Odum, 1996).

$$c = \sum(ni/N)^2$$

Where,

n_i = Number of individuals of a species

N = Total no. individuals of all species

e) Determination of Saprobic water quality class:

Saprobic water quality class of each station at different station during investigation period was calculated by using the Original Nepalese Biotic Score/Average Score Per Taxon (NEPBIOS/ASPT) (Sharma, 1996), Nepalese Biotic Score – Bagmati River

System /Average Score Per Taxon (NEPBIOS-BRS/ASPT) (Pradhan, 1998), Ganga River System index /Average Score Per Taxon (GRS/ASPT) (Nesemann, 2006) and newly prepared Extended Nepalese Biotic Score/Average Score Per Taxon (Extended NEPBIOS/ASPT) (Sharma *et al.* 2007, to be published and obtained through personal communication). The average scores per taxon (Original NEPBIOS/ASPT, NEPBIOS-BRS/ASPT, GRS/ASPT and Extended NEPBIOS/ASPT) based on respectively Original NEPBIOS, NEPBIOS-BRS, GRS and Extended NEPBIOS values were calculated by summing the individual taxon i.e. to family or generic or species level as defined in the score list present in a sample and divided by the number of scoring taxa. Once Original NEPBIOS/ASPT, NEPBIOS-BRS/ASPT, GRS/ASPT and Extended NEPBIOS/ASPT were calculated, they were transformed to equivalent seven saprobic water quality classes as follows.

Table 13: NEPBIOS/ASPT transformation scale for Midland and Lowland Nepal

NEPBIOS/ASPT* Original scale	**NEPBIOS/ASPT** for Midland **	**NEPBIOS/ASPT** for lowland **	**Equivalent Saprobic Water Quality classes**
8.00 – 10.00	7.50 – 10.00	6.50 – 10.00	I
7.00 – 7.99	6.51 – 7.49	6.00 – 6.49	I – II
5.50 – 6.99	5.51 – 6.50	5.00 – 5.99	II
4.00 – 5.49	4.51 – 5.50	4.00 – 4.99	II – III
2.50 – 3.99	3.51 – 4.50	2.50 – 3.99	III
1.01 – 2.49	2.01 – 3.50	1.01 – 2.49	III – IV
1	1.00 – 2.00	1	IV

(Source: Sharma, 1996; Sharma *et al.* 2005; Nesemann, 2006; Sharma *et al.* 2007)

Note: * for Original NEPBIOS/ASPT and NEPBIOS-BRS/ASPT
** for GRS/ASPT and Extended NEPBIOS/ASPT.

5.3.3 Microbiological water quality

Water samples for microbiological examination was collected in bottles (glass) that had been cleansed and sterilized by keeping more than 60 minutes at a temperature of 170°C in an oven. When sample was collected, ample air space (at least 2.5 cm) was left in the bottle to facilitate mixing by shaking, before examination. They were

brought to the laboratory as soon as possible and total coliforms were studied by using membrane Filter method. For this, glasswares including sample bottles, dilution bottles, pipettes, graduated cylinders, containers for culture medium, culture plates and filtration units were sterilized. For the filtration of sample, a sterile membrane filter (grid side up) was placed over porous plate of receptacle using sterile forcep. A matched funnel unit was placed over receptacle carefully and locked it in place. The sample was filtered under partial vacuum with filter still in place, the interior surface of the funnel was rinsed by filtering three 20 to 30 mL portion of sterile dilution of water. Simultaneously, a pad was placed in the petridish dish and saturated with 1.8 – 2.0 mL M-endo broth. Upon completion of final rinse in the filter process, vacuum was disengaged, funnel was unlocked and removed and membrane filter was removed immediately with sterile forceps and pressed it on pad in the petridish with a rolling motion to avoid entrapment of air.The petridish was inverted and incubated for 22 to 24 hours at 35 ± 0.5 ^{0}C. By using a low-power10 to 15 magnifications binocular microscope, colonies on the membrane filter were counted. The typical coliform colony has a pink to dark red colour with metallic surface sheen. The sheen area may vary in size from small pin head to complete coverage of the colony surface. Atypical coliform colonies can be dark red or nucleated without sheen . Colonies that lack sheen may be pink red, white or colourless and are considered to be non coliform. Both typical and atypical colonies were verified by a test for lactose fermentation. For this all typical and atypical colonies were transferred to lauryl tryptose broth and incubated at 35 ± 0.5 ^{0}C for 48 hours. Gas formed in lauryl tryptose broth and confirmed in brilliant green lactose broth through formation of gas in any amount in the inverted vial within 48 hours verifies the colony as the coliforms (APHA, 1995).

5.4 Remote Sensing and Geographic Information System method

Remote Sensing (RS) and Geographic Information System (GIS) method was used to extract land use types, prepare water quality map of rivers and other maps preparation such as drainage map, location of sampling points, sewage outfalls and wastewater treatment plants etc. For this purpose, the softwares ILIWIS 3.3 Academic (ITC/RSG/GSD) and ArcView GIS 3.3 (Environmental Systems Research Institute, Inc.) were used.

5.5 Statistical analysis

5.5.1 Hypotheses

The hypotheses, null hypothesis (H_0) and alternative hypothesis (H_A) of the present study are as follows.

a) H_0: There is no significant difference in the physico-chemical and biological features of the Manahara river at different months of the investigation period.

H_A: There is significant difference in the physico-chimcal and biological features of the Manahara river at different months of the investigation period.

b) H_0: There is no significant difference in the physico-chimcal and biological features of the Manahara river in different stations of the investigation period.

H_A: There is significant difference in the physico-chimcal and biological features of the Manahara river in different stations of the investigation period.

c) H_0: $r = 0$ i.e. there is no significant correlation between chemically determined water quality index or class and biologically determined saprobic water quality class or average score per taxon in the river.

H_A: $r \neq 0$ i.e. there is significant correlation between chemically determined water quality index or class and biologically determined saprobic water quality class or average score per taxon in the river.

5.5.2 Pearson's correlation

The Pearson's correlation (r) as well as the test of significance were done between chemically determined water quality classes and biologically determined saprobic

water quality classes. In addition, the correlation analysis was also done between various physico-chemical parameters. The statistical software SPSS 10.0 was used to analyse Pearson's correlation.

5.5.3 Coefficient of determination

The coefficient of determination between chemically determined water quality classes and biologically determined saprobic water quality classes as r^2 is calculated by using Microsoft Office Excel 2003, Microsoft Office Professional 2003.

5.5.4 Analysis of Variance (ANOVA)

One way ANOVA was applied to test the significance of monthly variation of water quality as well as macroinvertebrates components of the Manahara river. It was also applied to know the significance of variation of water quality and macroinvertebrates components from upstream to downstream of the river (UNESCO, 1996). The statistical software SPSS 10.0 was used for this analysis.

CHAPTER SIX

6. RESULTS

6.1 Physico-chemical features

6.1.1 Velocity

The seasonal variation of average velocity at different stations of the Manahara River over the period of ten months (2005/2006) is given in the figure 13. The velocity of the river flow was erratic at stations 1, 2, 3, 4 and 7 but it showed a distinct pattern of variation at stations 5 and 6 of the Manahara River at different months during the present investigation period. The velocity of the river water of 0.68 m/s at station 5 and 0.74 m/s at station 6 in October decreased gradually and reached minimum levels of 0.27 m/s in February (winter) at station 5 and 0.16 m/s in March (pre-monsoon) at station 6. From then velocity increased gradually and reached maximum level in June (monsoon) at these two stations (0.72 m/s at station 5 and 0.66 m/s at station 6). However, at station 5, the maximum velocity of 0.72 m/s was also found in July as similar to June.

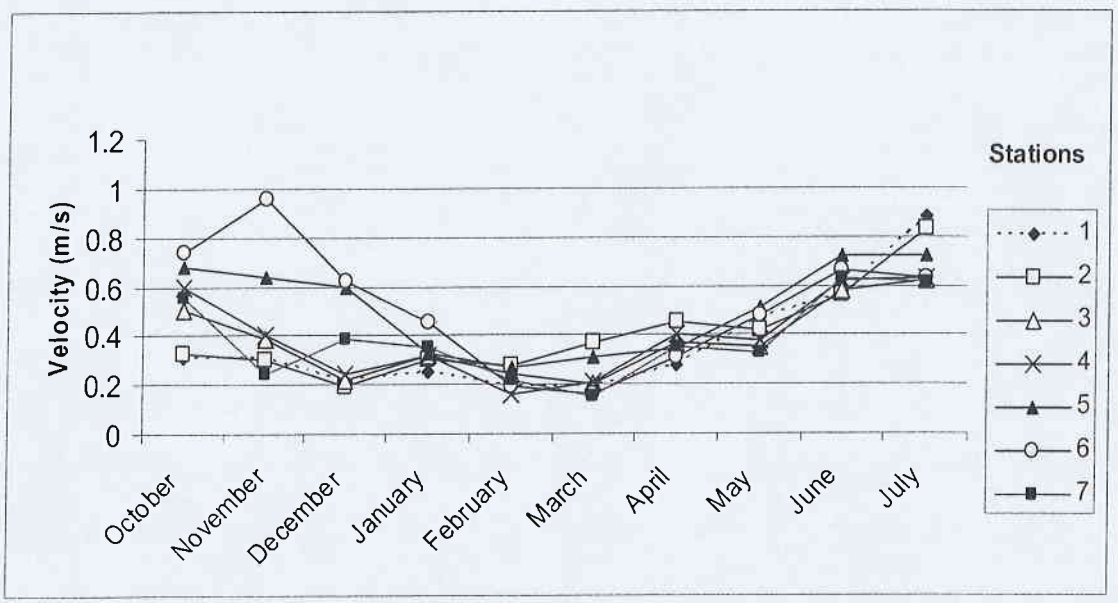


Figure 13: Seasonal variation of velocity over the period of ten months of Manahara River (2005/2006)

But a minimum level of velocity of 0.19 m/s at station 2 was recorded in December (winter). Minimum levels of velocity of 0.19 m/s at station 1; 0.2 m/s at station 3; 0.21 m/s at station 4 and 0.15 m/s at station 7 were observed in March (pre-monsoon).

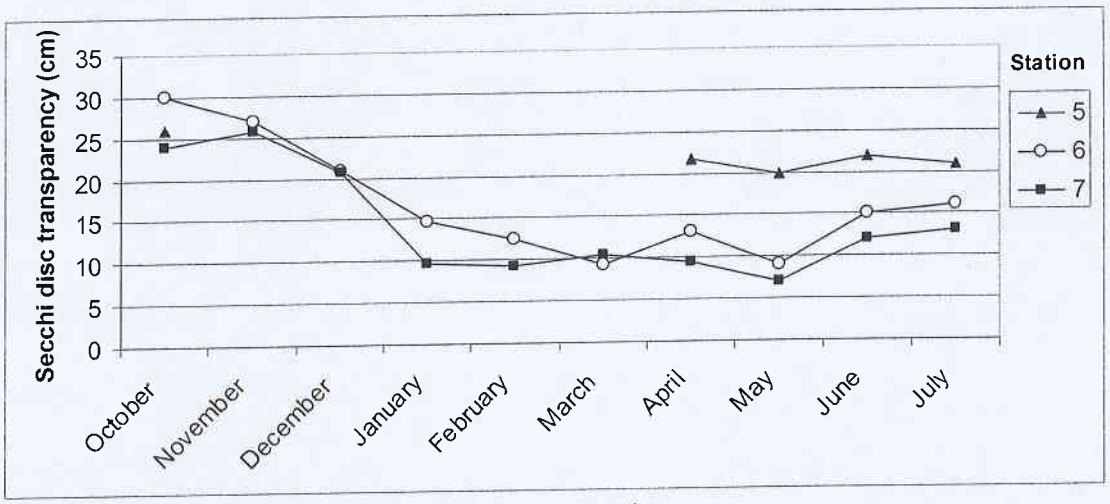
Similarly, the maximum levels of velocity of 0.88 m/s at station 1; 0.83 m/s at station 2; 0.62 m/s at station 3 and 0.63 m/s at station 4 were observed in July (monsoon) whereas that of 0.72 m/s was observed at station 5 in June and July. Such monthly variation of velocity during the investigation period is significant (F = 10.835, probability level = 0.01, d.f.= 69).

On the average, the mean velocities of the water of the Manahara river recorded were 0.37 m/s at station 1; 0.40 m/s at station 2; 0.38 m/s at station 3; 0.40 m/s at station 4; 0.51 m/s at station 5; 0.52 m/s at station 6 and 0.38 m/s at station 7 during the present investigation period. In general the velocity was more or less similar at stations 1, 2, 3, 4 and 7. The velocity was slightly higher at stations 5 and 6. The spatial variation of velocity along the river from stations 1 to 7 in not significant (F = 1.155, probability level = 0.01, d.f.= 69). Among all the stations, the lowest velocity of 0.15 m/s was recorded at station 7 in March (pre-monsoon) and the highest velocity of 0.88 m/s was recorded at station 1 in July (monsoon) during the present investigation period.

The amplitudes of variations of velocity during the investigation period were 0.26 m/s, 0.21 m/s, 0.30 m/s, 0.17 m/s, 0.29 m/s, 0.40 m/s and 0.94 m/s at stations 1, 2, 3, 4, 5, 6 and 7 respectively.

6.1.2 Secchi disc transparency

The water at stations 1 to 4 of Manahara river was found transparent throughout the investigation period except in April at station 3 where the secchi disc transparency was 23 cm. There was direct sunlight penetration to the bottom of the river. The value of Secchi disc transparency in the Manahara river during different months of the investigation period at stations 5, 6 and 7 are shown in figure 14. The Secchi disc transparency value of 26 cm at station 5 in October decreased to the level of 21.00 cm in July.



Note: Truncated part of the curve indcates the transparent river water.

Figure 14: Seasonal variation of secchi disc transparency (cm) over the period of ten months (2005/2006) at staions 6 and 7 of Manahara river

A maximum Secchi disc transparency value of 30.00 cm at station 6 in October gradually decreased and reached to minimum level of 9.0 cm in May. It again increased to 16.0 cm in July. At station 7, the Secchi disc transparency value of 24.00 cm in October increased to a maximum level of 25.67 cm in November which decreased to a minimum level of 7.00 cm in May. It again increased to 13.00 cm in July. Therefore, the minimum level of Secchi disc transparency was observed in May at these three stations 5, 6 and 7.

On the average, the water at stations 1 to 4 of Manahara river were found to be transparent during the present investigation period whereas the Secchi disc transparency was 22.15 cm to transparent at station 5; 16.73 cm at station 6 and 14.13 cm at station 7. Therefore, Secchi disc transparency was decreased towards downstream region.

The amplitudes of variations of Secchi disc transparency value were 6 cm at station 5; 21 cm at station 6 and 67 cm at station 7 of the Manahara river during the investigation period.

6.1.3 Mean depth

The seasonal variation of mean depth of water of the river over the period of ten months (2005/06) is shown in figure15. The mean depth of water of the river

fluctuated highly at stations 1, 4 and 6 from October and reached minimum level in February at station 1 (0.09 m), in January at station 4 (0.09 m) and in March at station 6 (0.08 m). But, at stations 2, 3, 5 and 7 it gradually decreased from October from the mean depth of 0.2 m at station 2; 0.27 m at station 3; 0.22 m at station 5 and 0.68 m at station 7 and reached minimum level of 0.06 m at station 2; 0.05 m at station 3; 0.07 m at station 5 and 0.10 m at station 7 in March (pre-monsoon). From these minima, it generally increased and reached maximum level in July (monsoon) with mean depth of 0.23 m at station 2; 0.35 m at station 3; 0.28 m at station 4; 0.36 m at station 5; 0.48 m at station 6 and 1.04 m at station 7. But, it reached maximum level of 0.25 m in June at station 1. Therefore, mean depth generally decreased from post–monsoon (October) to late winter (February) or early pre-monsoon (March) and then increased in monsoon (June/July). Such variation of mean depth in different months during the investigation period is significant (F = 3.524, probability level = 0.01. d.f.= 69).

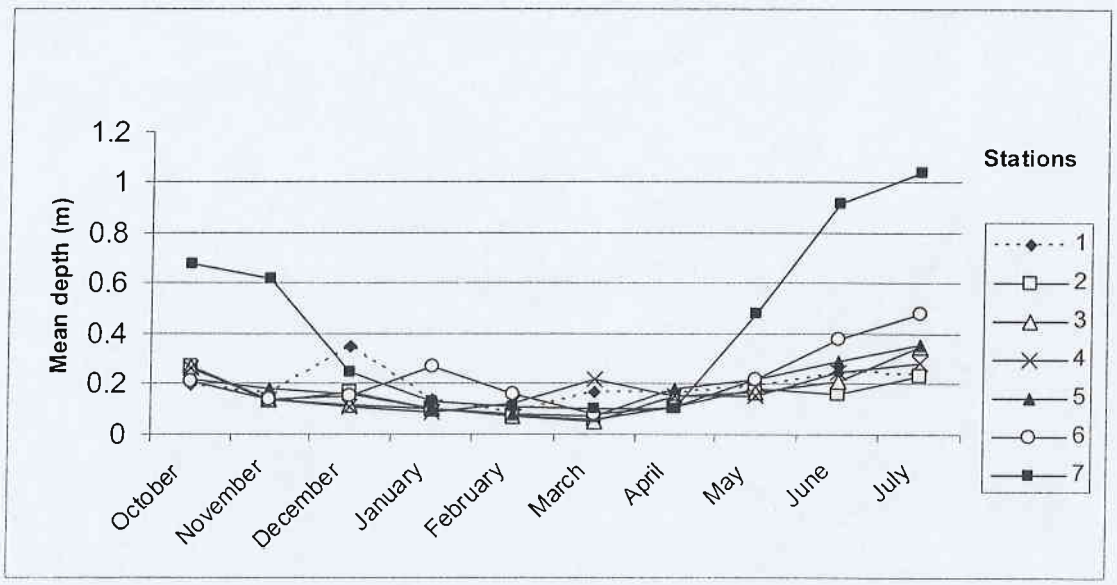


Figure 15: Seasonal variation of mean depth of Manahara River over the period of ten months (2005/2006)

On the average the mean depths were found to be 0.196 m at station1; 0.148 m at station 2; 0.1635 m at station 3; 0.1777 m at station 4; 0.186 m at station 5; 0.22 m at station 6 and 0.443 m at station 7. Therefore, mean depth of the river was usually minimum in upstream part and maximum in downstream part. But, particularly in winter (December, January, February) and early and mid–pre-monsoon (March and April), the mean depth fluctuated from upstream to downstream. The spatial variation of mean depth along the river stretch is significant at 0.05 significance level and not

significant at 0.01 significance level (F = 4.102, d.f.=69). During the entire investigation period, the lowest mean depth of 0.05 m was recorded at station 3 in March and the highest mean depth of 1.04 m was recorded at station 7 in July.

The amplitudes of variations of mean depth of the Manahara river were 0.26 m, 0.21 m, 0.30 m, 0.17 m, 0.29 m, 0.40 m and 0.94 m at stations 1, 2, 3, 4, 5, 6 and 7 respectively.

6.1.4 Discharge

The seasonal variation of discharge of the Manahara River over the period of ten months (2005/2006) is presented in figure 16. The discharge of the river generally decreased from the values of 0.3742 m^3/s at station 1; 0.2582 m^3/s at station 2; 1.1059 m^3/s at station 3; 1.9903 m^3/s at station 4; 1.7183 m^3/s at station 5; 5.5410 m^3/s at station 6 and 5.8920 m^3/s at station 7 in the month of October and reached minimum levels in February (late winter) at station 1 (0.0511m^3/s), station 4 (0.0959 m^3/s) and station 5 (0.0770 m^3/s) and March (early pre-monsoon) at station 2 (0.0909 m^3/s), station 3(0.0174 m^3/s), station 6 (0.0855 m^3/s) and station 7 (0.1005 m^3/s) although there was slight decrease in discharge level from October to November at stations 1 and 2. From then it gradually increased and reached maxima in July at all the stations i.e. 1.6204 m^3/s at station1; 1.7812 m^3/s at station 2; 1.8142 m^3/s at station 3; 2.7212 m^3/s at station 4; 3.7214 m^3/s at station 5; 9.2045 m^3/s at station 6 and 9.8321 m^3/s at station 7. The monthly variation of discharge in the study period is significant (F = 4.14, probability level0.01, d.f.= 69).

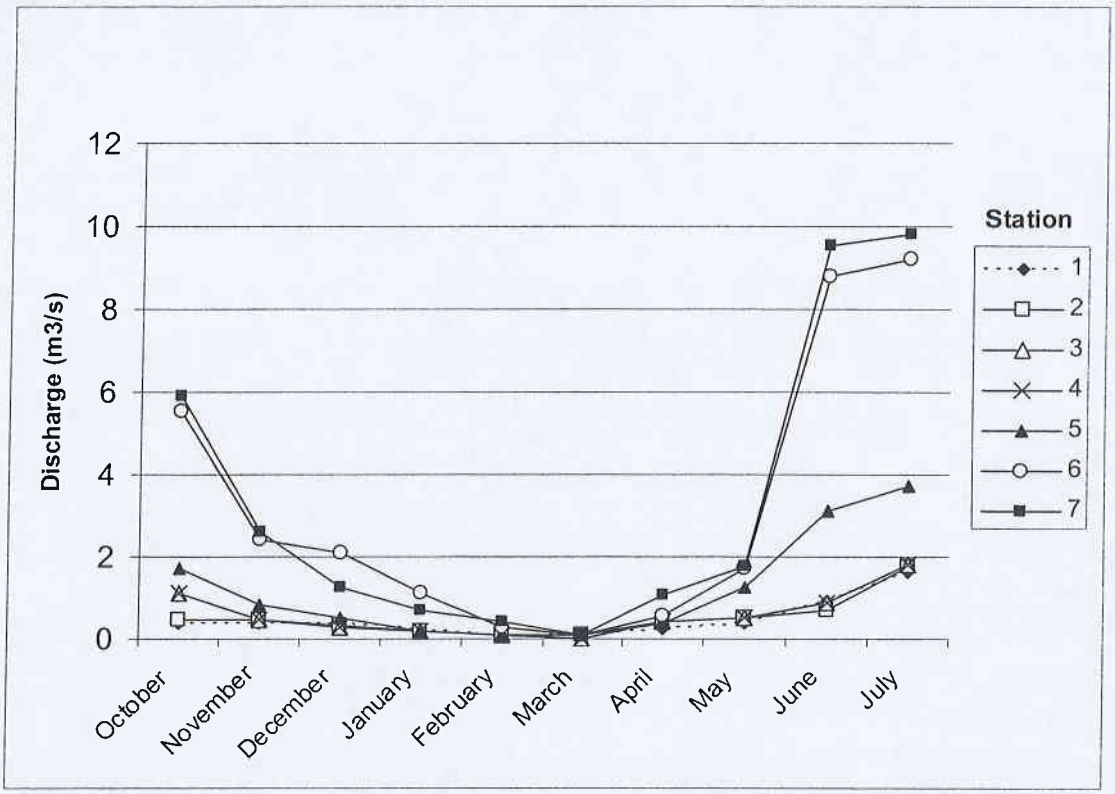


Figure 16: Seasonal variation of discharge of Manahara River over the period of ten months (2005/2006)

On the average, the discharge of the Manahara river recorded were 0.4638 m^3/s, 0.5000 m^3/s, 0.5871 m^3/s, 0.5871 m^3/s, 1.1858 m^3/s, 3.1788 m^3/s and 3.3149 m^3/s at stations 1, 2, 3, 4, 5, 6 and 7 respectively. Therefore, the discharge increased from stations 1 to 7 i.e. upstream to downstream in most of the months during the present investigation period . The lowest discharge of 0.0174 m^3/s was recorded at station 3 in March and the highest discharge of 9.8321 m^3/s was recorded at station 7 in July among all the stations in different months of the investigation period. The spatial variation of discharge value along the river stretch is significant at 0.05 significant level and not significance at 0.01 significance level ($F = 4.036$, d.f.= 69).

The amplitudes of discharge variations during the investigation period were 1.113 m^3/s, 1.6903 m^3/s, 1.7968 m^3/s, 2.6253 m^3/s, 3.6444 m^3/s, 9.119 m^3/s and 9.7315 m^3/s recorded at stations 1, 2, 3, 4, 5, 6 and 7 respectively.

6.1.5 Water temperature

The seasonal variations of surface water temperature of the Manahara river over the period of ten months (2005/2006) are shown in figure 17. The surface water

temperature of 17.2°C, 20.5°C, 16.0 °C, 18.33 °C and 23.0 °C respectively at stations 1, 2, 3, 6 and 7 of Manahara river of October decreased and reached the minimum level of 9.0°C at stations 1, 2 and 3 and also 10.5 ° C at stations 6 and 7 in December (winter). But at stations 4 and 5, surface water temperature of 16.5^0 C at station 4 and 19.67^{0}C at station 5 decreased from October to the minimum level of 8.5^{0}C at station 4 and 9.5^{0}C at station 5 in January (winter) for both stations.

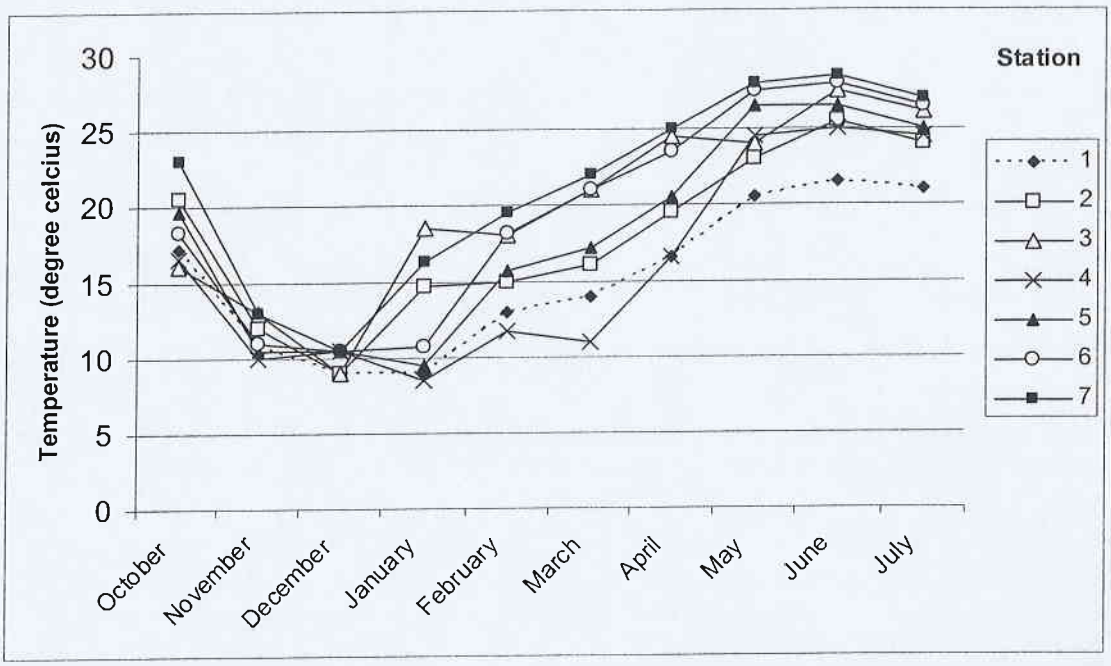


Figure 17: Seasonal variation of water temperature of Manahara River over the period of ten months (2005/2006)

After these minima, the surface water temperature increased and reached maximum level in June at all stations i.e. 21.5° C at station 1; 25.5°C at station 2; 27.5°C at station 3; 25.0 ° C at station 4; 26.5° C at station 5; 28.0°C at station 6 and 28.5 ° C at station 7 which again decreased in July at all the stations. However at station 1, minimum level of temperature of 9.0 °C was observed in December as well as in January and at station 5, equal maximum temperature i.e. 26.5°C was observed in June as well as in May. Such temperature variation in different months of investigation period is significant (F = 30.562, probability level=0.01, d.f.= 69).

On the average, surface water temperature recorded were 15.25 ± 0.836 °C at station 1; 17.92 ± 0.9431 °C at station 2; 19.77 ± 1.0379 °C at station 3; 15.87 ± 1.1433 °C at station 4; 18.15 ± 1.1452 °C at station 5; 19.52 ± 1.2088 °C at station 6 and 21.28 ± 1.0956 °C at station 7 over the ten months of the present investigation

period. In general, the surface water temperature increased gradually from stations 1 to 3 and then decreased highly at station 4 from when it again increased to station 7. The water temperature was lower at station 1 and higher at station 7 during the investigation period. Among all the stations in all the months of investigation period, the lowest temperature of 8.5 ± 0 °C was recorded at station 4 in January and the highest temperature of 28.5 ± 0 °C was recorded at station 7 in June.

The amplitudes of surface water temperature variations over the ten months during the investigation period (2005/2006) were 12.5 °C, 16.5 °C, 18.5 °C, 16.5 °C, 17.0 °C , 17.5 °C and 18.0 °C at station 1, 2, 3, 4, 5, 6 and 7 respectively.

6.1.6 pH

The seasonal variation of pH of surface water of the river over the period of ten months (2005/2006) is shown in figure 18. The pH of surface water of 7.13 at station 1; 7.03 at station 2; 7.03 at station 6 and 6.2 at station 7 in October increased till December. At stations 1 and 2, pH fluctuated after December till July and pH was observed maximum level in March which was 7.37 at station 1 and 7.36 at station 2. But, the pH recorded in December at stations 6 and 7 were maximum level i.e. 7.26 at station 6 and 7.37 at station 7. The pH decreased gradually from December till April and then fluctuated till July at stations 6 and 7.

At stations 3, 4, and 5, the pH was recorded maximum in January which was 7.35 at station 3, 7.28 at station 4 and 7.27 at station 5. At station 3, the pH increased gradually from 6.67 in October till 7.35 in January and then fluctuated till July whereas at station 4, it fluctuated from October till July. At station 5, the pH decreased from 7.13 in October till 7.08 in December and then increased to 7.27 in January from when it again decreased till 6.67 in March and then after fluctuated till July. Such seasonal variation of pH of the river water is significant ($F = 5.485$, probability level = 0.01, d.f.= 69).

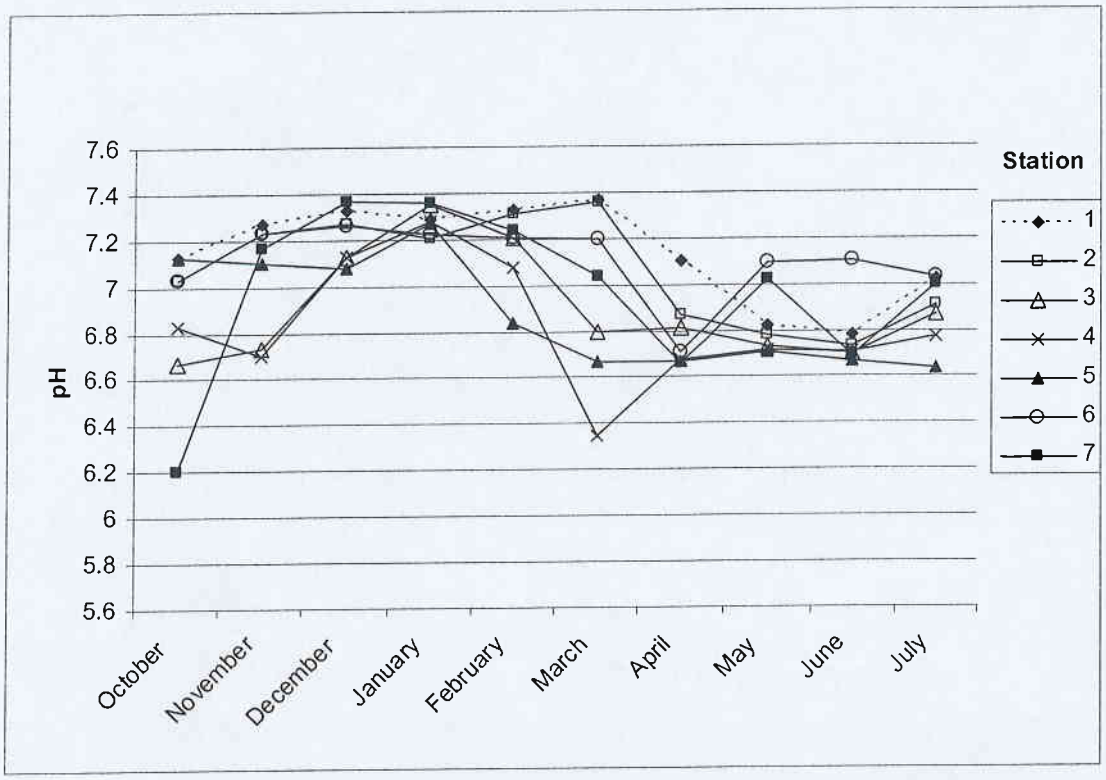


Figure 18: Seasonal variation of pH of Manahara River over the period of ten months (2005/2006)

On the average, the pH of the water of the Manahara river were recorded as 7.14± 0.0376 at station 1; 7.07 ± 0.0411 at station 2; 6.90 ± 0.0426 at station 3; 6.83 ±0.0492 at station 4; 6.88 ± 0.0430 at station 5; 7.11 ± 0.0356 at station 6 and 6.98 ±0.0638 at station 7. Such spatial variation of pH of the river water along the Manahara river is significant at 0.05 probability level and not significant at 0.01 probability level ($F = 2.388$, d.f.= 69).

Among various stations during the present investigation period, a lowest pH of 6.2 was recorded at station 7 in October whereas the highest pH of 7.37 was recorded at station 7 in December and also at station 1 in March.

The amplitudes of pH variations in the river during the present investigation period were 0.53, 0.63, 0.68, 0.93, 0.63, 0.55 and 1.17 recorded at stations 1, 2, 3, 4, 5, 6 and 7 respectively. Therefore, station 1 had the water with less range of pH variability whereas station 7 had the highly variable pH.

6.1.7 Dissolved Oxygen and Oxygen Saturation %

The seasonal variation of dissolved oxygen (DO) the Manahara river over the period of ten months (2005/2006) is shown in the figure19.The monthly variation of dissolved oxygen showed that oxygen content of 7.91 mg/L at station 1; 6.89 mg/L at station 2; 6.11 mg/L at station 3; 6.2 mg/L at station 4 and 5.73 mg/L at station 5 in October increased to December and then decreased to January at these stations 1, 2, 3, 4 and 5. Then after, at stations 2, 3 and 4, the dissolved oxygen increased from January to February and then decreased till June except at station 3. From June, dissolved oxygen increased to July at stations 2 and 4 whereas it decreased at station 3 from June to July.

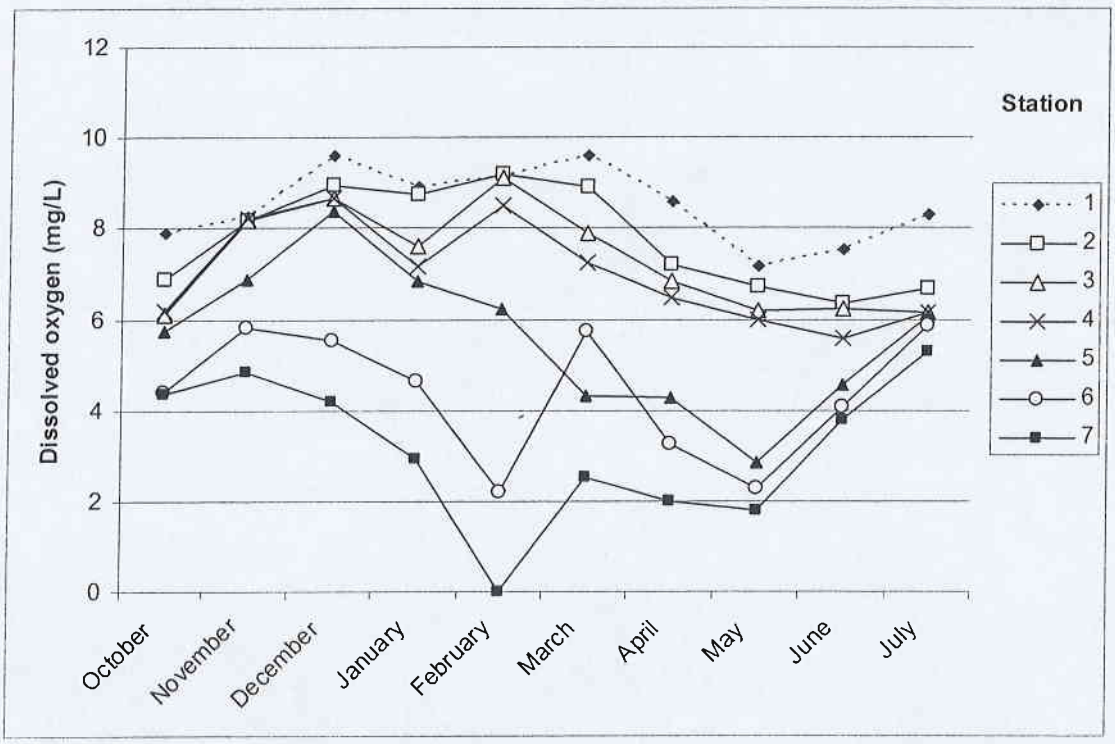


Figure 19: Seasonal variation of dissolved oxygen of Manahara River over the period of ten months (2005/2006)

At station 1, dissolved oxygen content decreased from December to January and then increased from January to March which again decreased to May and then increased from May to July. However, at station 5, dissolved oxygen content decreased from January to May which again increased to July. However, the pattern of dissolved oxygen fluctuation was similar for stations 6 and 7. At stations 6 and 7, dissolved oxygen content increased from 4.39 mg/L at station 6 and 4.36 mg/L at station 7 in October to November and then decreased gradually from November and reached

minimum level of 2.2 mg/L at station 6 and nil at station 7 in February. Again dissolved oxygen content was increased from February to March and then decreased till May from where dissolved oxygen was again increased until July. In general, dissolved oxygen content increased from post-monsoon to winter (except stations 5, 6 and 7) which then decreased till late pre-monsoon and then again increased in monsoon season. Such variation in dissolved oxygen content in the river water in different months is not significant at 0.01 and 0.05 probability level (F = 1.160, d.f.= 69).

On the average, the dissolved oxygen contents of the water of the Manahara river were recorded as 8.50 ± 0.1529 mg/L at station 1; 7.78 ± 0.1975 mg/L at station 2; 7.30 ± 0.2066 mg/L at station 3; 7.02 ± 0.2056 mg/L at station 4; 5.61 ± 0.2826 mg/L at station 5; 4.38 ± 0.4375 mg/L at station 6 and 3.53 ± 0.2862 mg/L at station 7. In general, the dissolved oxygen content of the river water was decreased from stations 1 to 7. The highest dissolved oxygen of surface water of the river was recorded at site 1 in all the months of investigation period except in February and the lowest dissolved oxygen of surface water was recorded always at site 7 in all the months of investigation period. Such variation of dissolved oxygen content along the river from stations 1 to 7 is significant (F = 22.239, probability level = 0.01, d.f.= 69). Throughout the entire investigation period, the lowest dissolved oxygen content recorded was 0 mg/L at station 7 (at all three sampling points) in February whereas the maximum dissolved oxygen content recorded was 9.59 mg/L at station 1 in December and in March.

The amplitudes of variations of dissolved oxygen content were 2.49 mg/L; 2.85 mg/L; 3.01 mg/L; 3.1 mg/L; 5.54 mg/L; 3.64 mg/L and 5.27 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 of the river during the investigation period.

The seasonal variation of Oxygen saturation % of the surface water of the Manahara river over the period of ten months (2005/2006) is presented in figure20. The oxygen saturation % fluctuated from October till July at all the stations during the investigation period.

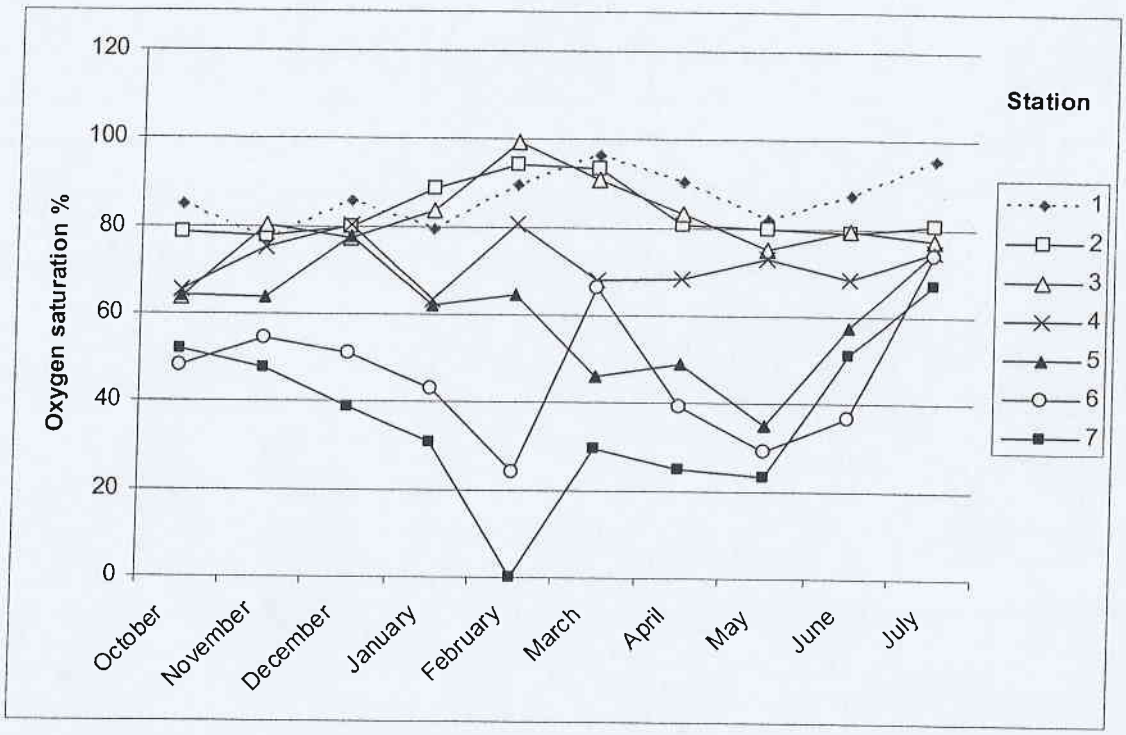


Figure 20: Seasonal variation of oxygen saturation % of the water of Manahara River over the period of ten months (2005/2006)

At station 1, the maximum level of oxygen saturation % of 96.13 % was observed in March (pre-monsoon). At stations 2, 3, and 4, the maximum levels of oxygen saturation % were observed in February (late winter) i.e. 94.23 % at station 2; 99.39 % at station 3 and 80.82 % at station 4. But the maximum level of oxygen saturation % was observed in July (monsoon) at station 6 (73.74 %) and at station 7 (67.09 %). At station 5, the maximum level of oxygen saturation % of 77.56 % was observed in December (winter). Such monthly variation of oxygen saturation % is not significant at 0.01 and 0.05 probability level ($F = 0.431$, d.f.= 69).

On the average, the oxygen saturation % of the water of the Manahara river recorded were 86.85 ± 1.2389 % at station 1; 83.33 ± 1.551 % at station 2; 81.10 ± 1.778 % at station 3; 71.83 ± 1.4121 % at station 4; 59.48 ± 2.278 % at station 5; 40.60 ± 4.5776 % at station 6 and 36.52 ± 3.3320 % at station 7. Generally, the oxygen saturation % decreased from station 1 to 7 i.e. upstream to downstream except at some stations in some months. Among all the stations during the investigation period, the lowest oxygen saturation % of 0 % was recorded at station 7 in February and the highest

Oxygen saturation of 99.39 % was recorded at station 3 in February. Such spatial variation of oxygen saturation % from stations 1 to 7 is significant. (F = 27.227, probability level = 0.01, d.f.= 69).

The amplitudes of variations of oxygen saturation % were 19.12 %, 16.40 %, 35.44 %, 17.59 %, 42.46 %, 49.74 % and 67.09 % respectively at stations 1, 2, 3, 4, 5, 6 and 7 of the river during the present investigation period.

6.1.8 Biochemical Oxygen Demand (BOD)

The seasonal variation of BOD in the Manahara River over the period of ten months (2005/2006) during the present investigation is shown in figure 21. The BOD was decreased from 1.84 mg/L at station 1; 2.98 mg/L at station 2; 9.12 mg/L at station 3; 15.2 mg/L at station 4; 37.04 mg/L at station 5; 75.99 mg/L at station 6 and 78.35 mg/L at station 7 in October to November at all these stations. But at stations 1, 2 and 3, the BOD value from November fluctuated slightly and reached maximum level in June (2.71 mg/L at station 1; 4.41 mg/L at station 2 and 10.92 mg/L at station 3) and then again decreased in July at these three stations. At station 4 and 5, BOD increased gradually from November and reached maximum in June at station 4 (19.07 mg/L) and in May at station 5 (56.15 mg/L) from where BOD again decreased to July. However, at station 6 and 7, the BOD fluctuated highly having minimum value in January for both stations (68.04 mg/L at station 6 and 72.7 mg/L at station 7) whereas maximum value was recorded in February at station 6 (154.94 mg/L) and in May at station 7 (167.25 mg/L). The observed monthly variation of BOD_5 in the river water during the investigation period is not significant at 0.01 and 0.05 significance level. (F =0.336, d.f..= 69).

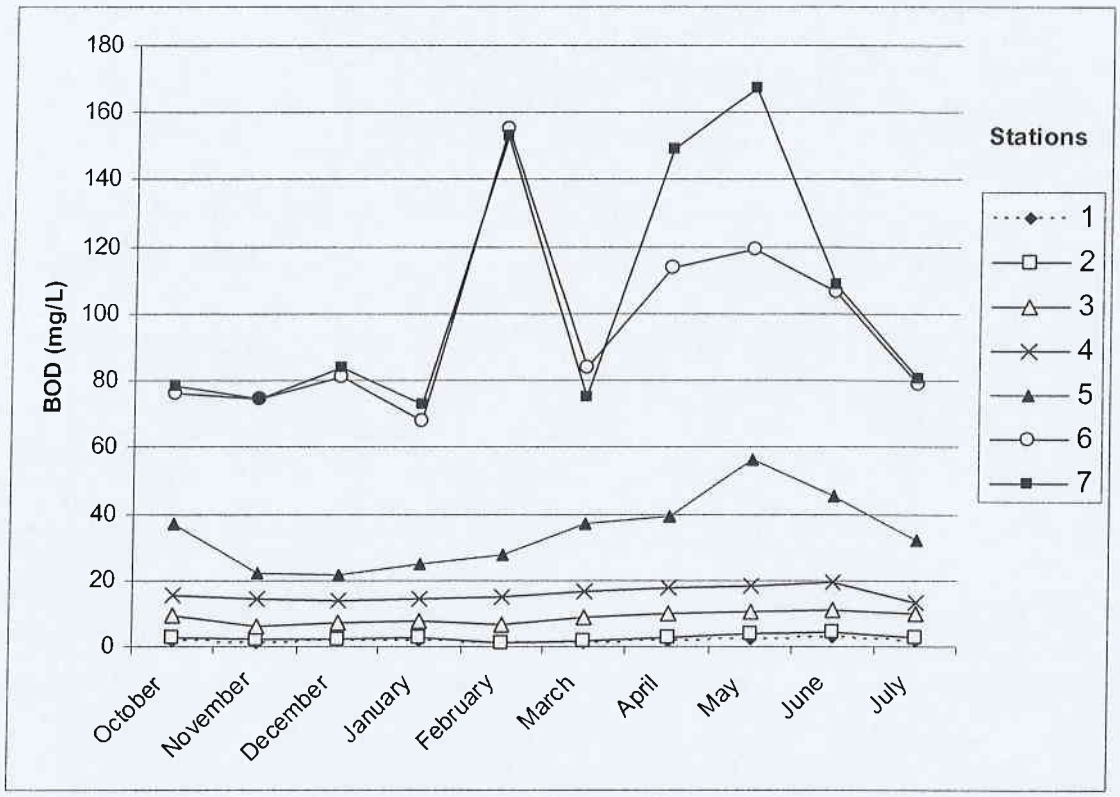


Figure 21: Seasonal variation of BOD of Manahara river over the period of ten months (2005/2006)

On the average, the BOD values of 1.74 ± 0.0912 mg/L; 2.67 ± 0.1682 mg/L; 8.71 ± 0.3073 mg/L; 15.80 ± 0.3768 mg/L; 34.31 ± 1.9418 mg/L; 95.64 ±8.2406 mg/L and 104.37 ± 6.8771 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 of the river were recorded during the investigation period. BOD increased from station 1 to 7 in all the months of investigation period except from stations 6 to 7 in February and March. During the entire investigation period, the lowest BOD was observed at station 1 in November (1.13 mg/L) and the highest BOD was observed at station 7 in May (167.25 mg/L). Such variation of BOD_5 along the river from stations 1 to 7 is significant (F =59.332, probability level = 0.01, d.f.= 69).

The amplitudes of variations of BOD values of 1.59 mg/L; 3.13 mg/L; 4.89 mg/L; 6.04 mg/L; 34.35 mg/L; 86.90 mg/L and 94.55 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 were recorded in the river during the investigation period.

3.1.9 Free carbondioxide (CO_2)

The seasonal variation of free CO_2 of surface water of the river over the period of ten months (2005/2006) of the investigation period is shown in figure22. At station 1, the content of free CO_2 of 9.68 mg/L in October decreased till December from when it fluctuated and reached maximum level in June (10.73 mg/L) and again decreased in July. But free CO_2 of 10.85 mg/L at station 2 and 11.73 mg/L at station 3 in October were increased to November from when it decreased to January. From January, free CO_2 fluctuated and reached maximum in May (13.35 mg/L at station 2 and 13.87 mg/L at station 3) and then after it decreased till July.

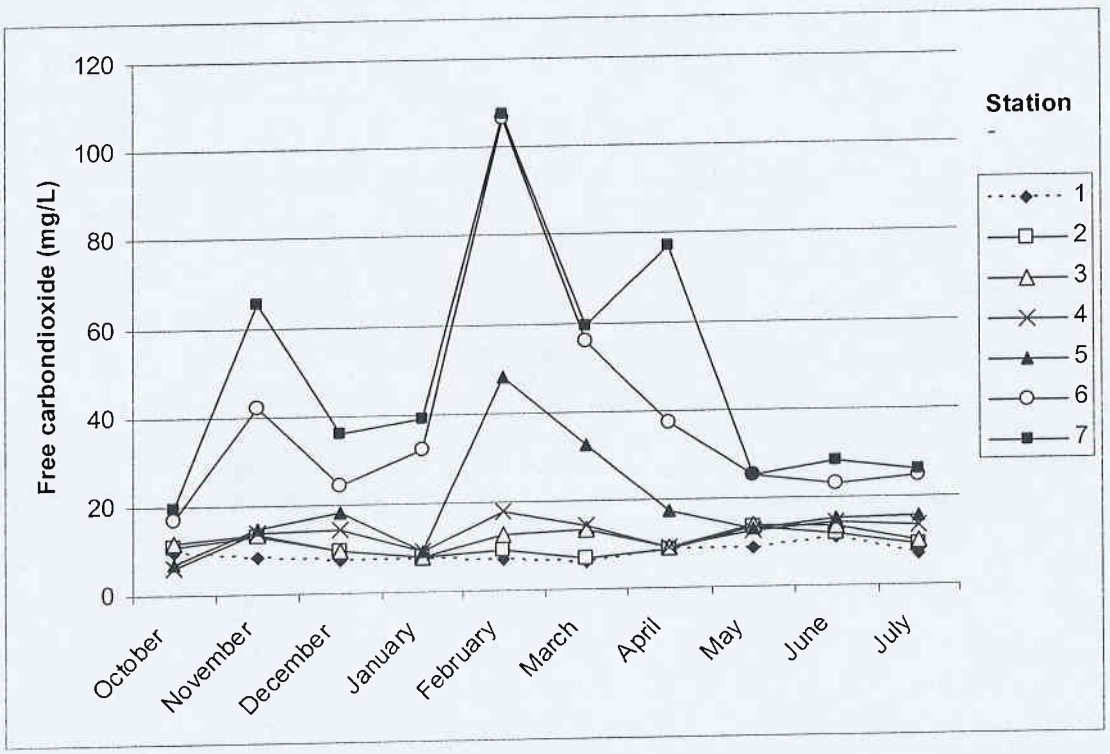


Figure 22: Seasonal variation of free carbondioxide content of Manahara River over the period of ten months (2005/2006)

Similarly, at stations 4 and 5, free CO_2 was increased from October (6.13 mg/L at station 4 and 7.11 mg/L at station 5) to December and then fluctuated till July. In these stations, maximum free CO_2 was observed in February (17.82 mg/L at station 4 and 48.25 mg/L at station 5). At stations 6 and 7, the content of free CO_2 was increased from October (16.87 mg/L at station 6 and 19.48 mg/L at station 7) to November and then fluctuated till July and the maximum free CO_2 was observed in February (106.7 mg/L at station 6 and 107.45 mg/L at station 7) as similar to stations

4 and 5. Thus observed monthly variation of free carbondioxide in the river water is not significant at 0.01 and 0.05 probability level (F = 1.508, d.f.= 69).

On the average, the free CO_2 of the surface water was found as 8.08 ± 0.2618 mg/L; 9.98 ± 0.39 mg/L; 11.47 ± 0.3933 mg/L; 12.45 ± 0.595 mg/L; 19.09 ± 2.2113 mg/L; 38.79 ± 6.019 mg/L and 48.31 ± 4.9988 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. Free CO_2 was increased from stations 1 to 7 in all the months during the investigation period except at stations 4 and 5 in October. Such spatial variation of free carbondioxide in the river water is significant at 0.01 level (F = 10.545, d.f.= 69). During the entire investigation period, the lowest free CO_2 of 6.16 mg/L was recorded at station 1 in March and the highest free CO_2 of 107.45 mg/L was recorded at station 7 in February.

The amplitudes of variations of free CO_2 of 4.57 mg/L; 6.46 mg/L; 6.17 mg/L; 11.69 mg/L; 41.14 mg/L; 89.89 mg/L and 87.97 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 were recorded in the river during the investigation period.

6.1.10 Total alkalinity, bicarbonate alkalinity and bicarbonate content

The alkalinity was found only due to the bicarbonate (HCO_3^-) ions in the surface water of the river because carbonate (CO_3^{--}) alkalinity and hydroxide(OH^-) alkalinity never appeared in the samples collected at all stations during the entire investigation period. Therefore, total alkalinity is equal to bicarbonate alkalinity. The seasonal variation of total alkalinity i.e. bicarbonate alkalinity of the river over the period of ten months of investigation period is shown in figure23. At station 1, total alkalinity fluctuated from October (22.00 mg/L as $CaCO_3$) which then reached maximum in May (32.21 mg/L as $CaCO_3$) and again decreased till July. At stations 2 and 3, total alkalinity increased from October (23.17 mg/L as $CaCO_3$ at station 2 and 24.00 mg/L as $CaCO_3$) at station 3 till December and reached maximum in December (46.07 mg/L as $CaCO_3$ at station 2 and 45.83 mg/L as $CaCO_3$ at station 3). From December, total alkalinity fluctuated till July at stations 2 and 3.

But at stations 4, 5, 6 and 7, total alkalinity gradually increased from October (24.83, 25.83, 60.33 and 114.00 mg/L as $CaCO_3$ at stations 4, 5, 6 and 7 respectively) and reached maximum level in March at stations 4 and 5 (73.33 mg/L as $CaCO_3$ at station

4 and 151.17 mg/L as $CaCO_3$ at station 5) and reached maximum level in February at stations 6 and 7 (352.0 mg/L as $CaCO_3$ at station 6 and 379.0 mg/L as $CaCO_3$ at station 7). After these maxima, total alkalinity fluctuated till July at these stations 4, 5, 6 and 7. Such monthly variation of total alkalinity content in the river water is not significant at 0.01 and 0.05 significant level (F =1.110, d.f.= 69).

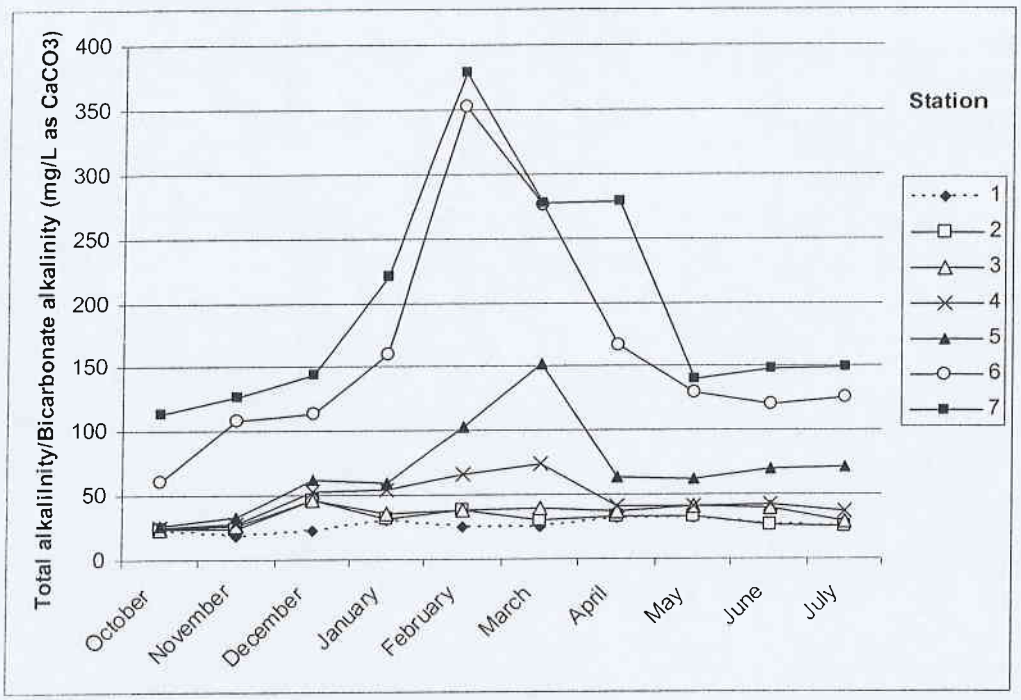


Figure 23: Seasonal variation of total alkalinity/bicarbonate alkalinity of Manahara River over the period of ten months (2005/2006)

On the average, the total alkalinity or bicarbonate alkalinity recorded were 25.87 ± 0.7927; 31.35 ± 1.2573; 35.53 ± 1.2381; 45.89 ± 2.7624; 70.13 ± 6.1246; 161.11 ± 20.667 and 197.62 ± 15.2012 mg/L as $CaCO_3$ respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period. The total alkalinity increased from stations 1 to 7 i.e. upstream to downstream in all the investigated months except stations 2 to 3 in December. The spatial variation of total alkalinity along the river water is significant at 0.01 significance level (F = 19.900, d.f.= 69). Among all the stations during the entire investigation period, the lowest total alkalinity of 18.83 mg/L as $CaCO_3$ was observed at station 1 in November and the highest total alkalinity of 379.00 mg/L as $CaCO_3$ was observed at station 7 with in February.

The amplitudes of variations of total alkalinity were 13.38; 22.9; 21.83; 48.5; 125.34; 291.67 and 265 mg/L as $CaCO_3$ respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period.

The seasonal variation of bicarbonate content of surface water of the river over the ten months (2005/2006) as shown in figure24 has the similar pattern as that of bicarbonate alkalinity (or total alkalinity) because bicarbonate alkalinity is due to the presence of bicarbonate content of water and bicarbonate alkalinity has linear relationship with bicarbonate content. Bicarbonate content of the river water as similar to bicarbonate alkalinity fluctuated from October (26.84 mg/L) which then reached maximum in May (39.3 mg/L) and again decreased till July at station 1. At station 2 and 3, bicarbonate content increased from October (28.26 mg/L at station 2 and 29.28 mg/l at station 3) till December and reached maximum in December (56.2 mg/L at station 2 and 55.92 mg/L at station 3). From December, bicarbonate content of the river water fluctuated till July at both stations 2 and 3.

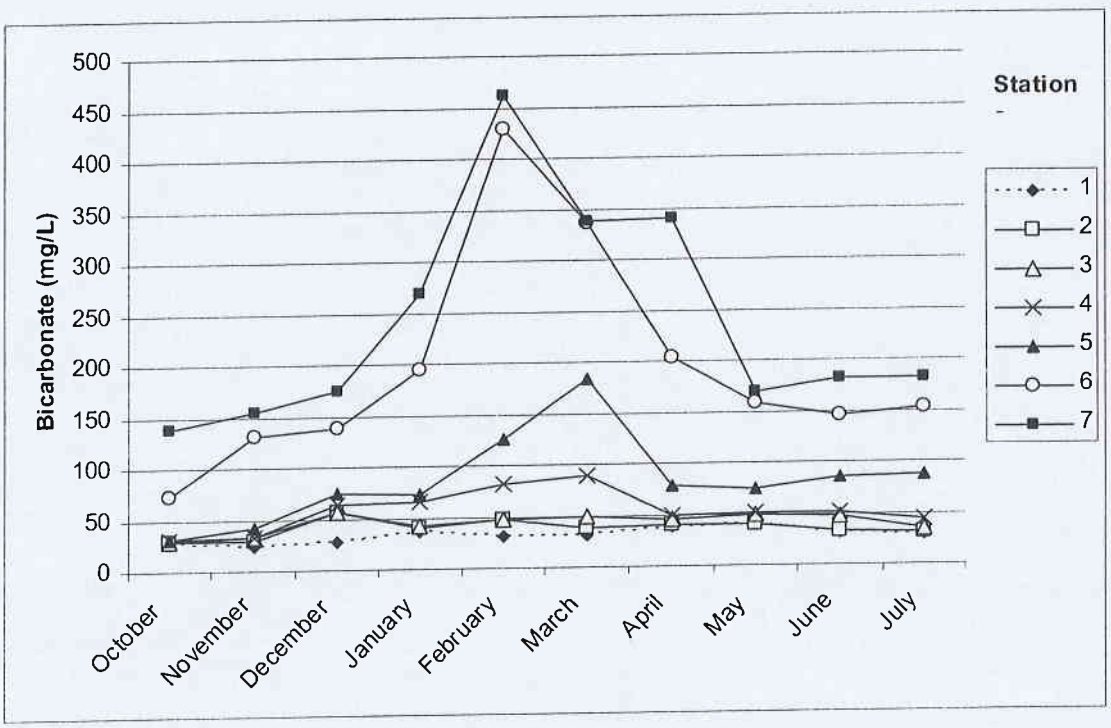


Figure 24: Seasonal variation of bicarbonate content of Manahara river over the period of ten months (2005/2006)

At stations 4, 5, 6 and 7 bicarbonate content gradually increased from October (30.30 mg/L at station 4; 31.52 mg/L at station 5; 73.61 mg/L at station 6 and 139.08 mg/L at station 7) and reached maximum in March at stations 4 and 5 (89.47 mg/L at station 4

and 184.4 mg/L at station 5) and reached maximum in February at stations 6 and 7 (429.44 mg/L at station 6 and 462.38 mg/L at station 7). The bicarbonate content fluctuated after these maxima till July in these stations 4, 5, 6 and 7. Such monthly variation of bicarbonate content in the river water is not significant at 0.01 and 0.05 significance level (F =1.110, d.f.= 69).

The average bicarbonate contents recorded were 31.57 ± 0.9670 mg/L; 38.24 ± 1.5338 mg/L; 43.35 ± 1.5128 mg/L; 55.98 ± 3.3696 mg/L; 85.55 ± 7.4717 mg/L; 196.56 ± 27.242 mg/L and 241.10 ± 18.5454 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The bicarbonate content as similar to bicarbonate alkalinity increased from stations 1 to 7 i.e. upstream to downstream in all the months except stations 2 to 3 in December. The spatial variation of bicarbonate content in the river water is significant at 0.01 significance level (F = 19.900, d.f.= 69). Among all the stations during the entire investigation period, the lowest bicarbonate content of 22.97 mg/L was found at station1 in November and the highest bicarbonate content of 462.38 mg/L was found at station 7 in February.

The amplitudes of variations of carbonate content were 16.33 mg/L; 27.94 mg/L; 26.64 mg/L; 59.17 mg/L; 152.9 mg/L; 355.83mg/L and 323.3 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period.

6.1.11 Hardness and carbonate hardness

The hardness was found only due to carbonates (HCO_3^- ions or CO_3^{--} ions) in the surface water of the river because non-carbonate hardness was never appeared in the samples collected in all stations during the entire investigation period. Therefore, hardness is equal to carbonate hardness. The seasonal variation of hardness i.e.carbonate hardness over the period of ten months (2005/2006) is shown in figure25. At stations 1 and 2, the hardness increased from October (13.67 mg/L as $CaCO_3$ at station 1 and 14.00 mg/L as $CaCO_3$ at station 2) till January, from then it fluctuated. At station 1, the maximum hardness was observed in January (18.13 mg/L as $CaCO_3$) whereas at station 2, the maximum hardness was observed in May (23.53 mg/L as $CaCO_3$).

At stations 3 and 4, hardness increased from October (18.00 mg/L as $CaCO_3$ at station 3 and 19.67 mg/L as $CaCO_3$ at station 4) to December, from then it fluctuated and reached maximum level in February at station 3 (35.87 mg/L as $CaCO_3$) and in July at station 4 (33.79 mg/L as $CaCO_3$).

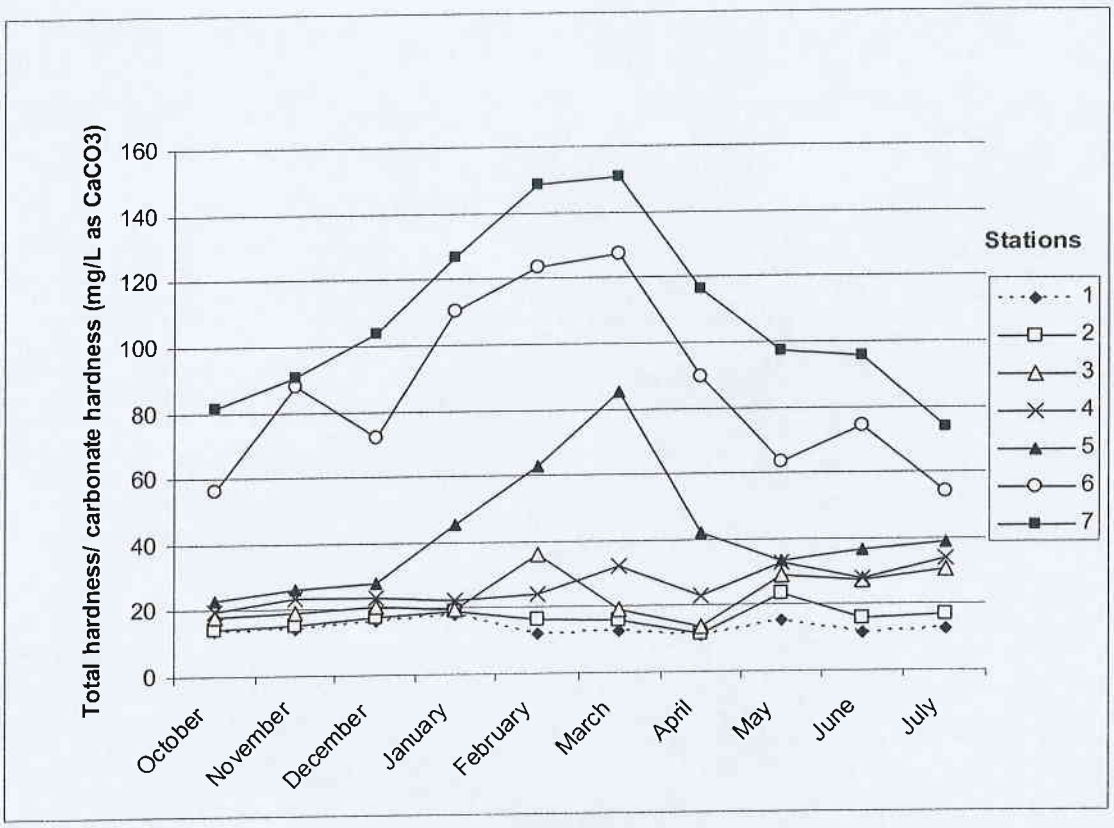


Figure 25: Seasonal variation of total hardness/carbonate hardness of Manahara river over the period of ten months (2005/2006)

At stations 5 and 7, hardness increased gradually from October (22.75 mg/L as $CaCO_3$ at station 5 and 81.2 mg/L as $CaCO_3$ at station 7) and reached maximum level of 85.13 mg/L as $CaCO_3$ at station 5 and 150.55 mg/L as $CaCO_3$ at station 7 in March. From then, hardness fluctuated. But at station 6, the hardness fluctuated during the entire investigation period and reached maximum level of 127.33 mg/L as $CaCO_3$ in March. Thus observed monthly variation of hardness in the river water is not significant at 0.01 and 0.05 probability level ($F = 0.459$, d.f.= 69).

On the average, the hardness recorded were 13.66 ± 0.4262; 16.62 ± 0.5868; 23.29 ± 1.2092; 26.34 ± 0.8795; 42.15 ± 3.3136; 85.80 ± 8.6816 and 108.37 ± 4.6127 mg/L as $CaCO_3$ respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the

investigation period. The hardness increased from stations 1 to 7 i.e. upstream to downstream in all the months during the investigation period except from stations 3 to 4 in February. During the entire investigation period, the lowest hardness of 10.73 mg/L as $CaCO_3$ was recorded at station 1 in April whereas the highest hardness of 150.55 mg/L as $CaCO_3$ was recorded at station 7 in March. Thus observed spatial variation of hardness from stations 1 to 7 in the river is significant at 0.01 probability level ($F = 51.704$, d.f.= 69).

The amplitudes of variations of hardness were 7.4; 12.00; 17.87; 14.12; 62.38; 73.08 and 76.71 mg/L as $CaCO_3$ respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the present investigation period.

6.1.12 Calcium and calcium hardness

Figures 26 and 27 show the seasonal variation of calcium and calcium hardness respectively of surface water of the river over the period of ten months (2005/2006) during the investigation period. The pattern of variation of calcium is similar to that of calcium hardness because calcium hardness is due to the presence of calcium and they have linear relationship. Calcium and calcium hardness fluctuated from October (3.13 mg/L of calcium content and 7.8 mg/L as $CaCO_3$ of calcium hardness at station 1 and 5.23 mg/L of calcium content and 13.04 mg/L as $CaCO_3$ of calcium hardness at station 4) till July at stations 1 and 4 where the maximum values were observed in January at station 1 (5.61 mg/L of calcium content and 14.01 mg/L as $CaCO_3$ of calcium hardness) and in March at station 4 (10.21 mg/L of calcium content and 25.48 mg/L as $CaCO_3$ of calcium hardness). The calcium and calcium hardness increased from October (3.26 mg/L of calcium content and 8.13 mg/L as $CaCO_3$ of calcium hardness at station 2 and 4.57 mg/L of calcium content and 11.39 mg/L as $CaCO_3$ of calcium hardness at station 3) till January at station 2 and till February at station 3, and then fluctuated at both stations. The maximum calcium and calcium hardness were found in May (6.58 mg/L of calcium content and 16.42 mg/L as $CaCO_3$ of calcium hardness at station 2 and 8.65 mg/L of calcium content and 21.58 mg/L as $CaCO_3$ of calcium hardness at station 3).

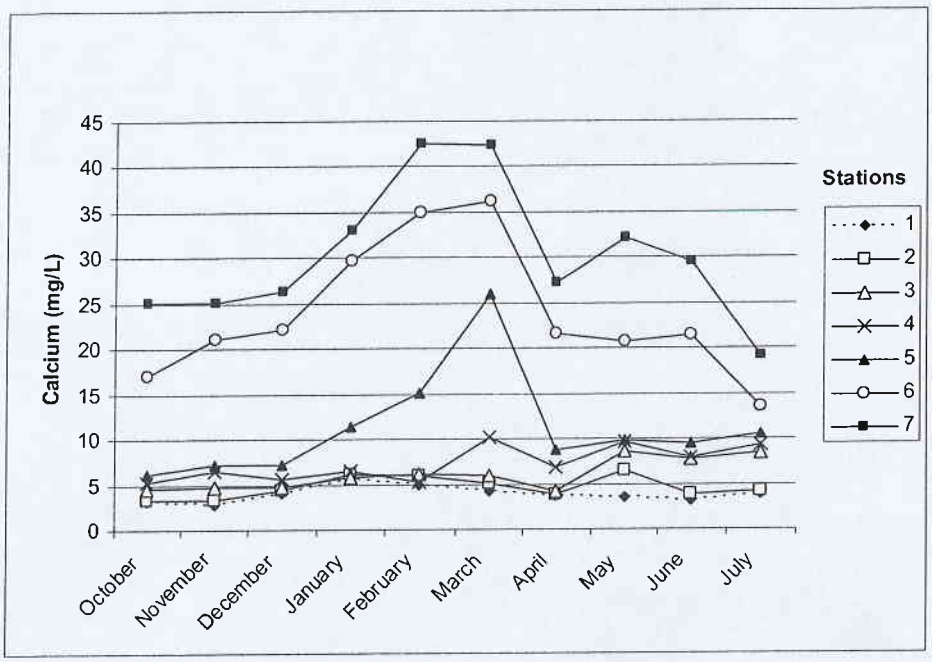


Figure 26: Seasonal variation of calcium content of the water of Manahara river over the period of ten months (2005/2006)

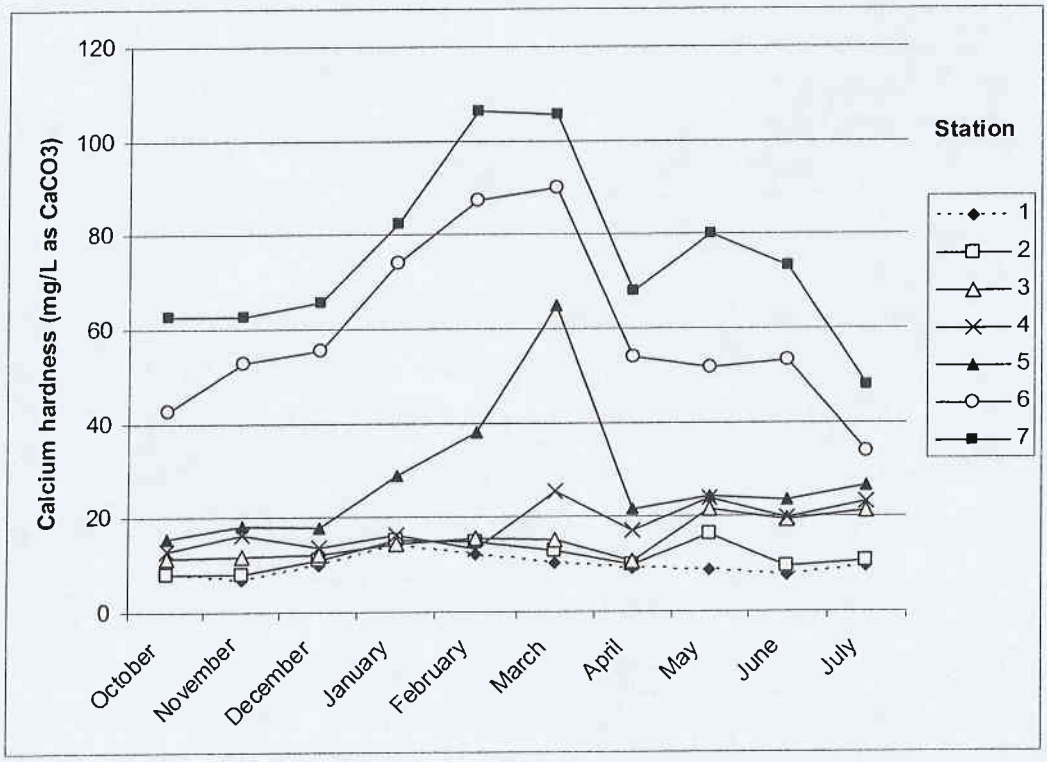


Figure 27: Seasonal variation of calcium hardness of the water of Manahara river over the period of ten months (2005/2006)

At stations 5, 6 and 7, the calcium and calcium hardness increased from October (6.19 mg/L of calcium content and 15.44 mg/L as $CaCO_3$ of calcium hardness at station 5; 17.11 mg/L of calcium content and 42.69 mg/L as $CaCO_3$ of calcium hardness at station 6 and 25.17 mg/L of calcium content and 62.81 mg/L as $CaCO_3$ of calcium hardness at station 7) and reached maximum level in March at station 5 (25.96 mg/L of calcium content and 64.77 mg/L as $CaCO_3$ of calcium hardness) and also at station 6 (36.14 mg/L of calcium content and 90.18 mg/L as $CaCO_3$ of calcium hardness) and in February at station 7 (42.61 mg/L of calcium content and 105.65 mg/L as $CaCO_3$ of calcium hardness) with slight decrease from November to December and October to November at stations 5 and 7 respectively. These chemical parameters fluctuated till July in these stations 5, 6 and 7. Thus observed monthly variation of calcium hardness and calcium content in the river water is not significant at 0.01 and 0.05 significant level. ($F = 0.0.542$ for calcium content and $F = 0.453$ for calcium hardness, d.f.= 69 for both).

The average calcium contents were recorded as 3.86 ± 0.1598 mg/L, 4.66 ± 0.2155 mg/L, 6.13 ± 0.2982 mg/L, 7.30 ± 0.3326 mg/L, 11.18 ± 1.005 mg/L, 23.85 ± 2.5281 mg/L and 30.26 ± 1.3275 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. Similarly, the average calcium hardness were found as 9.63 ± 0.3990, 11.63 ± 0.5386, 15.29 ± 0.7435, 18.21 ± 0.8301, 27.89 ± 2.5075, 59.50 ± 6.3265 and 75.50 ± 3.4711 mg/L as $CaCO_3$ at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The calcium and calcium hardness increased from stations 1 to 7 i.e. upstream to downstream at all the months of investigation period. Such spatial variation of calcium content and calcium hardness in the river water is significant at 0.01 significant level ($F = 49.452$ for calcium content and $F = 49.439$ for calcium hardness, d.f.= 69 for both). During the entire investigation period, the lowest calcium content of 2.73 0.16 mg/L and calcium hardness of 6.82 mg/L as $CaCO_3$ were recorded at station 1 in November and the highest calcium content of 42.61 mg/L and calcium hardness of 106.32 mg/L as $CaCO_3$ were recorded at station 7 in February.

The amplitudes of variations of calcium contents were 2.88 mg/L; 3.32 mg/L; 4.45 mg/L; 4.98mg/L; 19.77 mg/L; 22.59 mg/L and 23.43 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. Similarly, the

amplitude of variation of calcium hardness were 7.19; 8.29; 11.11; 12.44; 49.33; 56.38 and 58.47 mg/L as $CaCO_3$ respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period.

6.1.13 Magnesium

The seasonal variation of magnesium content of surface water of the river over the period of ten months (2005/2006) is presented in the figure 28. The magnesium content fluctuated highly and differently in various stations from October till July. The maximum level of magnesium content was observed in February at stations 2 (2.56 mg/L), station 3 (4.96 mg/L), station 4 (2.61 mg/L) and station 6 (11.79 mg/L) whereas it was observed maximum in November at station 1 (1.77 mg/L) and in April at station 7 (11.74 mg/L). The monthly variation of magnesium content of the river water is not significant at 0.05 and 0.01 probability level (F = 0.664, d.f.= 69).

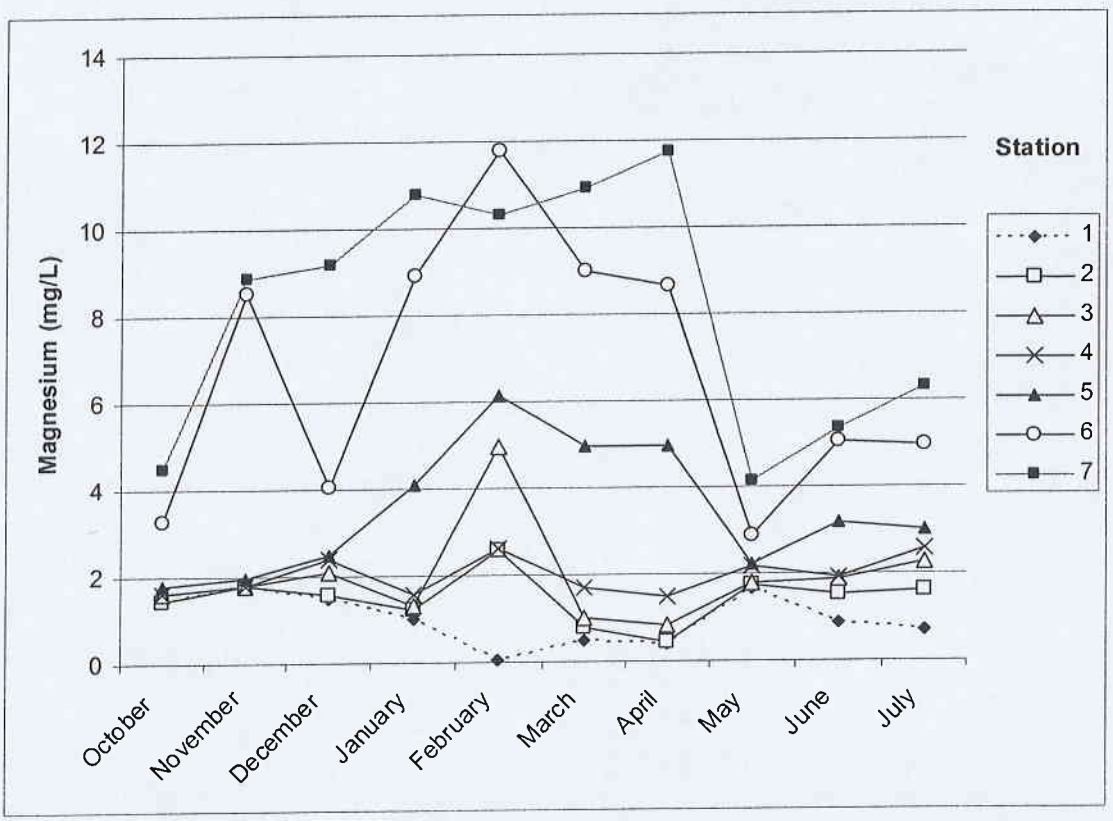


Figure 28: Seasonal variation of magnesium content of the water of Manahara River over the period of ten months (2005/2006)

On the average, the magnesium content was found as 0.99 ± 0.1058 mg/L, 1.46 ± 0.1426 mg/L, 1.95 ± 0.2061 mg/L, 1.98 ± 0.0971 mg/L, 3.47 ± 0.2798 mg/L, 6.71 ± 2.3116 mg/L and 8.21 ± 0.5151 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in

the river during the investigation period. The magnesium content increased from station 1 to 7 during all the months of the investigation period except stations 1 to 2 and stations 3 to 4 in October and stations 2 to 3 in November that showed equal concentration and stations 3 to 4 and 6 to 7 in February that showed decrement in magnesium content. Such spatial variation of magnesium content in the river water is significant at 0.01 probability level (F =25.425, d.f.= 69). The lowest magnesium content of 0.05 mg/L was recorded at station 1 in February and the highest magnesium content of 11.74 mg/L was recorded at station 7 in April.

The amplitudes of variations of magnesium content were 1.72 mg/L; 2.14 mg/L; 4.13 mg/L; 1.0 mg/L; 4.34 mg/L; 8.93 mg/L and 7.63 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period.

6.1.14 Chloride

The figure 29 shows the seasonal variation of chloride content of surface water of the river over the period of ten months (2005/2006) during the investigation period. At station 1, chloride concentration increased from 7.34 mg/L in October to November and then it fluctuated till July and reached maximum level in May (9.28 mg/l). At stations 2, 3 and 4, chloride content increased from October (8.72 mg/L at station 2, 9.28 mg/L at station 3 and 9.42 mg/L at station 4) to December which then fluctuated. The maximum chloride content was observed in July at station 2 (10.08 mg/L) and also at station 4 (14.09 mg/L) and in May at station 3 (10.89 mg/L).

At stations 5, 6 and 7, chloride content increased gradually from October (9.92 mg/L at station 5; 12.88 mg/L at station 6 and 17.19 mg/L at station 7) till March where it reached maximum with concentrations of 38.72 mg/L at station 5; 68.73 mg/L at station 6 and 78.48 mg/L at station 7. From then, it decreased till June at stations 5 and 7 and till May at station 6 and slightly increased after that till July. The monthly variation of chloride content of the river water is not significant at 0.05 and 0.01 probability level (F = 0.944, d.f.= 69).

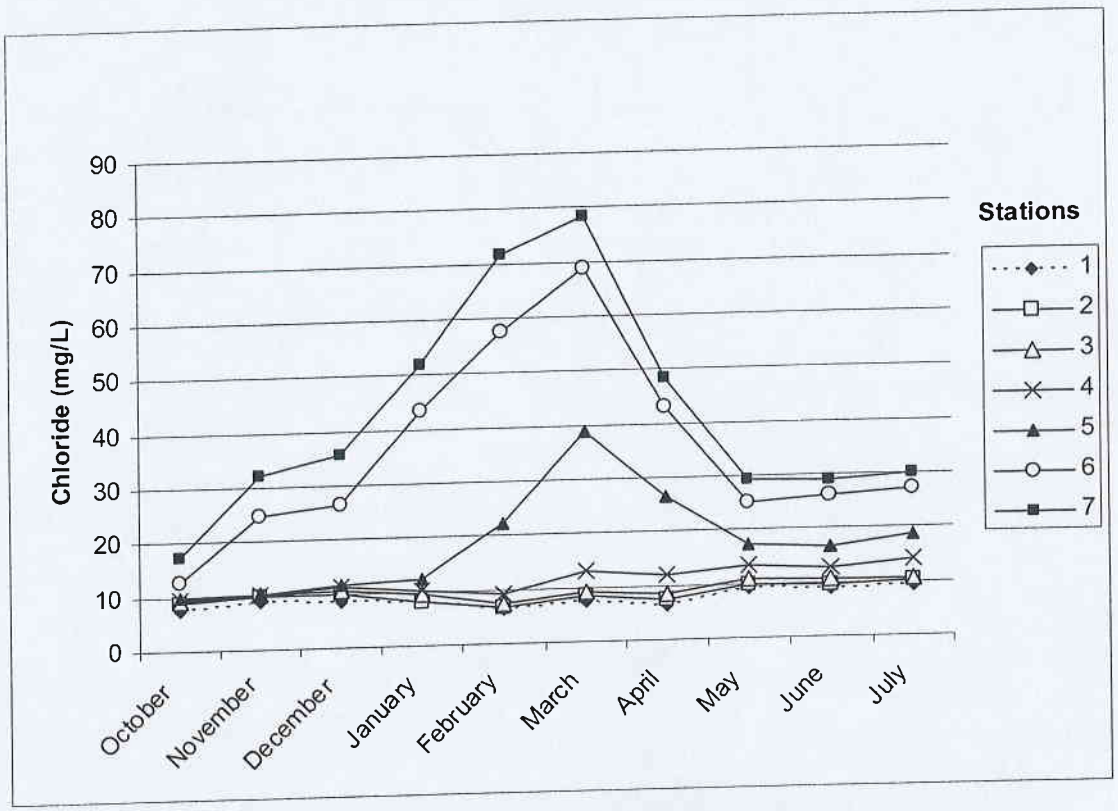


Figure 29: Seasonal variation of chloride content of the water of Manahara river over the period of ten months (2005/20060)

The average chloride concentrations recorded were 7.96 ± 0.1992 mg/L, 8.86 ± 0.2184 mg/L, 9.68 ± 0.2366 mg/L, 11.54 ± 0.3104 mg/L, 18.41 ± 1.545 mg/L, 35.55 ± 3.832 mg/L and 42.36 ± 3.4614 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The chloride content increased from stations 1 to7 i.e upstream to downstream in all the months of investigation period. Such spatial variation of chloride content is significant at 0.01 probability level (F = 17.683, d.f.= 69). Among all the stations during the entire investigation period, the lowest chloride concentration of 6.2 mg/L was recorded at station 1 in April and the highest chloride concentration of 78.48 mg/L was recorded at station 7 in March.

The amplitudes of variations of chloride content were 3.08 mg/L; 3.36 mg/L; 3.65 mg/L; 5.08 mg/L; 28.8 mg/L; 55.85 mg/L and 61.29 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period.

6.1.15 Nitrate-nitrogen

The seasonal variation of nitrate-nitrogen concentration of surface water of the river over the period of ten months (2005/2006) is shown in figure 30. At stations 1, 3, 4

and 5, the nitrate-nitrogen concentration increased from October (0.08 mg/L at station 1, 0.33 mg/L at station 3, 0.39 mg/L at station 4 and 0.52 mg/L at station 5) and reached maximum in March with values 0.19 mg/L at station 1; 0.7 mg/L at station 3; 0.75 mg/L at station 4 and 0.88 mg/L at station 5. From then the nitrate-nitrogen concentration fluctuated in these stations.

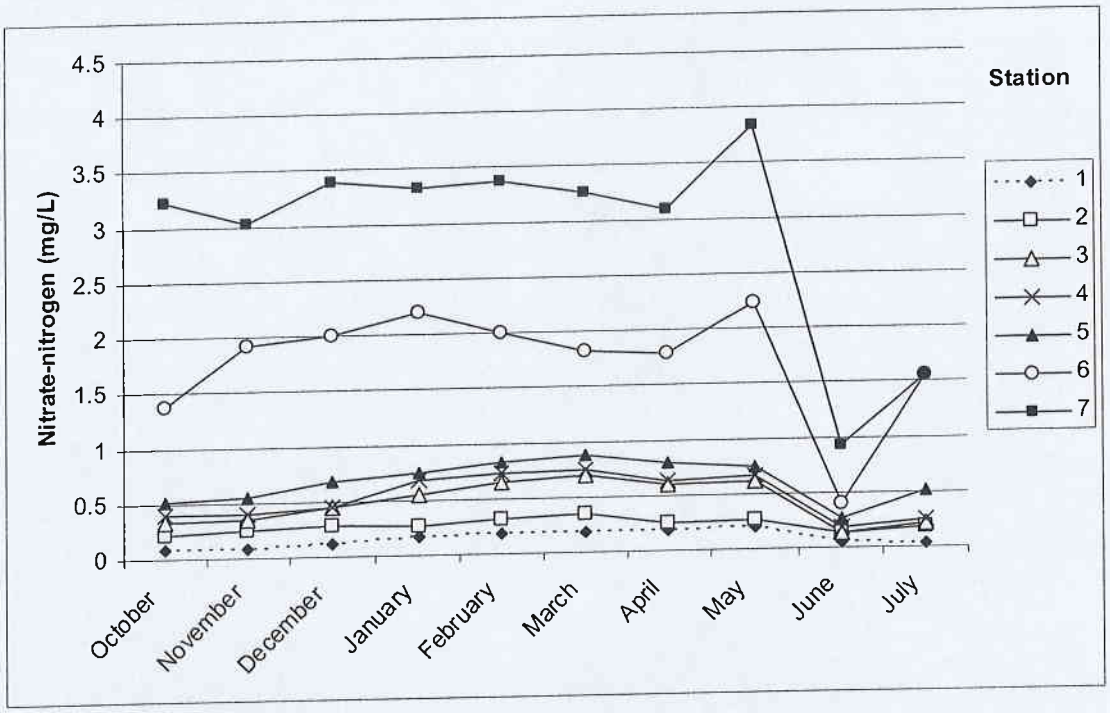


Figure 30: Seasonal variation of nitrate-nitrogen of the water of Manahara river over the period of ten months (2005/2006)

At station 2, nitrate-nitrogen concentration increased from October with value 0.21 mg/L till December from when it fluctuated till July by reaching maximum concentration in March (0.35 mg/L). At station 6, the nitrate-nitrogen concentration increased gradually from 0.75 mg/L in October and reached maximum in January (2.2 mg/L) and from then it fluctuated till July. But at station 7, the nitrate-nitrogen concentration decreased from October (3.23 mg/L) to November and then fluctuated till July and reached maximum in May (3.83 mg/L). The monthly variation of nitrate-nitrogen content of the river water is not significant at 0.05 and 0.01 probability level ($F = 0.519$, d.f.= 69).

The average nitrate-nitrogen concentrations recorded were 0.13 ± 0.0110 mg/L, 0.25 ± 0.0127 mg/L, 0.46 ± 0.0341 mg/L, 0.51 ± 0.0357 mg/L, 0.65 ± 0.0337 mg/L, 1.73 ± 0.126 mg/L and 2.90 ± 0.1589 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 in

the river during the investigation period. The nitrate-nitrogen concentration increased gradually from stations 1 to 7 in all the months of investigation period except stations 3 to 4 in December and stations 2 to 3 in June being equal. During the entire investigation period, the lowest nitrate-nitrogen of 0.04 mg/L was recorded at station 1 in July and the highest nitrate-nitrogen of 3.83 mg/L was recorded in station 7 in May. Such spatial variation of nitrate-nitrogen content in the river water from stations 1 to 7 is significant at 0.01 probability level ($F = 57.108$, d.f.= 69).

The amplitudes of variations of nitrate-nitrogen concentrations recorded were 0.16 mg/L; 0.22 mg/L; 0.57 mg/L; 0.56 mg/L; 0.62 mg/L; 1.84 mg/L and 2.9 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the present investigation period.

6.1.16 Ammoniacal nitrogen

The seasonal variation of ammoniacal nitrogen over the period of ten months (2005/2006) is presented in figure 31. At stations 1, 2 and 3, the ammoniacal-nitrogen increased gradually from October (0.05 mg/L at station 1; 0.12 mg/L at station 2 and 0.16 mg/L at station 3) and reached maximum in March i.e. pre-monsoon (0.08 mg/L at station 1; 0.22 mg/L at station 2 and 0.28 mg/L at station 3) and then it fluctuated till July. At stations 4 and 6, ammoniacal nitrogen decreased from October (0.31 mg/L at station 4 and 0.83 mg/L at station 6) to November and then increased and reached maximum level in March i.e. pre-monsoon in station 4 (0.66 mg/L) and in February at station 6 (4.42 mg/L). Then after, it fluctuated till July in both of these stations.

At station 5, ammoniacal nitrogen increased gradually from October (0.42 mg/L) and reached maximum in April i.e. pre-monsoon (1.32 mg/L) and then it decreased gradually. At station 7, ammoniacal nitrogen increased from October (1.31 mg/L) to November and then decreased to December. From December it increased gradually and reached maximum in March i.e. pre-monsoon (8.84 mg/L) and then it decreased till July. Such monthly variation of ammoniacal nitrogen content of the river water is not significant at 0.05 and 0.01 probability level ($F = 0.320$, d.f.= 69).

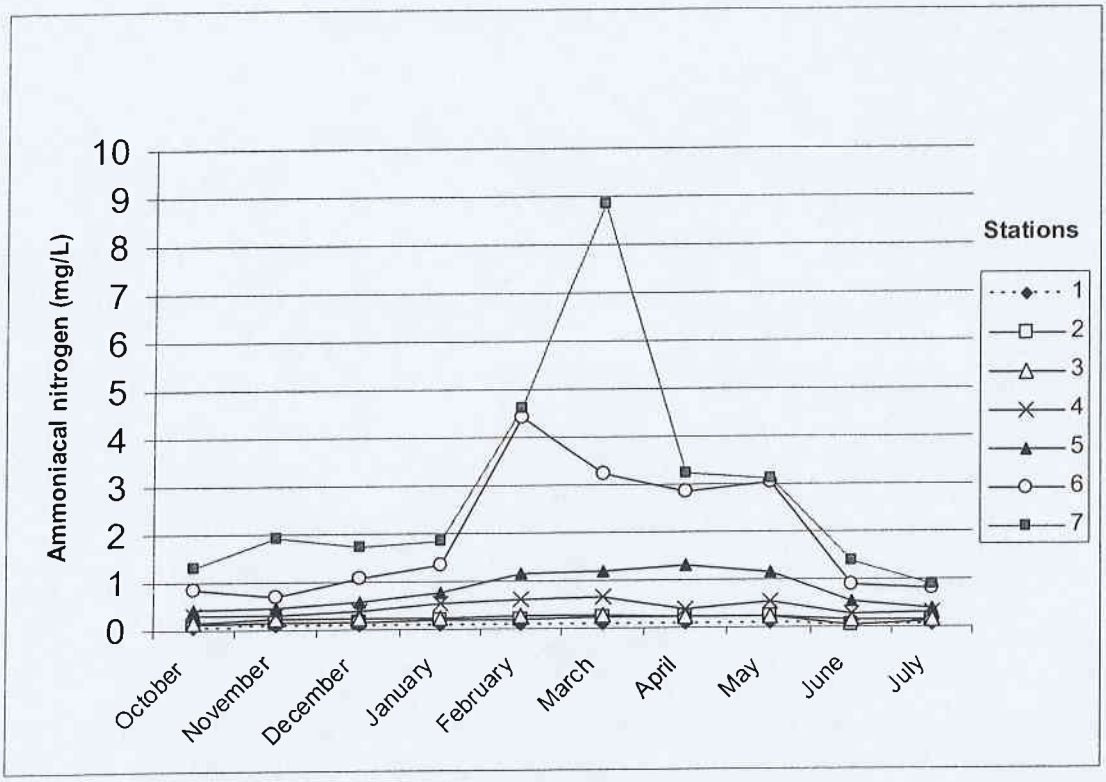


Figure 31: Seasonal variation of ammoniacal-nitrogen content of the water of Manahara river over the period of ten months (2005/2006)

On the average, the concentration of ammoniacal nitrogen recorded were 0.06 ± 0.0042 mg/L; 0.16 ± 0.0115 mg/L; 0.22 ± 0.0099 mg/L; 0.43 ± 0.026 mg/L; 0.80 ± 0.067 mg/L; 1.92 ± 0.2654 mg/L and 2.88 ± 0.4180 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The concentration of ammoniacal nitrogen increased from stations 1 to 7 i.e. upstream to downstream in all the months of investigation period. The amount of increment of NH_3-N is more in downstream region. Such spatial variation of the ammoniacal nitrogen from stations 1 to 7 is significant at 0.01 probability level ($F = 10.610$, d.f.= 69). Among all the stations in all the months of investigation period, the lowest ammoniacal nitrogen of 0.02 mg/L was recorded at station 1 in June (monsoon) and the highest ammoniacal nitrogen of 8.84 mg/L was recorded at station 7 in March (pre-monsoon).

The amplitudes of variations of ammoniacal nitrogen concentrations were 0.06 mg/L; 0.19 mg/L; 0.13 mg/L; 0.38 mg/L; 0.94 mg/L; 3.74 mg/L and 7.53 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period.

6.1.17 Ortho-phosphate

The seasonal variation of ortho-phosphate concentration over the period of ten months (2005/2006) is presented in figure 32. At stations 1, 6 and 7, ortho-phosphate concentration fluctuated from October (0.1 mg/L at station 1; 1.47 mg/L at station 6 and 1.81 mg/L at station 7) and reached maximum level in January at station 1 (0.1 mg/L) and in February at station 6 (4.42 mg/L) and also at station 7 (5.28 mg/L). From then, the ortho-phosphate concentration decreased gradually till July at stations 1 and 7 and till June at station 6.

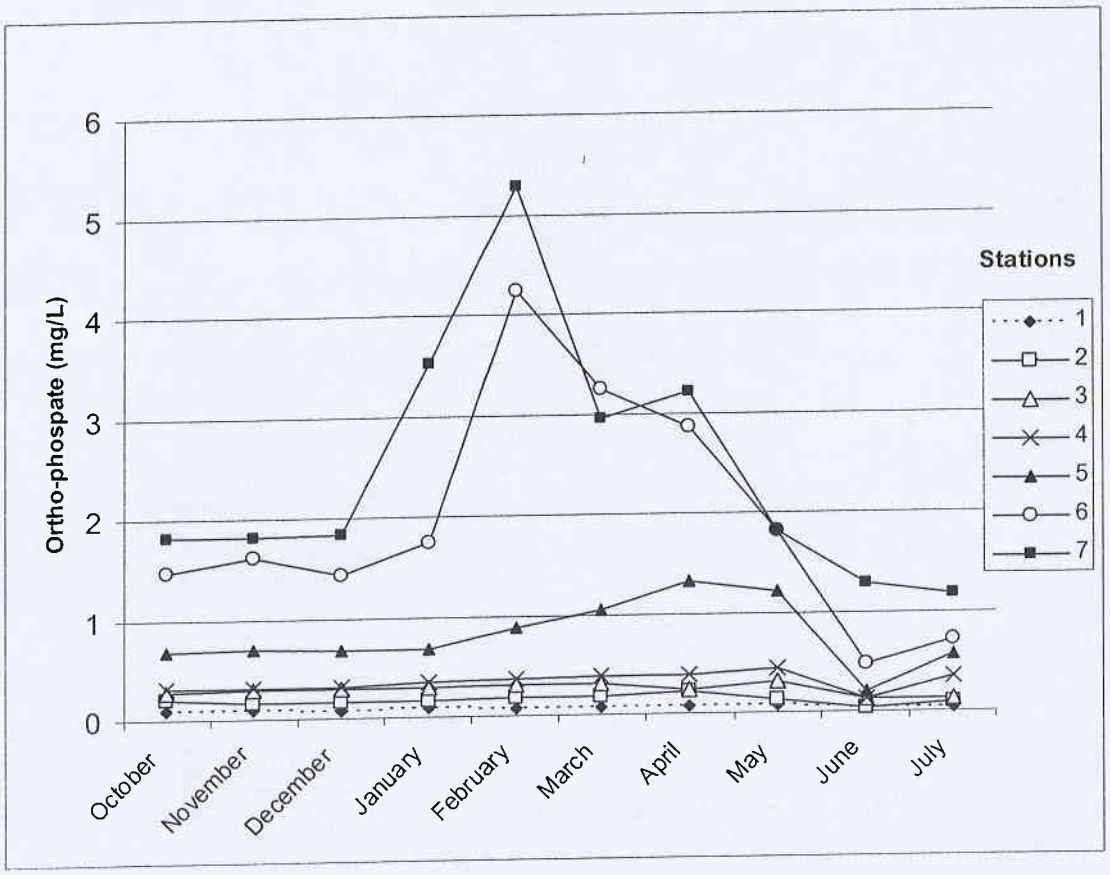


Figure 32: Seasonal variation of ortho-phosphate content of the water of Manahara river over the period of ten months (2005/2006)

At stations 2 and 4, the ortho-phosphate content decreased from October (0.2 mg/L at station 2 and 0.32 mg/L at station 4) to November and then increased and reached maximum level in April at station 2 (0.22 mg/L) and in May at station 4 (0.44 mg/L). After that the ortho-phosphate concentration fluctuated till July. But at station 5, the ortho-phosphate content fluctuated from 0.42 mg/L in October till December and then increased and reached maximum level of 1.32 mg/L in April. Then again it fluctuated till July. At station 3, the ortho-phosphate concentration fluctuated highly and had two

maxima, each being 0.32 mg/L in February and also in May. Such seasonal variation of ortho-phosphate content of the river water is not significant at 0.05 and 0.01 probability level (F = 0.575, d.f.= 69).

The average concentration of ortho-phosphate recorded were 0.08 ± 0.0046 mg/L, 0.15 ± 0.0101 mg/L, 0.26 ± 0.0226 mg/L, 0.34 ± 0.0165 mg/L, 0.80 ± 0.0671 mg/L, 1.96 ± 0.2648 mg/L and 2.47 ± 0.2246 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period. The ortho-phosphate content increased from stations 1 to 7 i.e. upstream to downstream in all the months of investigation period except stations 6 to 7 in March and stations 1 to 2 (being equal concentration) in June. Such spatial variation of ortho-phosphate content of the river water is significant at 0.01 probability level (F = 20.991, d.f.= 69). Among all the stations during the investigation period, the lowest ortho-phosphate concentration of 0.04 mg/L was recorded at station 1 in June as well as in July whereas the highest ortho-phosphate concentration of 5.28 mg/L was recorded at station 7 in February.

The amplitudes of variations of ortho-phosphate concentration were 0.06 mg/L; 0.18 mg/L; 0.20 mg/L; 0.31 mg/L; 1.12 mg/L; 3.67 mg/L and 4.10 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period.

6.1.18 Electrical conductivity

The seasonal variation of electrical conductivity of surface water of the river over the period of ten months (2005/2006) is presented in figure 33. The electrical conductivity increased from October (33.33 µS/cm at station 1, 42.1 µS/cm at station 2, 57.4 µS/cm at station 3, 122.03 µS/cm at station 6 and 276.40 µS/cm at station 7) till February at these stations 1, 2, 3, 6 and 7. Then after, it fluctuated till July at stations 1, 2 and 3 but it decreased gradually from February till July at stations 6 and 7. The maximum level of electrical conductivity were found in May at station 2 (97.33 µS/cm) and also at station 3 (114.33 µS/cm) and that was maximum in February at stations 1 (60.33 µS/cm), station 6 (925.00 mg/L) and also at station 7 (857.73 mg/L). But, at stations 4 and 5 the electrical conductivity increased from October (62.43 µS/cm at station 4 and 71.93 µS/cm at station 5) till March. In March, the electrical conductivity reached maximum at station 5 (405.33 µS/cm) and then fluctuated till July. But at station 4, the electrical conductivity fluctuated from March

till July reaching maximum in May (122.33 µS/cm). Such monthly variation of conductivity of the river water is not significant at 0.05 and 0.01 probability level (F = 1.119, d.f.= 69).

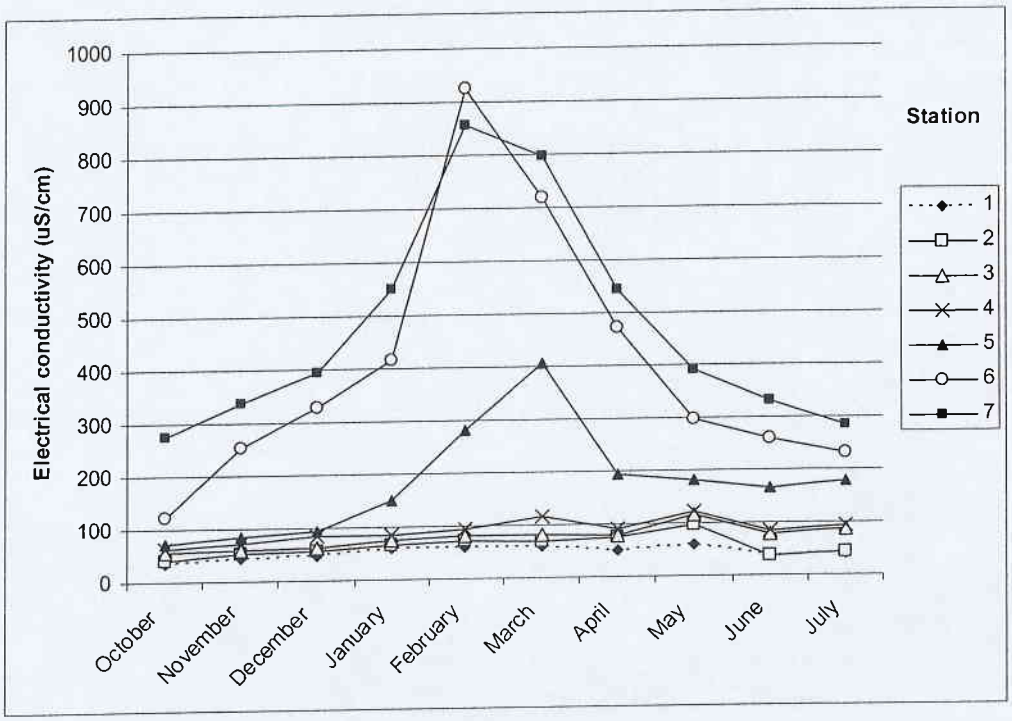


Figure 33: Seasonal variation of electrical conductivity of the water of Manahara river over the period of ten months (2005/2006)

On the average, the electrical conductivity of surface water of the river recorded were 48.57 ± 1.7861 µS/cm, 60.84 ± 3.2712 µS/cm, 77.60 ± 2.8388 µS/cm, 90.58 ± 3.1638 µS/cm, 179.99 ± 17.438 µS/cm, 402.41 ± 76.577 µS/cm and 475.98 ± 36.0587 µS/cm respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period. The electrical conductivity of surface water of the river increased gradually from stations 1 to 7 along the river. Such spatial variation of conductivity of the river water is significant at 0.01 probability level (F = 18.864, d.f.= 69). Among all the stations during the entire investigation period, lowest electrical conductivity of 33.33µS/cm was recorded at station 1 in October and the highest electrical conductivity of 857.73µS/cm was recorded at station 7 in February.

The amplitudes of variations of electrical conductivity were 27.00 µS/cm, 59.33 µS/cm, 56.99 µS/cm, 59.90 µS/cm, 333.40 µS/cm, 802.97 µS/cm and 581.33 µS/cm respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the investigation period.

6.1.19 Total Dissolved Solids (TDS)

The seasonal variation of TDS of surface water of the river over the period of ten months (2005/2006) is presented in figure 34. At stations 1, 2, 3, 6 and 7, the TDS increased from October (22.09 mg/L at station 1, 33.56 mg/L at station 2, 38.00 mg/L at station 3, 80.51 mg/L at station 6 and 182.35 mg/L at station 7) till February. Then after, it fluctuated till July at Stations 1, 2 and 3 but it increased gradually from February till July at stations 6 and 7. The maximum TDS was found in May at station 2 (64.16 mg/L) and also at sation 3 (75.73 mg/L) and in February at station 1 (39.99 mg/L), station 6 (613.04 mg/L) and also at station 7 (567.04 mg/L). But at stations 4 and 5, the TDS increased from October (41.29 mg/L at station 4 and 47.64 mg/L at station 5) till March. In March, the TDS reached maximum level at station 5 (267.52 mg/L) and then fluctuated till July. At station 4, the TDS fluctuated from March till July and reached maximum level in May (80.64 mg/L). Such monthly variation of total dissolved solids of the river water is not significant at 0.05 and 0.01 probability level ($F = 1.102$, d.f.= 69).

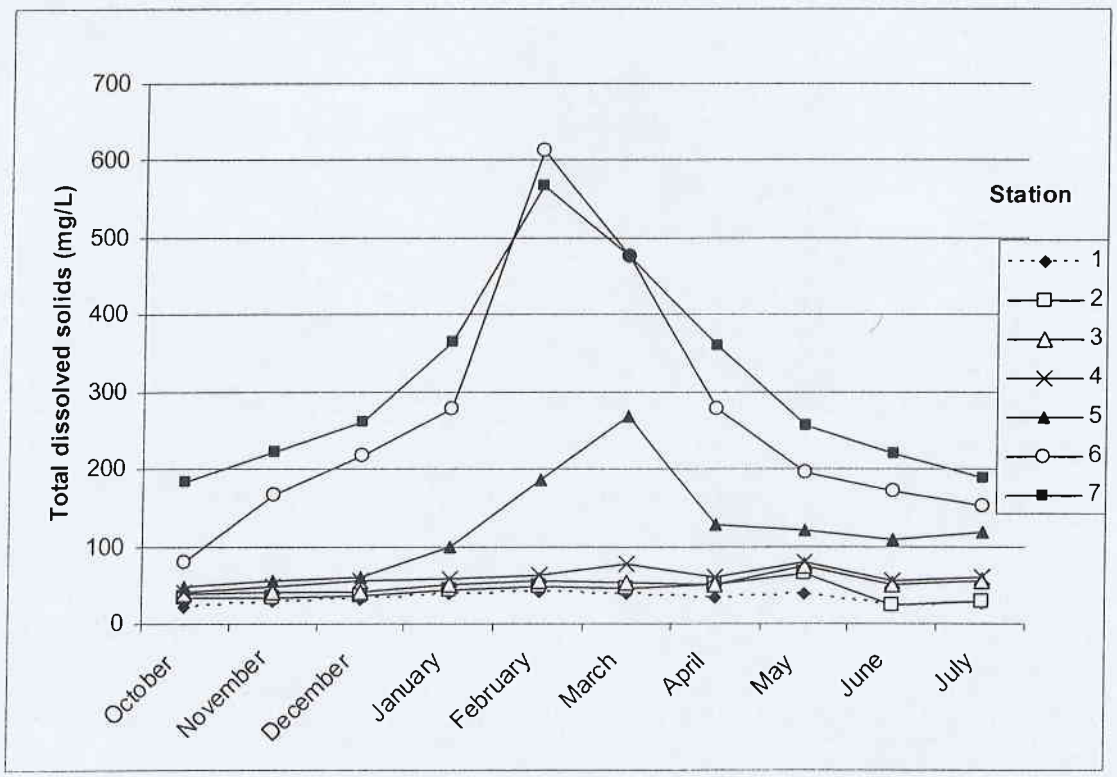


Figure 34: Seasonal variation of total dissolved solids of the water of Manahara river over the period of ten months (2005/2006)

The average TDS of surface water along the river were recorded as 32.14 ± 1.1837 mg/L, 40.83 ± 2.1205 mg/L, 51.35 ± 1.8622 mg/L, 59.90 ± 2.0796 mg/L, 118.92 ± 11.516 mg/L, 262.68 ± 33.868 mg/L and 309.37 ± 22.6818 mg/L at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The TDS of surface water of the river increased gradually from stations 1 to 7 along the river. Such spatial variation of total dissolved solids of the river water is significant at 0.01 probability level (F = 19.026, d.f.= 69). Among all the stations during the entire investigation period, the lowest TDS of 22.09 mg/L was recorded at station 1 in October and the highest TDS of 567.04 mg/L was recorded at station 7 in February.

The amplitudes of variations of TDS were 27.00 mg/L, 59.33 mg/L, 56.99 mg/L, 59.90 mg/L, 333.40 mg/L, 802.97 mg/L and 581.33 mg/L respectively at stations 1, 2, 3, 4, 5, 6 and 7 in the river during the present investigation period.

6.1.20 Spatial variation of water quality in December

For the analysis of spatial variation of water quality of the same time, the water sampling was done at the same time on the same day i.e at 9:00 am on 22nd December, 2005 at all the stations1 to 7.

The spatial variation of water temperature, dissolved oxygen, BOD_5, and Oxygen saturation % in December are shown in figure 35. The temperature of surface water was 9°C at stations 1 to 3 and 10.5 ° C at stations 4 to 7. The surface water temperature increased from headwater (station 1) to downstream (station 7) in general.

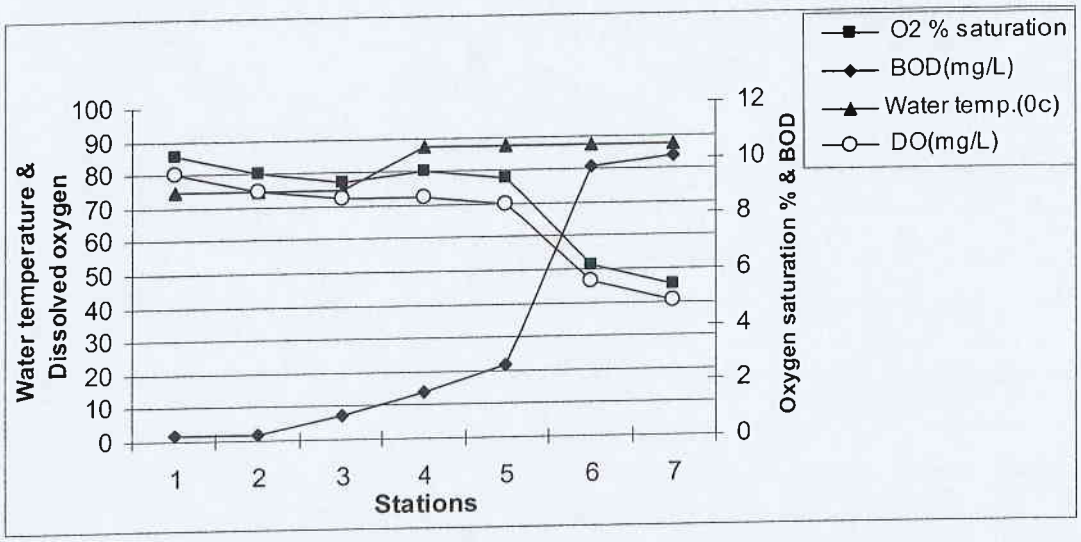


Figure 35: Spatial variation of Dissolved oxygen (DO), BOD, oxygen saturation % and Water temperature along the Manahara river in December (2005)

Dissolved oxygen decreased gradually from 9.59 ± 0.14 mg/L at station 1 to 4.86 ± 0.24 mg/L at station 7 except slight increase from 8.65 ± 0.27 mg/L at station 3 to 8.67 ± 0.17 mg/L at station 4. Similarly, oxygen saturation % decreased gradually from 85.73 ± 1.22 % at station 1 to 45.03 ± 2.16 % at station 7. However, BOD_5 increased gradually from 1.53 ± 0.24 mg/L at station 1 to 83.86 ± 5.97 mg/L at station 7.

The figure 36 shows the spatial variation of depth, velocity and discharge of Manahara river from stations 1 to 7 in December. More or less these parameters fluctuated from stations 1 to 7. The velocity and discharge were lower at upstream region (stations 1 to 4) and higher in downstream (stations 5 to 7).

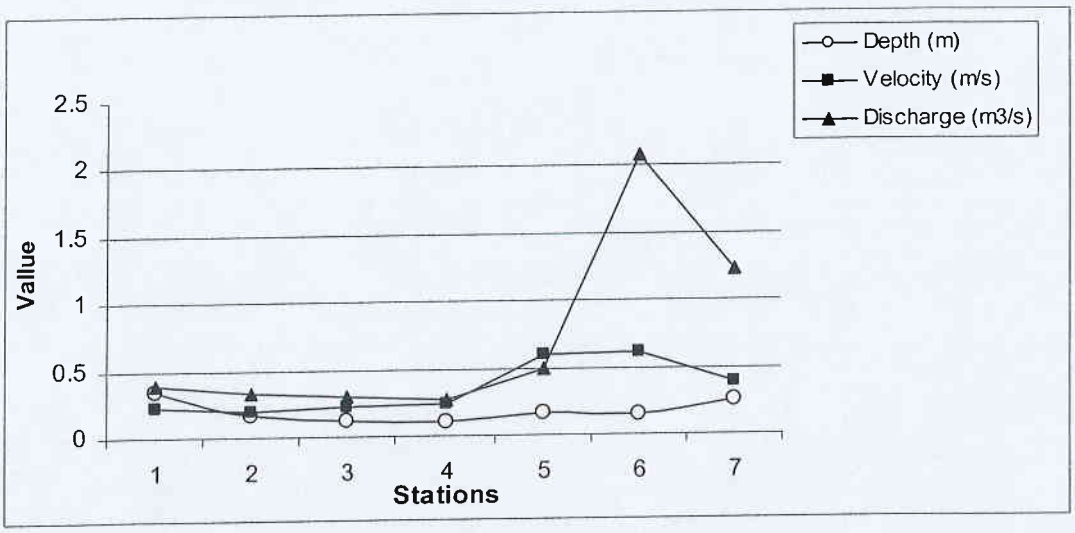


Figure 36: Spatial variation of depth, velocity and discharge along the Manahara river in December (2005)

The spatial variation of pH and free carbondioxide in the river in the month of December is shown in figure 37. Free CO_2 content of the water of the river increased gradually from 7.47 ± 0.33 mg/L at station 1 to 36.00 ± 0.80 mg/L at station 7. However, pH decreased gradually from 7.33 ± 0.01 at station 1 to pH 7.08 ± 0.06 at station 5 and then again increased to 7.37 ± 0.11 at station 7.

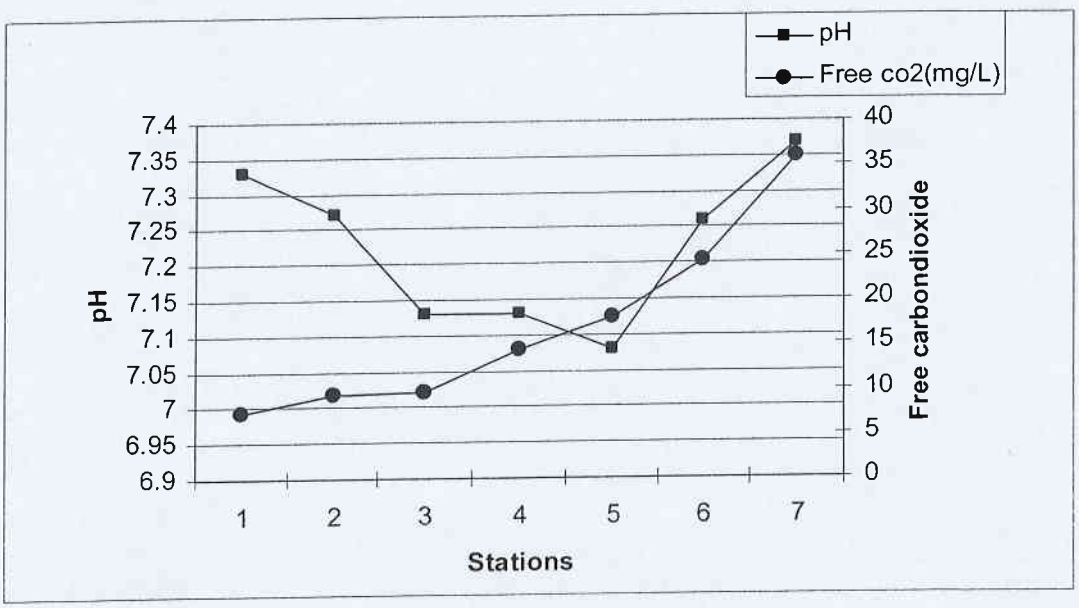


Figure 37: Spatial variation of pH and free carbondioxide content of the water of Manahara river in December (2005)

Hardness, chloride, calcium, calcium hardness and magnesium content of surface waters of the Manahara river in December is shown in figure 38. The figure 38 showed that the values of all these parameters increased gradually from headwater (station 1) to downstream (station 7). hardness increased gradually from 16.16 ± 0.66 mg/L as $CaCO_3$ at station 1 to 103.67 ± 1.77 mg/L as $CaCO_3$ at station 7.

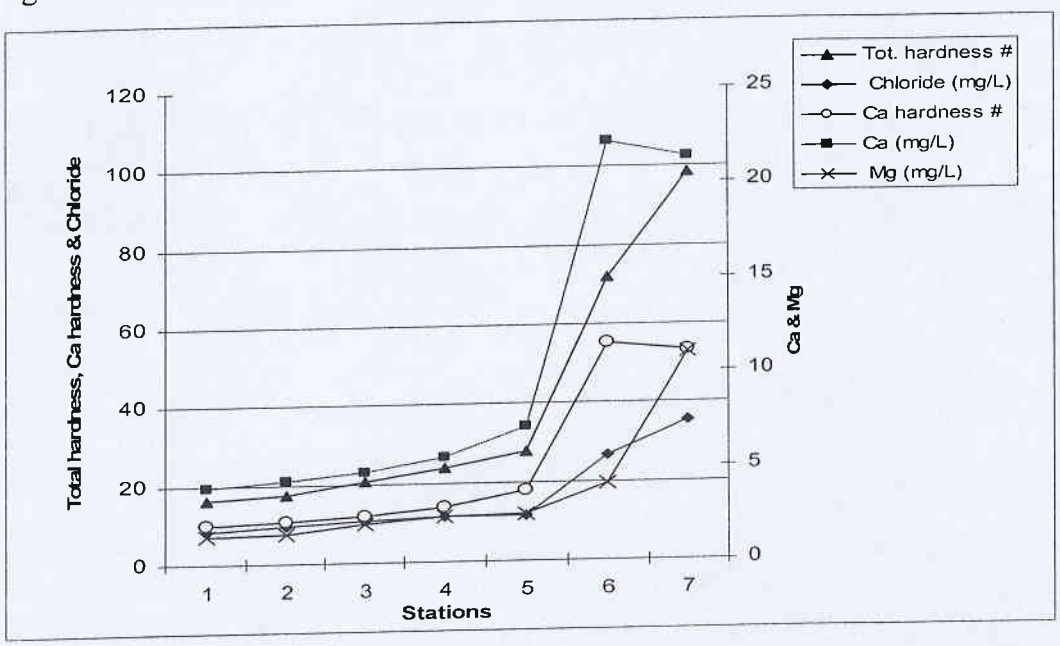


Figure 38: Spatial variation of hardness, chloride, calcium hardness, calcium and magnesium content of water of Manahara river in December (2005)

Similarly, chloride content increased gradually from 8.34 ± 0.23 mg/L at station 1 to 35.5 ± 1.64 mg/L at station 7 and calcium content increased from 4.03 ± 0.21 mg/L at station 1 to 26.39 ± 0.71 mg/L at station 7. The calcium hardness increased from 10.06 ± 0.54 mg/L as $CaCO_3$ at station 1 to 65.83 ± 1.77 mg/L as $CaCO_3$ at station 7 and magnesium content increased gradually from 1.48 ± 0.05 mg/L at station 1 to 9.19 ± 0.16 mg/L at station 7.

Figure 39 shows the spatial variation of total alkalinity or bicarbonate alkalinity and bicarbonate content of water of Manahara river. Total alkalinity was composed of only bicarbonate alkalinity as carbonate and hydroxide alkalinity were absent. Therefore, total alkalinity and bicarbonate alkalinity were equal.

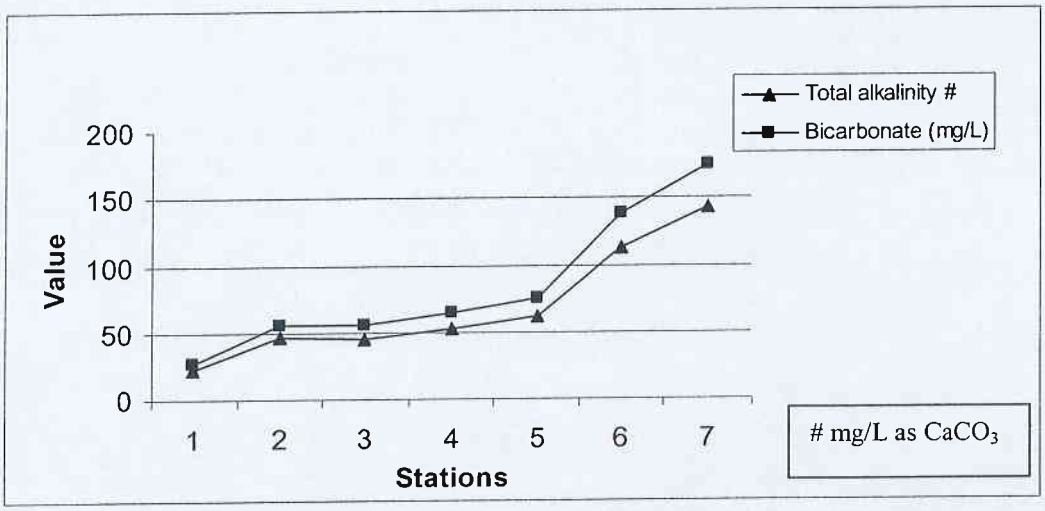


Figure 39: Spatial variation of total alkalinity and bicarbonate contente ot water along the Manahara river in December (2005)

Bicarbonate alkalinity and bicarbonate content were increased gradually from stations 1 (22.5 ± 1.44 mg/L as $CaCO_3$ of bicarbonate alkalinity and 27.45 ± 1.76 mg/L of bicarbonate content) to station 7 (143.33 ± 1.67 mg/L as $CaCO_3$ of bicarbonate alkalinity and 174.87 ± 2.03 mg/L of bicarbonate content) except a slight decrease of bicarbonate alkalinity from 46.07 ± 1.07 mg/L as $CaCO_3$ at station 2 to 45.83 ± 0.83 mg/L as $CaCO_3$ at station 3 and also a slight decrease of bicarbonate content from 56.2 ± 1.30mg/L at station 2 to 55.92 ± 1.02 mg/L at station 3. The bicarbonate alkalinity and bicarbonate concentration increased proportionally because they have linear relationship.

The spatial variation of nitrate-nitrogen, ortho-phosphate and ammoniacal nitrogen as shown in figure 40 increased gradually from station 1 to 7 except nitrate-nitrogen from stations 3 to 4.

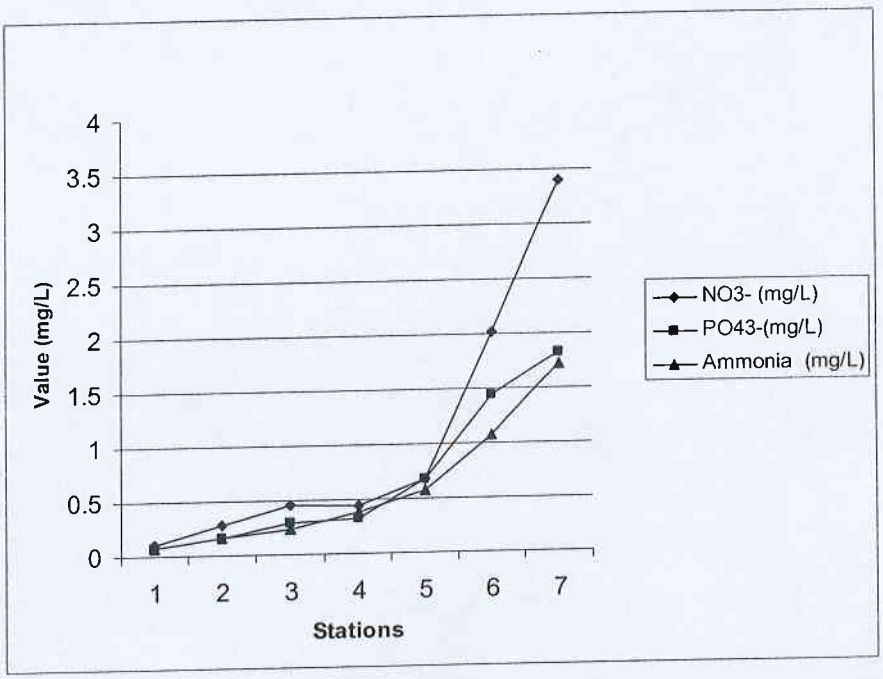


Figure 40: Spatial variation of nitrate-nitrogen, ortho-phosphate and ammoniacal nitrogen of water along the Manahara river in December (2005)

In the river water the nitrate-nitrogen content was 0.11 ± 0.01 mg/L, ortho-phosphate content was 0.08 ± 0.01 mg/L and ammoniacal-nitrogen content was 0.07 ± 0.01 mg/L at station 1 which gradually increased to station 7 reaching the level of 3.39 ± 0.01 mg/L nitrate-nitrogen content, 1.83 ± 0.03 mg/L of ortho-phosphate content and 1.72 ± 0.06 mg/L of ammoniacal nitrogen content at station 7..

The conductivity and TDS and Total coliforms increased gradually from station 1 to 7 along the river as shown in figure 41. The conductivity was 47.33 ± 2.60 µS/cm at station 1 whereas it was 393.00 ± 4.93 µS/cm at station 7. Similarly, TDS was 31.37 ± 1.66 mg/L at station 1 and 260.49 ± 3.73 mg/L at station 7. The conductivity and TDS changed proportionally because they have linear relationship (Trivedi and Goel, 1986; APHA, 1995).

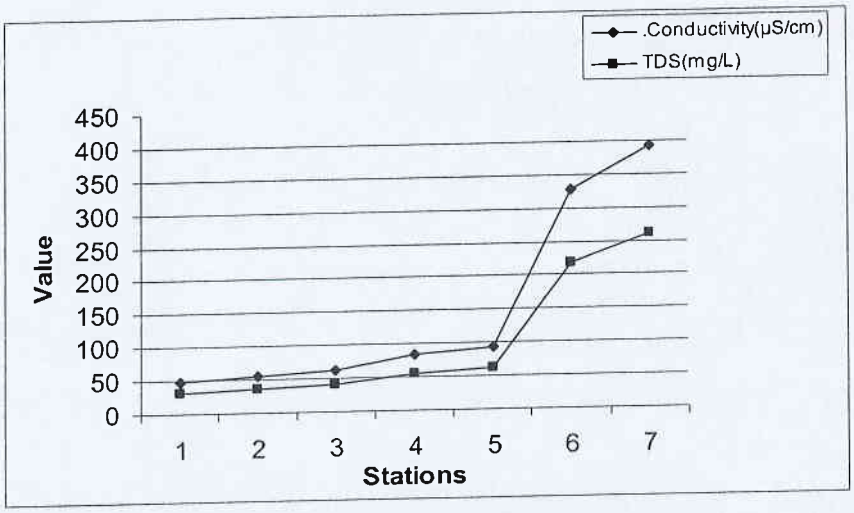
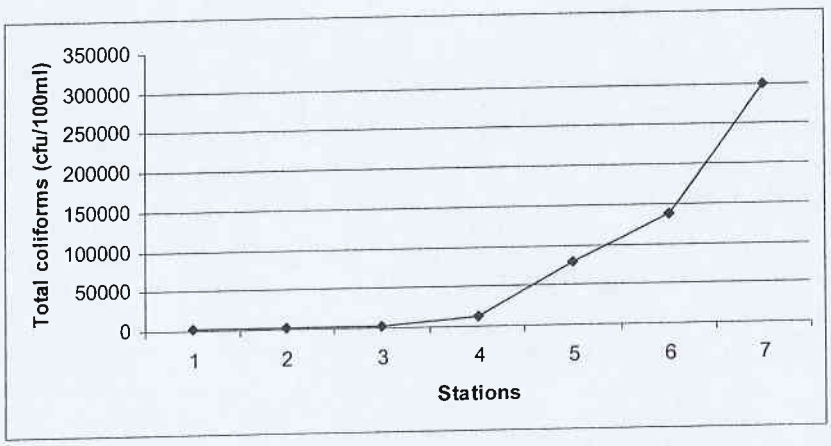


Figure 41: Spatial variation of conductivity and total dissolved solids of water along the Manahara river in December (2005)

The spatial variation of total coliforms along the river from station 1 to 7 is shown in figure 42. The total coliforms increased gradually from station 1 to 7 along the river. The total coliforms were 1547 ± 88 cfu/100ml at station 1 and greater than 300,000 cfu/ 100 ml at station 7.



.Figure 42: Spatial variation of total coliforms in river water along the Manahara river in December (2005)

6.1.21 Diurnal variation of Water Quality

The diurnal variation of water quality of the Manahara river was measured once at station 4 from 07:00 hours to 18:00 hours on 21 September, 2006. The diurnal variation of surface water temperature in relation with air temperature is shown in figure 43.

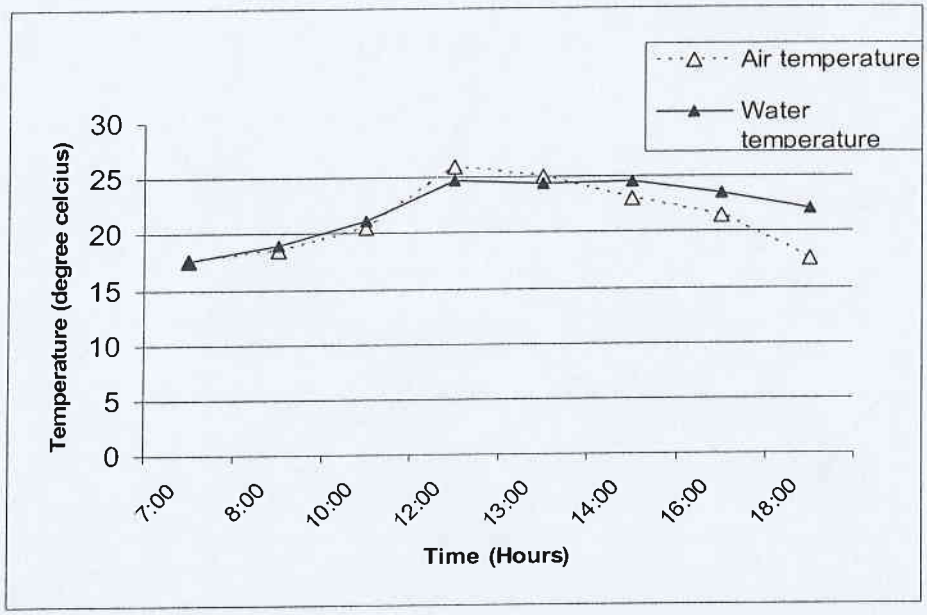


Figure 43: Diurnal variation of air and water temperature of the river water at station 4

The water temperature increased gradually from 17.5 °C at 7:00 hours (morning) to 24.67 °C at 12:00 (noon) and reached the maximum leval at the noon and then decreased gradually till 22.0 °C at 18:00 hours. In that duration the amplitude of variation of water temperature was 7.17^0C.

The figure 44 shows the diurnal variation of free carbondioxide (CO_2) and pH.

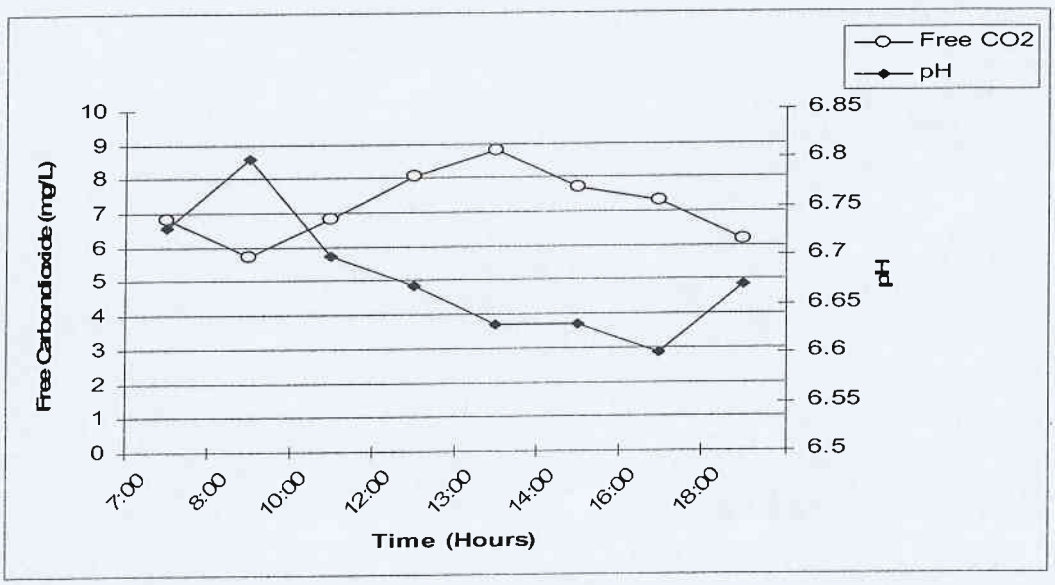


Figure 44: Diurnal variation of free carbondioxide and pH of the river water at station 4

Free CO_2 decreased from 6.82 mg/L at 07:00 hours (a.m.) to 5.72 mg/L at 08:00 hours (a.m.) and then increased to the maximum level of 8.8 mg/L at 13:00 hours (p.m.) from when it again decreased to 6.16 mg/L at 18:00 hours. The free CO_2 content ranged from 5.72 mg/L at 8:00 hours to 8.8 mg/L at 13:00 hours its amplitude of variation was 3.08 mg/L. Similarly, the pH level followed inversely the fluctuation trend of the free CO_2. There is moderate negative correlation between free CO_2 and pH (r = - 0.700, insignificant at probability level = 0.01 and probability level = 0.05, two-tailed). This is true for free CO_2 content below pH 8.3 (Saxena, 1987). The amplitude of variation of pH was 0.2 ranging from 6.6 at 16:00 hours to 6.8 at 8:00 hours by 0.2.

The dissolved Oxygen fluctuated from 8.35 mg/L at 7:00 hours to 7.62 mg/L at 18:00 hours with the minimum level of 7.1 mg/L at 13:00 hours and the maximum level of 8.35 mg/L at 07:00 hours which is shown in figure 45.

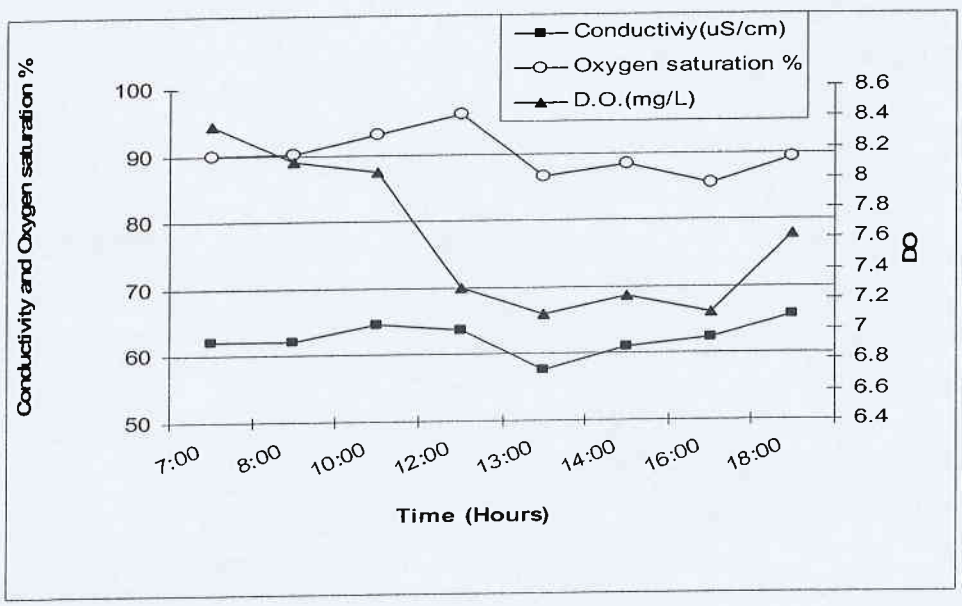


Figure 45: Diurnal variation of oxygen saturation %, dissolved oxygen and conductivity of the river water at station 4

The amplitude of variation of dissolved oxygen was 1.25 mg/L in the duration of 11 hours. The oxygen saturation fluctuated from 89.98 % at 7:00 hours to 89.33 % at 18:00 hours. The minimum level of oxygen saturation % was 85.42 % which was recorded at 16:00 hours and the maximum level of oxygen saturation % of 95.91 % was recorded at 12:00 hours which is shown in figure 45. The amplitude of variation of oxygen saturation % was 10.49 % during the observation period of 11 hours. The

figure also showed the fluctuation of electrical conductivity from 62.0μS/cm at 7:00 hours to 65.67 μS/cm at 18:00 hours. The minimum level of electrical conductivity of 57.67μS/cm was recorded at 13:00 hours whereas the maximum level of electrical conductivity of 65.67μS/cm was recorded at 18:00 hours. The amplitude of variation of conductivity was 8.0μs/cm during 11 hours investigation period.

6.1.22 Water Quality class by using Bach Index

The water quality class calculated by using Bach, 1980 for seven stations for all the months of investigation period is shown in table 14.

Table 14: Monthly variation of water quality class in different stations of Manahara river using Bach index

Months/stations	1	2	3	4	5	6	7
October	I	I-II	II-III	III	III	III-IV	III-IV
November	I	I	II	III	III	III-IV	III-IV
December	I	I	II	III	III	III-IV	III-IV
January	I	I	II-III	III	III	III-IV	IV
February	I	I	II	III	III	IV	IV
March	I	II-III	II-III	III	III-IV	III-IV	IV
April	I	I-II	III	III	III-IV	IV	IV
May	I	II	III	III	IV	IV	IV
June	I	II	III	III	III	III-IV	IV
July	I	I-II	II-III	III	III	III-IV	III-IV

Water quality class remained I (no or very low pollution) at station 1 and III (severe pollution) at station 4 in all the months during the investigation period whereas water quality class fluctuated at the remaining stations. Water quality class fluctuated from class I to class II-III at station 2, class II to class III at station 3, class III to class IV at station 5, class III-IV to class IV at station 6 and 7. In general, the low water pollution was observed in late post-monsoon (November) and early winter (December) whereas high water pollution was observed in late pre-monsoon (May). Among different months, the month May was found to be the most polluted month for the Manahara The monthly variation of water quality class given by Bach index at different stations in the Manahara river is not significant at 0.05 and 0.01 probability level ($F = 0.225$, d.f.= 69). But, there is significant spatial variation of Bach water quality class from stations 1 to 7 at 0.01 probability level ($F = 114.928$ d.f.= 69). The station 1 remained the most pollution-free station and station 7 remained the most-polluted station. river.

6.1.23 Water quality condition by using Ministry of Public Transport and Public works WQI, Netherlands

The water quality condition calculated by using Ministry of Public Transport and Public works (MPTPW) Water Quality Index (WQI), Netherlands for seven stations for all the months of investigation period is shown in table 15.

Table 15: Monthly variation of water quality class in different stations of Manahara river using MPTPW index

Months/ Stations	1	2	3	4	5	6	7
October	Excellent	Good	Fair	Fair	Fair	Bad	Bad
November	Excellent	Excellent	Good	Good	Fair	Fair	Bad
December	Excellent	Excellent	Good	Good	Fair	Bad	Bad
January	Excellent	Excellent	Good	Fair	Fair	Bad	Bad
February	Excellent	Excellent	Good	Fair	Bad	Very bad	Very bad
March	Excellent	Excellent	Good	Fair	Bad	Bad	Very bad
April	Excellent	Excellent	Good	Fair	Bad	Bad	Very bad
May	Excellent	Good	Good	Fair	Bad	Very bad	Very bad
June	Excellent	Good	Good	Fair	Fair	Bad	Bad
July	Excellent	Excellent	Good	Good	Fair	Fair	Fair

Similar to water quality class by using Bach index, the water quality condition remained "Excellent" at station 1 in all the months during the investigation period. However, water quality condition fluctuated at other stations during different months. The station 7 remained the most polluted station, with water quality condition "Fair" to "Very Bad". At station 2, Water quality condition fluctuated between "Excellent" to "Good" whereas it fluctuated between "Good" to "Fair" at stations 3 and 4. Similarly, water quality condition fluctuated between "Fair" to "Bad" at station 5, and "Good" to "Very Bad" at station 6. The monthly variation of water quality condition at different stations in the Manahara river is not significant at 0.05 and 0.01 probability level ($F = 0.400$ d.f.= 69). Similar to Bach water quality class, water quality condition of the month May remained the most polluted month in the Manahara river. However, there is significant spatial variation in the water quality condition of the river at 0.01 probability level ($F = 66.962$ d.f.= 69).

3.1.24 Relationship between Bach WQ class and MPTPW WQ condition

The correlation analysis showed a high positive correlation coefficient r = 0.913 in between Bach water quality class and Ministry of Public Transport and Public Works (MPTPW) water quality condition. Thus, obtained correlation coefficient is significant at 0.01 probability level. The coefficient of determination (r^2) between these two water quality classes is 0.8836 i.e. the change in Bach water quality class is 88 % explained by the change in MPTPW water quality condition and vice versa.

6.2 Microbial features

Total Coliforms

The monthly variation of total coliforms of surface water of the river over the period of three months (2005) is shown in figure 46.

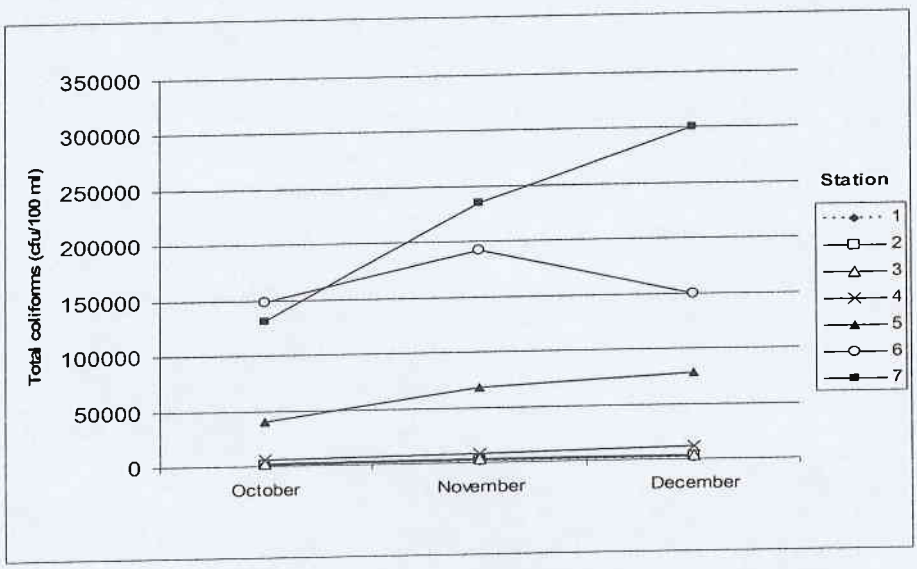


Figure 46: Monthly variation of total coliforms in the water of Manahara river in different stations (2005)

The total coliforms density was found maximum in December (winter) at station 1 (1547 cfu/100 mL), station 2 (2477 cfu/100 mL), station 3 (2910 cfu/100 mL), station 4 (11,600 cfu/100 mL), station 5 (78,333 cfu/100 mL) and station 7 (> 300,000 cfu/100 mL) whereas it was found maximum in November (pre-monsoon) at station 6 (192,000 cfu/100 mL) during the investigation period. But, the minimum total coliforms density was observed in October at all the stations (903 cfu/100 mL at station 1; 1617 cfu/100 mL at station 2; 2703 cfu/100 mL at station 3; 5333 cfu/100 mL at station 4; 40,667 cfu/100 mL at station 5; 148667 cfu/100 mL at station 6 and

131667 cfu/100 mL at station 7). The monthly variation of total coliforms in the Manahara river water is not significant at 0.05 and 0.01 probability level (F = 0.033, d.f.= 20).

On the average, the total coliforms density were found as 1232 ± 28.4817 cfu/100 mL; 2127 ± 41.554 cfu/100 mL; 2835 ± 18.251 cfu/100 mL; 8144 ± 272.12 cfu/100 mL; 62222 ± 1875.1 cfu/100 mL; 163556 ± 15757 cfu/100 mL and 222000 ± 7192.24 cfu/100 mL at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The total coliforms density increased from station 1 to 7 (upstream to downstream) in all the months of investigation. Such spatial variation of total coliforms from stations 1 to 7 in the Manahara river is significant at 0.01 probability level (F = 19.801, d.f.= 20). During the investigation period, the lowest total coliforms density of 903 cfu/100 mL was recorded at station 1 in October and the highest total coliforms density of greater than 3 x 10^5 cfu/100 mL was recorded at station 7 in December.

The amplitude of variation of total coliforms density were 644, 860, 207, 6267, 37666, 43333 and greater than 168,333 cfu/100 mL at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period.

6.3 Macroinvertebrates

The macroinvertebrates individuals of 36 families were identified from the Manahara river from stations 1 to 7. They belong to 13 orders, 5 classes and 4 phyla. Due to the lack of complete taxonomic identification keys of this region, only 5 macroinvertebrates species were identified up to genus level using the previously identified species and literatures on identification of species of this region.

3.3.1 Macroinvertebrate taxa of the river

The benthic macroinvertebrates occurred in the river are listed in the table 16.

Table 16: Benthic macroinvertebrates taxa collected and identified in the Manahara river during the investigation period

Phylum	Class	Order	Family	Genus/species
Platyhelmithes	Turbellaria	Tricladida	Planaridae	*Dugesia sp.*
Annelida	Oligochaeta	Plesiopora	Tubificidae	*Limnodrilus sp.*
		Opisthopora	Megascolecidae	
	Hirudinea	Arhynchobdellida	Salifidae	
Arthropoda	Insecta	Plecoptera	Perlidae	
		Ephemeroptera	Baetidae	*Baetis sp.*
			Caenidae	*Caenis sp.*
			Heptageniidae	
			Ephemerellidae	
			Leptophlebiidae	
		Trichoptera	Philopotamidae	
			Glossosomatidae	
			Hydropsychidae	
			Lepidostomatidae	
		Coleoptera	Psephenidae	
			Dytiscidae	
			Elmidae	
			Gyrinidae	
			Hydrophilidae	
		Diptera	Athericidae	
			Limoniidae	
			Simuliidae	
			Chironomidae	
			Blephariceridae	
			Tabanidae	
			Stratiomyidae	
			Muscidae	
		Heteroptera	Nepidae	
			Aphelocheiridae	
			Gerridae	
			Corixidae	
			Vellidae	
		Odonata	Macromiidae	
			Gomphidae	
		Megaloptera	Corydalidae	
Mollusca	Gastropoda	Basomatophora	Physidae	*Physa mexicana*

6.3.1.1 Tricladida

The individuals of the only one family Planaridae belonging to the order Tricladida was recorded in the Manahara river during the present investigation period. Only one species i.e. *Dugesia sp.* belonging to the family Planaridae was recorded at stations 1 and 2 from October to May and at station 3 from March to May. Therefore, the species was present at stations 1 and 2 and also at station 3 in spring season. The average population density of *Dugesia sp.* was found as 2.33 indv./m^2, 1.22 indv./m^2, 0.33 indv./m^2 at the stations 1, 2 and 3 respectively which was never found at other stations 4, 5, 6 and 7 during the present investigation period.

6.3.1.2 Oligochaeta

The macroinvertebrates belonging to two families of the class Oligochaeta were recorded in the Manahara river during the present study period. These families were Tubificidae and Megascolecidae.

One species i.e. *Limnodrilus sp.* was identified in the family Tubificidae. *Limnodrilus sp.* was recorded from stations 5 to 7 whereas other Tubificids (not *Limnodrilus sp.)* were recorded only at station 3 in March and also in April. The individuals of the family Tubificidae were found only in March and April at staion 3, in October at station 5 whereas they were regularly recorded at station 6 from October to May. The tubificids were found at station 7 in November and December only. The average population density of Tubificidae was found as 0.22 indv./m^2, 0.33 indv./m^2, 13.00 indv./m^2, 4.56 indv./m^2 at stations 3, 5, 6, and 7 respectively which was never found at stations 1, 2 and 4 during the present study. The individuals of the family Megascolecidae were recorded once at station 7 in November during the investigation period. The average population density of the family Megascolecidae was found as 0.11 indv./m^2 at the stations 7 and was never found at other stations 1, 2, 3, 4, 5 and 6 during the investigation period.

6.3.1.3 Hirudinea

In the Manahara river, the individuals of the only one family Salifidae of the class Hirudinea were recorded during the present study period. The organisms belonging to this family were recorded only at station 6 in October and November. The average

population density of the family Salifidae was found as 0.89 indv./m^2 at station 1 and which were never found at stations 2, 3, 4, 5, 6 and 7 during the present investigation period.

6.3.1.4 Ephemeroptera

In the Manahara river, the individuals of five families of Ephemeroptera were recorded during the present investigation period. They were Baetidae, Caenidae, Heptageniidae, Ephemerellidae and Leptophlebiidae.

The individuals of the family Baetidae were regularly present at stations 1, 2, 3 and 4 and irregular at stations 5 and 6. The individuals of the family Baetide were never found at station 7 during the present investigation period. The average density of Baetidae was 26.78 individuals/m^2, 22.55 individuals/m^2, 46.34 individuals/m^2, 31.66 individuals/m^2, 40.56 individuals/m^2 and 19.44 individuals/m^2 at stations 1, 2, 3, 4, 5 and 6. The individuals of the family Caenidae and Heptageniidae were regularly present at stations 1 and 2, irregularly present at stations 3 and 4 and never found at stations 5, 6 and 7 during the present study. The average population density of family Caenidae was 19.33 indv./m^2, 12.44 indv./m^2, 19.89 indv./m^2 and 10.11 indv./m^2 at stations 1, 2, 3 and 4 respectively. Similarly, the average population density of family Heptageniidae was 6.67 indv./m^2, 4.89 indv./m^2, 0.67 indv./m^2 and 1.56 indv./m^2 at stations 1, 2, 3 and 4 respectively.

The individuals of family Ephemerellidae was recorded from only October to January during the investigation period. Ephemerellidae was regularly present at stations 1 and 2 and irregular at stations 3 and 4 from October to January. The individuals of this family were not recorded at stations 5, 6 and 7 during the present study. The average population density of this family Ephemerellidae was found to be 2.33 indv./m^2, 2.22 indv./m^2, 7.00 indv./$m^2$and 1.33 indv./m^2 at stations 1, 2, 3 and 4 respectively. The family Leptophlebiidae was recorded from only October to January during the investigation period. During this period, the individuals of this family were regularly present at station 1 and irregular at station 2. The individuals of this family were not recorded from stations 3 to 7 during the present study. The average population density of the family Leptophlebiidae was found to be 1.78 indv./m^2 and 1.78 indv./m^2 at stations 1 and 2 respectively.

6.3.1.5 Plecoptera

In the Manahara river, the individuals of only one family of the order Plecoptera i.e. Perlidae was recorded during this investigation period. The individuals of the family Perlidae were recorded exclusively at stations 1 and 2 in all the months except March and July. However, this family was found at stations 1 to 3 in March and only at station 1 in July. The average population density of Perlidae was 3.44 individuals/m^2, 2.55 individuals/m^2 and 2.89 individuals/m^2 at stations 1, 2 and 3 which was not recorded at stations 4, 5, 6 and 7 during the investigation period. The maximum population density of Perlidae of 5.56 individuals/m^2 was recorded in October at station 2, and in November at stations 1 and 2.

6.3.1.6 Trichoptera

The individuals of four families of the order Trichoptera were recorded in the Manahara river. They were Hydropsychidae, Glossosomatidae, Philopotamidae and Lepidostomatidae.

The individuals of the family Hydropsychidae were found regularly at stations 1, 2, 3 and 4 throughout the investigation period and irregular at stations 5 and 6. The individuals of the family Hydropsychidae were never recorded at station 7. The average population density of the family Hydropsychidae was13.56 indv./m^2, 17.33 indv./m^2, 26.78 indv./m^2, 20.67 indv./m^2, 11.89 indv./m^2 and 3.22 indv./m^2 at stations 1, 2,3,4,5and 6 respectively. Similarly, the family Glossosomatidae was regularly found at stations 1, 2 and 3 from October to April whereas it was also found in May only at stations 1 and 2 and entirely absent in June and July. The average population density of the family Glossossomatidae was 11.00 indv./m^2, 7.22 indv./m^2 and 4.78 indv./m^2 at stations 1, 2 and 3 respectively which was not recorded at stations 4,5, 6 and 7 during the present study.

The individuals of the family Philopotamidae was found only at stations 1 and 2 from November to May. The average population density of the family Philopotamidae was 2.11 indv./m^2 and 1.56 indv./m^2 at stations 1 and 2 respectively which was not recorded at stations 3,4,5, 6 and 7 during the present study. The individuals of the family Lepidostomatidae was recorded only at station 2 in November and December.

The average population density of this family Lepidostomatidae was 0.56 indv./m^2 at station 2 and this family was not recorded at stations 1,3,4,5,6 and 7 during the present study.

6.3.1.7 Coleoptera

In the Manahara river, the individuals of five families of the order Coleoptera were recorded during the present investigation period. These families were Elmidae, Dytiscidae, Hydrophilidae, Gyrinidae and Psephenidae.

The individuals of the family Elmidae were regularly found only at station 1 from October to July throughout the investigation period. At station 2, the individuals of the family Elmidae were found regularly from October to May and at station 3, this family was found in October to January and March to May. The family was never recorded at stations 4 to 7 during present investigation period. The average population density of the family Elmidae was found to be 52.00 indv./m^2, 31.45 indv./$m^2$and 23.22 indv./m^2 at stations 1, 2 and 3 respectively.

The families Dytiscidae, Hydrophilidae, Gyrinidae and Psephenidae were not recorded regularly in any station during the investigation period. The individuals of the family Dytiscidae were recorded irregularly from stations 2 to 5 in different months during the investigation period. The average population density of the family Dytiscidae was 1.78 indv./m^2, 2.78 indv./m^2, 2.22 indv./m^2 and 0.11 indv./m^2 at stations 2, 3, 4 and 5 respectively and were not found at stations 1, 6 and 7 during the found investigation period.. The individuals of the family Hydrophilidae was recorded once at station 2 in October whereas Gyrinidae was recorded at station 2 from October to December and once at station 1 in November. The average population density of the family Hydrophilidae was found to be 0.33 indv./m^2 at station 2 and was never recorded at stations 1, 3, 4, 5, 6 and 7 during the present investigation period. Similarly, the average population density of the family Gyrinidae was found to be 0.44 indv./m^2 and 1.00 indv./m^2 at stations 1 and 2 respectively and was never recorded at stations 3, 4, 5, 6 and 7 during the present investigation period. The individuals of the family Psephenidae was recorded only at station 2 in March, April and May. The average population density of the family Psephenidae was found to be

0.89 indv./m^2 at station 2 which was never recorded at stations 1, 3, 4, 5, 6 and 7 during the present investigation period.

6.3.1.8 Diptera

The individuals of eight families of the order Diptera were recorded in the Manahara river during the present investigation period. These families were Chironomidae, Simuliidae, Tabanidae, Limoniidae, Athericidae, Blephariceridae, Stratiomyidae and Muscidae.

The individuals of the family Chironomidae were recorded from stations 1 to 7 during the present study. The individuals of the family Chironomidae was found regularly at stations 5, 6 and 7 in all the months during the investigation period, but they were found regularly at stations 2, 3 and 4 from October to May only. At station 1, the individuals of this family were found from February to May only. The average population density of the family Chironomidae was found to be 13.00 indv./m^2, 22.22 indv./m^2, 59.23 indv./m^2, 26.56 indv./m^2, 70.11 indv./m^2, 364.58 indv./$m^2$and 334.58 indv./m^2 at the stations 1, 2, 3, 4, 5, 6 and 7 during the present study. The individuals of the family Simuliidae was recorded only from stations 2 to 4. The organisms of the family Simuliidae were found regularly at stations 3 and 4 from October to July and at station 3 from October to June, whereas it was recorded at station 4 in the months March, April and May. The average population density of the family Simuliidae was found to be 37.22 indv./m^2, 15.33 indv./m^2 and 6.44 indv./m^2 at stations 2, 3 and 4 respectively which were not found at stations 1, 5, 6 and 7 during the present investigation period.

The macroinvertebrates belonging to the family Tabanidae were recorded from stations 1 to 4. The individuals of the family Tabanidae were found at stations 2, 3 and 4 from October to May whereas they were recorded at station 1 from March to May (spring). This family was not recorded at these stations in June and July (monsoon). The average population density of the family Tabanidae was found to be 1.33 indv./m^2, 2.22 indv./m^2, 2.89 indv./m^2 and 3.44 indv./m^2 at stations 1, 2, 3 and 4 respectively which were never found at stations 5, 6 and 7 during the investigation period. The individuals of the family Limoniidae were recorded from stations 1 to 4 during the present investigation period. The macroinvertebrates belonging to the

family Limoniidae were found regularly at station 1 from March to June, at station 2 from October to June, at station 3 from November to June and at station 4 from March to May. The average population density of the family Limoniidae were found to be 2.00 indv./m^2, 4.44 indv./m^2, 3.44 indv./$m^2$and 1.22 indv./m^2 at stations 1, 2, 3 and 4 respectively and never showed its presence at stations 5, 6 and 7 during the investigation period.

The individuals of the family Athericidae were recorded only at station 2 in April and May. The average population density of the family Athericidae was found to be 0.11 indv./m^2 at station 2 which was never found at other stations 1, 3, 4, 5, 6 and 7 during the present investigation period. Similarly, the macroinvertebrates belonging to the family Blephariciдae was found only at station 1 in November and December and at station 2 in November. The average population density of the family Blephariceridae was found to be 0.56 indv./m^2 and 0.33 indv./m^2 at stations 1 and 2 respectively which was never recorded at other stations 3, 4, 5, 6 and 7 during the present study. The individuals of the families Stratiomyidae and Muscidae were recorded only at station 2 in October. The average population density of the families Stratiomyidae and Muscidae were 0.22 indv./m^2 for both at station 2 and both of these families were never found at other stations 1, 3, 4, 5, 6 and 7 during the investigation period.

6.3.1.9. Heteroptera

In the Manahara river, the individuals of the five families of the order Heteroptera were recorded during the present investgation. These families were Nepidae, Aphelocheiridae, Gerridae, Corixidae and Vellidae.

The individuals of the family Nepidae were recorded only at station 3 in October and November. The average population density of the family Nepidae was found to be 0.89 indv./m^2 at station 3 which was never found at other stations 1, 2, 4, 5, 6 and 7 during the present investigation period. The macroinvertebrates belonging to the family Aphelocheiridae were recorded exclusively at stations 1 and 2 in October and also from March to July. The average population density of the family Aphelocheiridae was found to be 1.33 indv./m^2 and 1.22 indv./m^2 at stations 1 and 2 respectively and were not recorded at stations 3, 4, 5, 6 and 7 during the investigation period. The individuals of the family Gerridae were found only at station 2 in March

and April and at station 3 in October. The average population density of the family Gerridae was found to be 0.44 indv./m^2 and 0.33 indv./m^2 at stations 2 and 3 respectively and were never found at stations 1, 4, 5, 6 and 7 during the present investigation period.

The individuals of the family Corixidae were recorded only in October at stations 3 and 4. The average population density of the family Corixidae was found as 0.56 indv./m^2 and 0.33 indv./m^2 at stations 3 and 4 and were never found at stations 1, 2, 5, 6 and 7 during the investigation period. Similarly, the individuals of the family Vellidae were recorded once at station 1 in October during the present study period. The average population density of the family Vellidae was found as 0.22 indv./m^2 at station 1 which was never found at stations 2, 3, 4, 5, 6 and 7 during the investigation period.

6.3.1.10 Odonata

The individuals of the two families of the order Odonata i.e. Gomphidae and Macromiidae were recorded in the Manahara river during the present study period.

The macroinvertebrates belonging to the family Gomphidae were recorded from station 1 to 6. The individuals of the family Gomphidae were found regularly at stations 3 and 4 from October to July; at station 1, 2 and 5 from October to May and at station 6 in October and also from December to May. The average population density of the family Gomphidae was found as 16.44 indv./m^2, 16.33 indv./m^2, 13.00 indv./m^2, 13.78 indv./m^2, 8.67 indv./m^2 and 4.89 indv./m^2 at the stations 1, 2, 3, 4, 5 and 6 respectively which was never found at station 7 during the present investigation period. The organisms belonging to the family Macromiidae were recorded at station 2 from October to December and at station 1 in October. The average population density of the family Macromiidae was found as 0.56 indv./m^2 and 0.89 indv./m^2 at stations 1 and 2 respectively which were never found at stations 3, 4, 5, 6 and 7 during the present study period.

6.3.1.11 Megaloptera

Among the order Megaloptera, the individuals of the only one family i.e. Corydalidae were recorded in the Manahara river during the present study period. The

macroinverterbrates belonging to the family Corydalidae were recorded at station 1 in October and also in March and at station 2 in October. Therefore, it was recorded at stations 1 and 2 and never found at stations 3, 4, 5, 6 and 7 during the study period. The average population density of the family Corydalidae was found as 0.56 indv./m^2 and 0.33 indv./m^2 at stations 1 and 2 respectively.

3.3.1.12 Gastropoda

In the class Gastropoda, the individuals of the only one family Physidae were recorded in the Manahara river during the present investigation period. All the individuals belonging to the family Physidae were *Physa mexicana. Physa mexicana* was recorded regularly at stations 1 to 6 from March to July and at stations 4 and 6 in October. The species was not recorded at any station from November to February. The average population density of *Physa mexicana* was found as 7.67 indv./m^2, 16.33 indv./m^2, 41.00 indv./m^2, 7.44 indv./m^2, 2.89 indv./m^2 and 11.11 indv./m^2 at stations 1, 2, 3, 4, 5 and 6 respectively which was never found at station 7.

6.3.2 Total density/abundance of macroinvertebrates

The seasonal variation of total density/abundance of benthic macro-invertebrates in the Manahara river over the period of ten months is shown in figure 47.

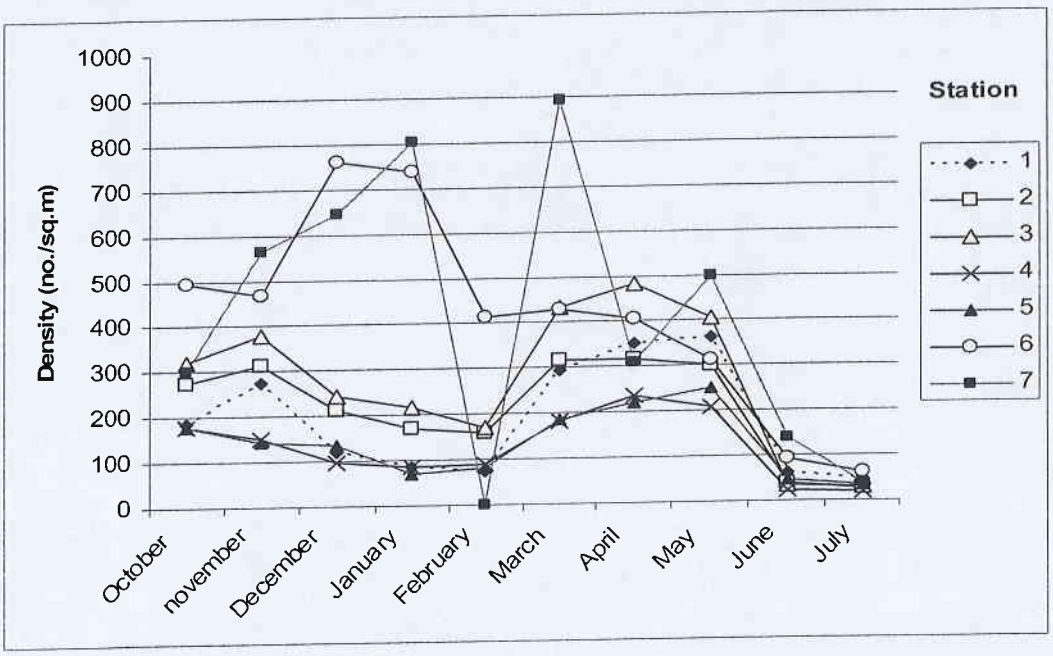


Figure 47: Seasonal variation of density of macroinvertebrates in Manahara river over the period of ten months

At stations 1, 2 and 3, the total density/abundance of macro-invertebrates increased from October (186.67 indviduals/m^2 at station 1, 273.33 indviduals/m^2 at station 2 and 318.89 indviduals/m^2 at station 3) to November (273.33 indviduals/m^2 at station 1, 313.33 indviduals/m^2 at station 2 and 378.89 indviduals/m^2 at station 3) i.e. during autumn and then decreased to February (winter) from when the density again increased and reached maximum level in April (Spring) at station 2 (317.78 individuals/m^2) and station 3 (484.44 indviduals/m^2) and in May (spring) at station 1 (362.22 indv./m^2). At stations 4 and 5, total density decreased gradually from October (Autumn) (176.67 indviduals/m^2 at station 4 and 178.89 indviduals/m^2 at station 5) to January (winter) which then increased and reached maximum level in April (spring) at station 4 (235.56 individuals/m^2) and in May (spring) at station 5 (250 individuals/m^2). At stations 6 and 7, total density fluctuated from October (494.44 indviduals/m^2 at station 6 and 302.22 indviduals/m^2 at station 7) and reached maximum level in May (spring) at station 6 (312.22 indv./m^2) and also at station 7 (497.78 indv./m^2).

The total density abruptly decreased in June and July (summer or monsoon) in all the stations and reached the minimum level in July at every station except station 7 i.e. 47.78 individuals/m^2 at station 1; 25.56 individuals/m^2 at station 2; 31.11 individuals/m^2 at station 3; 20.0 individuals/m^2 at station 4; 33.33 individuals/ m^2 at station 5 and 62.22 individuals/m^2 at station 6. At station 7, the minimum level of macroinvertebrates density of 1.11individuals/m^2 was recorded in February, probably because of severe pollution with nil dissolved oxygen in February. Therefore, maximum density was recorded in spring and minimum density was recorded summer (monsoon) at almost all stations. Such monthly variation of total density of benthic macro-invertebrates of the river water is significant at 0.01 probability level ($F = 3.528$, d.f. = 69).

On the average, the total density were found as 185.44 ± 39.4291 indv./m^2, 212.34 ± 35.5821 indv./m^2, 271.55 ± 50.607 indv./m^2, 126.78 ± 23.5727 indv./m^2, 134.55 ± 23.667 indv./m^2, 417.22 ± 72.3273 indv./m^2 and 419.22 ± 98.481 indv./m^2 at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The total density fluctuated from stations 1 to 7. Such spatial variation of total density of macroinvertebrates is significant at 0.01 probability level ($F = 4.961$, d.f. = 69).

Among all the stations during the investigation period, the highest and the lowest density of macroinvertebrates were found at station 7 which were respectively 892.22 individuals/m^2 in March (spring) and 1.11 individuals/m^2 in February (winter).

The amplitude of variation of total density of macroinvertebrates were 314.44 indv./m^2, 292.22 indv./m^2, 453.33 indv./m^2, 215.56 indv./m^2, 216.67 indv./m^2, 698.89 indv./m^2 and 891.11 indv./m^2 at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period.

6.3.3 Shannon Weiner Diversity index (H)

The seasonal variation of Shannon Weiner Diversity index (H) of benthic macroinvertebrates in the riverine ecosystem of the Manahara river over the period of ten months is shown in the figure 48.

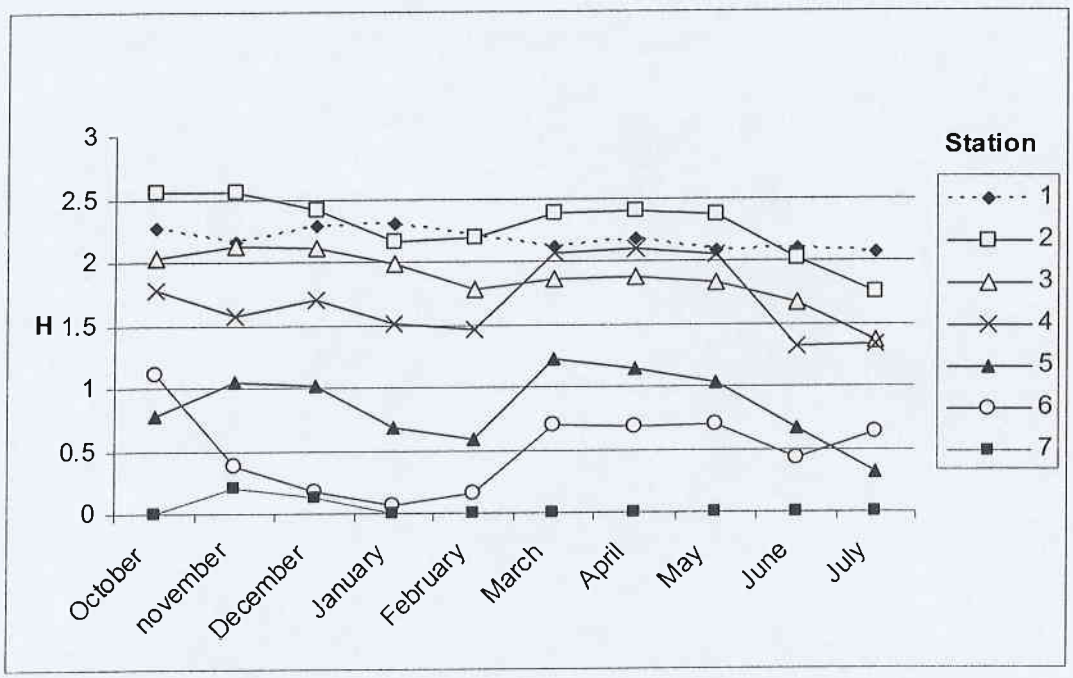


Figure 48: Seasonal variation of Shannon Weiner diversity index (H) of macroinvertebrates in Manahara river over the period of ten months

At stations 3, 5 and 7, the diversity index H increased from October (2.0388 at station 3; 0.77 at station 5 and 0 at station 7) to November i.e. autumn (2.1285 at station 3; 1.0496 at station 5 and 0.2042 at station 7) and then decreased till February (winter) from when it again increased until April/May (spring) and then decreased in June and July (monsoon) except at station 7, where H is zero from January to July and in

October, since only one taxa Chironomidae was found in these months at the station 7. At stations 2 and 6, the diversity index H decreased from October (2.5567 at station 2 and 1.1183 at station 6) till January (winter) and then increased up to May (spring). From May, H decreased till July in station 2 whereas H increased slightly from June to July in station 6. However, at station 1, the diversity index H decreased from October (2.27) to November (2.16), from when it increased till January and then decreased till May and became nearly equal in May, June and July. Similarly at station 4, the diversity index H decreased from October (1.77) to November (1.5706) and then increased to December (winter), from when it decreased till February and then increased gradually till April (spring) and then after decreased in June and July (monsoon).

The diversity index H was maximum in October (autumn) at station 2 (H = 2.56) and station 6 (H = 1.12); in November (autumn) at station 3 (H = 2.13) and station 7 (H = 0.20); in March (spring) at station 5 (H = 1.22); in April (spring) at station 4 (H = 2.1) and in January (winter) at station 1 (H = 2.31). However, the minimum diversity index H was observed in July (monsoon) at all stations i.e. 2.07 at station 1; 1.75 at station 2; 1.36 at station 3; 1.33 at station 4; 0.33 at station 5; 0.63 at station 6 and 0 at station 7 indicating lower diversity of benthos in July. Such monthly variation of Shannon diversity index of the benthic macroinvertebrates in the Manahara river is not significant at 0.05 and 0.01 probability level (F = 0.214, d.f.= 69).

On the average, the Shannon Weiner Diversity index (H) were found as 2.1754 ± 0.0260; 2.2765 ± 0.0759; 1.8645 ± 0.0690; 1.6890 ± 0.0900; 0.8487 ± 0.0861; 0.5025 ± 0.0968 and 0.0337 ± 0.0219 at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The Shannon Weiner Diversity index decreased from upstream (station 1 and 2) to downstream (station 7). Therefore, the stations 1 and 2 had highly diverse fauna of macroinvertebrates and the station 7 had the least diverse fauna of macroinvertebrates. Such spatial variation of Shannon diversity index of the benthic macroinvertebrates in the Manahara river is significant at 0.01 probability level (F = 132.733, d.f.= 69). Among the various stations during the investigation period, the highest value of diversity index H of 2.56 was recorded at station 2 in October and the lowest value of diversity index H of zero was recorded at station 7 in October and also from January to July.

The amplitude of variation of Shannon Weiner Diversity index were 0.2373; 0.808; 0.768; 0.7846; .8945; 1.0503 and 0.2042 at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period.

6.3.4 Index of dominance (c)

Figure 49 depicts the seasonal variation of index of dominance (c) of benthic macroinvertebrates of the aquatic ecosystem of the Manahara river over the period of ten months.

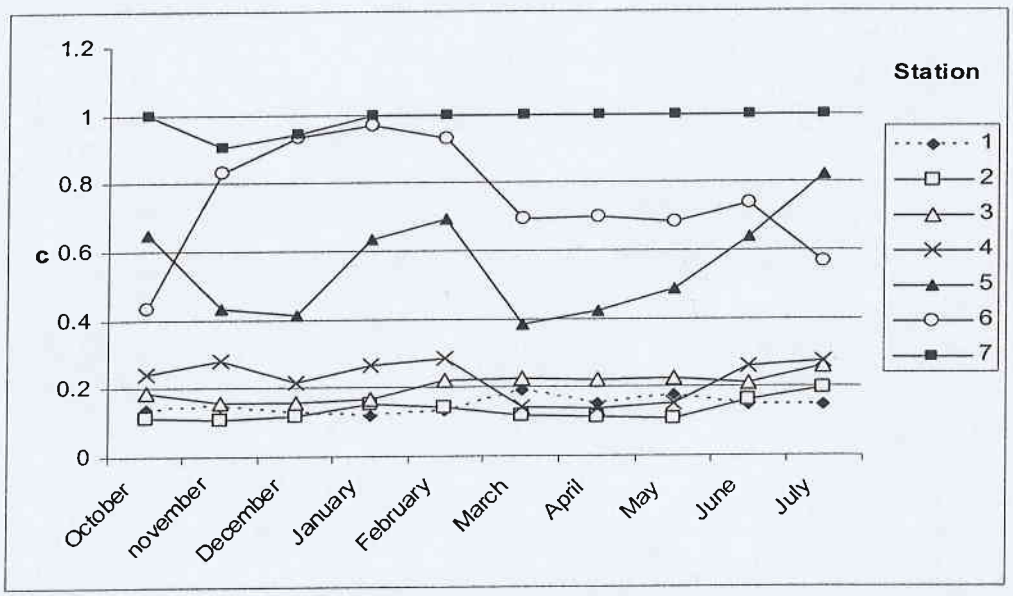


Figure 49: Monthly variation of index of dominance (c) of macroinvertebrates in Manahara river in different stations

At stations 3 and 5, the index of dominance decreased from October (0.185 at station 3 and 0.65 at station 5) till December (winter) (i.e. till 0.1555 at station 3 and 0.4117 at station 5) from when, it again increased until February (winter). At station 5, the index of dominance decreased from February to March and then became nearly equal in March, April and May (during spring) and then gradually increased from May to July. But at station 3, it was nearly equal from February to July. However at station 7, the index of dominance decreased from 1.00 in October to 0.9064 in November and then increased to the maximum level of 1.00 in January and then remained constant till July.

At stations 2 and 6, the index of dominance increased gradually from October (0.1125 at station 2 and 0.4351 at station 6) to January (winter) (0.1543 at station 2 and 0.9673 at station 6) and then decreased till March (spring) which remained nearly equal from March to May (spring), then after fluctuated. However at station 1, the index of dominance increased from 0.14 in October to 0.15 in November and then decreased till 0.1169 in January from when it again increased to 0.1940 in March (spring) and fluctuated then after. Similarly, at station 4, the index of dominance increased from 0.24 in October to 0.2824 in November and then decreased to 0.2147 in December which increased from December till 0.1314 in February (during winter) and fluctuated then after

During the investigation period, the maximum index of dominance was recorded in July (monsoon) at station 2 (c = 0.20), station 3(c = 0.26), and station 5 (c = 0.82); in January (winter) at station 6 (c = 0.9673); in February at station 4 (c = 0.29) and in October as well as from January to July at station 7 (c = 1). The minimum index of dominance was recorded in October at station 6 (c = 0.4351), in November at station 2 (c = 0.11) and station 7(c = 0.9064), in December at station 3 (c = 0.1555), in January at station 1 (c = 0.1169), in March at station 5 (c = 0.3831) and in April at station 4 (c = 0.1379). Such monthly variation of index of dominance of the benthic macroinvertebrates in the Manahara river is not significant at 0.05 and 0.01 probability level (F = 0.076, d.f.= 69).

On the average, the index of dominance was found as 0.1485 ± 0.00716; 0.1345 ± 0.00947; 0.2032 ± 0.01125; 0.2258 ± 0.01907; 0.5577 ± 0.04697; 0.7472 ± 0.05399 and 0.9850 ± 0.0104 at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. The lower index of dominance was recorded in upstream (stations 1 and 2) and the higher index of dominance was recorded in downstream (station 7). Such spatial variation of index of dominance of the benthic macroinvertebrates in the Manahara river is significant at 0.01 probability level (F = 136.302, d.f.= 69). Among the different stations during the investigation period, the lowest index of dominance of 0.11 was recorded at station 2 in November and the highest index of dominance of 1 was observed several times at station 7 in October, January to July.

The amplitude of variation of the index of dominance were 0.0771; 0.0885; 0.1073; 0.148; 0.4369; 0.5322 and 0.0936 at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period.

6.3.5 Evenness index (e)

The seasonal variation of Evenness index of benthic macroinvertebrates in the Manahara river over the period of ten months is shown in figure 50.

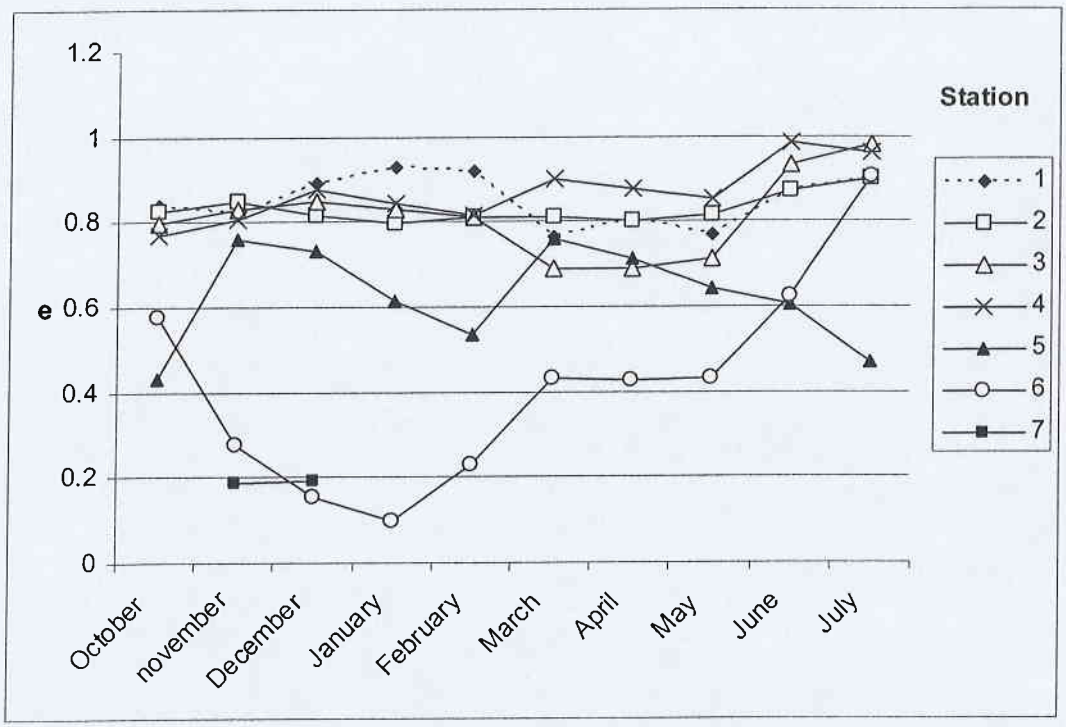


Figure 50: Seasonal variation of evenness index (e) of macroinvertebrates in Manahara river over the period of ten months

There was high fluctuation of Evenness index of benthic macroinvertebrates at all the stations from October to July. During the investigation period, the maximum Evenness index was recorded in July (monsoon) at station 2 (e = 0.8987), station 3 (e = 0.9814) and station 6 (e = 0.9059); in June (monsoon) at station 4 (e = 0.9844), in December (winter) at station 7 (e = 0.1909), in January (winter) at station 1 (e = 0.928) and in March at station 5 (e = 0.7578). However, the minimum evenness index was recorded in October at station 4 (e = 0.77) and station 5 (e = 0.43); in January at station 2 (e = 0.7951) and station 6 (e = 0.0981); in March at station 1 (e = 0.76634) and station 3 (e = 0.6883) and in November (e = 0.1859) at station 7. Such monthly

variation of evenness index of the benthic macroinvertebrates in the Manahara river is not significant at 0.05 and 0.01 probability level (F = 0.534, d.f.= 69).

On the average, the evenness index was found as 0.8502 ± 0.01891 ; 0.8299 ± 0.01059 ; 0.8121 ± 0.03078 ; 0.8691 ± 0.02112; 0.6256 ± 0.03734 ; 0.4146 ± 0.07689 and 0.1884 ± 0.0025 at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period. Therefore, evenness index was higher at stations 1 and 2 (no or least pollution), and at stations 3 and 4 (moderate pollution) and lower in stations 6 and 7 (highly polluted stations). Such spatial variation of evenness index of the benthic macroinvertebrates in the Manahara river is significant at 0.01 probability level (F = 24.253, d.f.= 69).

The amplitude of variation of the evenness index were 0.1646; 0.1036; 0.2931; 0.2149; 0.3278; 0.8078 and 0.0050 at stations 1, 2, 3, 4, 5, 6 and 7 respectively in the river during the investigation period.

6.3.6 Biological assessment of water quality using macroinvertebrates

The saprobic water quality class was calculated for stations 1 to 7 along the river from October 2005 to July 2006 by using benthic macroinvetebrates as bioindicator. The caoculation tables are shown in the Appendix XXVIIIA and XXVIIIB only for the month of October to display the steps of calculation. Thus obtained saprobic water quality class by using four systems namely, Original NEPBIOS, NEPBIOS-BRS, Extended NEPBIOS and GRS index are presented in tables 17, 18, 19 and 20 respectively.

Table 17: Seasonal variation of saprobic water quality class of Manahara river using Original NEPBIOS over the period of ten months

Months/stations	1	2	3	4	5	6	7
October	II	II	II-III	II-III	III	III	IV
November	II	II	II	II-III	II-III	III	IV
December	II	II	II	II-III	II-III	III	IV
January	II	II	II	II-III	III	IV	IV
February	II	II	II	II-III	III	IV	IV
March	II	II	II-III	II-III	II-III	III	IV
April	II	II	II-III	II-III	II-III	III	IV
May	II	II	II	II-III	II-III	III	IV
June	II	II	II	II-III	III	III-IV	IV
July	II	II	II-III	II-III	III-IV	III-IV	IV

Table 18: Seasonal variation of saprobic water quality class of Manahara river using NEPBIOS-BRS over the period of ten months

Months/stations	1	2	3	4	5	6	7
October	I-II	II	II-III	II-III	II-III	III	IV
November	I-II	II	II	II-III	II-III	III	IV
December	I-II	II	II	II-III	II-III	III	IV
January	I-II	II	II	II-III	III	IV	IV
February	II	II	II	II-III	III	IV	IV
March	II	II	II	II	II-III	III	IV
April	II	II	II	II-III	II-III	III	IV
May	II	II	II	II-III	II-III	III	IV
June	II	II	II	II-III	III	III-IV	IV
July	II	II	II-III	II-III	III-IV	III-IV	IV

Table 19: Monthly variation of saprobic water quality class of Manahara river in different stations using NEPBIOS extended

Months/stations	1	2	3	4	5	6	7
October	I-II	I-II	II-III	III	III	III	IV
November	I-II	I-II	II	II-III	II-III	III-IV	IV
December	I-II	I-II	II	II-III	II-III	III-IV	IV
January	I-II	I-II	II	II-III	III-IV	IV	IV
February	I-II	II	II	II-III	III-IV	IV	IV
March	II	II	II	II-III	III	III-IV	IV
April	II	II	II	II-III	III	III-IV	IV
May	II	I-II	II-III	II-III	III	III-IV	IV
June	II	II	II	II-III	III-IV	IV	IV
July	II	II	II-III	II-III	III-IV	IV	IV

Table 20: Monthly variation of saprobic water quality class of Manahara river in different stations using GRS index

Months/stations	1	2	3	4	5	6	7
October	I-II	I-II	II-III	III	III	III-IV	IV
November	I	I-II	II	III	III	III-IV	III
December	I	I-II	II	III	III	IV	IV
January	I	I-II	II	III	IV	IV	IV
February	I-II	I-II	II-III	III	IV	IV	IV
March	I-II	II	II	II-III	III-IV	III-IV	IV
April	II	II	II	II-III	III-IV	III-IV	IV
May	II	I-II	II	II-III	III-IV	III-IV	IV
June	I-II	II	II-III	III	III-IV	IV	IV
July	I-II	II	III	III	IV	IV	IV

The correlation analysis is done between Chemical water quality class (Bach water quality class and MPTPW water quality condition) and Saprobic water quality class (NEPBIOS Original, Extended NEPBIOS, NEPBIOS-BRS and GRS) including

monsoon samples (tables 21 and 22) as well as excluding monsoon samples (tables 23 and 24) which are tabulated below.

Table 21: Pearson correlation coefficient r between Index of chemical water quality classification and ASPT of saprobic water quality classification (with monsoon season)

n = 70

	NEPBIOS Original ASPT	NEPBIOS-BRS ASPT	Extended NEPBIOS ASPT	GRS/ASPT	Bach index
Bach index	0.841	0.849	0.836	0.891	1
MPTPW index	- 0.868	- 0.874	- 0.868	- 0.887	- 0.924

Note: All values are significant at 0.01 (2 tailed).

Table 22: Pearson correlation coefficient r between chemical water quality class and Saprobic water quality class (with monsoon season)

n = 70

	NEPBIOS Original	NEPBIOS-BRS	Extended NEPBIOS	GRS	Bach WQC
Bach WQC	0.789	0.789	0.860	0.889	1
MPTPW WQC	0.837	0.840	0.892	0.892	0.913

Note: All values are significant at 0.01 (2 tailed).

The table 21 shows that the correlation coefficient (r) between Bach water quality index and ASPT of NEPBIOS Original was 0.841 (significant, probability level = 0.01, two-tailed) and which is slightly improved between Bach water quality index and ASPT of NEPBIOS–BRS being 0.849 (significant, probability level = 0.01, two-tailed). Similarly, the correlation coefficient in between Bach water quality index and ASPT of Extended NEPBIOS is 0.836 (significant, probability level = 0.01, two-tailed). The correlation coefficient is increased between Bach water quality index and ASPT of GRS index (r = 0.891, significant, probability level = 0.01, two-tailed).

Similarly, the correlation coefficient between MPTPW water quality index and ASPT of original NEPBIOS was 0.868 (significant, probability level = 0.01, two-tailed) which was slightly increased in between MPTPW water quality index and ASPT of NEPBIOS-BRS being 0.874 (significant, probability level = 0.01, two-tailed). It is more or less similar to the correlation coefficient between MPTPW water quality index and ASPT of Extended NEPBIOS (r = 0.868, significant at probability level = 0.01, two-tailed). The correlation coefficient is increased in between MPTPW water quality index and ASPT of GRS index (r = 0.887, two-tailed, probability level = 0.01).

More or less, similar results are obtained in correlation analysis between chemical water quality class and saprobic water quality class (SWQC) as shown in table 22.

The correlation coefficient between Bach water quality class and saprobic water quality class using NEPBIOS original was 0.789 (significant, probability level = 0.01, two-tailed) which is equal to the correlation coefficient between Bach water quality class and saprobic water quality class using NEPBIOS-BRS (r = 0.789, significant, probability level = 0.01, two-tailed). The correlation coefficient was improved in between Bach water quality class and SWQC using Extended NEPBIOS (r = 0.860, significant, probability level = 0.01, two-tailed) and more improved in between Bach water quality class and SWQC using GRS index (r = 0.889, significant, probability level = 0.01, two-tailed).

Similarly, the correlation coefficient between water quality condition of MPTPW classification and SWQC using NEPBIOS original was 0.837 (significant, probability level = 0.01, two-tailed) which was slightly increased in between water quality condition of MPTPW classification and SWQC using NEPBIOS-BRS being 0.840 (significant, probability level = 0.01, two-tailed). The correlation coefficient was more improved in between water quality condition of MPTPW classification and SWQC using Extended NEPBIOS and also in between water quality condition of MPTPW classification and SWQC using GRS index both being equal with r = 0.892 (significant, probability level = 0.01, two-tailed).

The authors (developers) of the biological assessment methods of water quality assessment using macroinvertebrates recommend for not sampling the macroinvertebrates during or shortly after floods or rain. In this regards, the correlation analysis between Chemical water quality class (Bach water quality class and MPTPW water quality condition) and Saprobic water quality class (NEPBIOS Original, Extended NEPBIOS, NEPBIOS-BRS and GRS) by excluding the data of monsoon season are given in tables 23 and 24.

Table 23: Pearson correlation coefficient r between Index of chemical water quality classification and ASPT of saprobic water quality classification (excluding monsoon season)

n = 56

	NEPBIOS Original ASPT	NEPBIOS-BRS ASPT	Extended NEPBIOS ASPT	GRS/ASPT	Bach index
Bach index	0.837	0.855	0.836	0.891	1
MPTPW index	-0.913	-0.913	-0.894	-0.919	-0.926

Note: All values are significant at 0.01 (2 tailed).

Table 24: Pearson correlation coefficient r between chemical water quality class and Saprobic water quality class (excluding monsoon season)

n = 56

	NEPBIOS Original	NEPBIOS-BRS	Extended NEPBIOS	GRS	Bach WQC
Bach WQC	0.782	0.791	0.878	0.901	1
MPTPW WQC	0.837	0.862	0.923	0.918	0.921

Note: All values are significant at 0.01 (2 tailed).

When the data of monsoon season (June and July) are excluded, the result is more or less similar to that including data of monsoon. There is significantly high positive correlation between various chemical water quality classes and saprobic water quality classes by using macroinvetebrates. The correlation was more improved in newly developed GRS index and Extended NEPBIOS.

The regression analysis of various chemical water quality classes and saprobic water quality classes were done. The r^2 value (coefficient of determination) and the regression equation are shown in figures below. The figures 51 to 58 show the regression analysis between chemical water quality index and ASPT of SWQC using various methods.

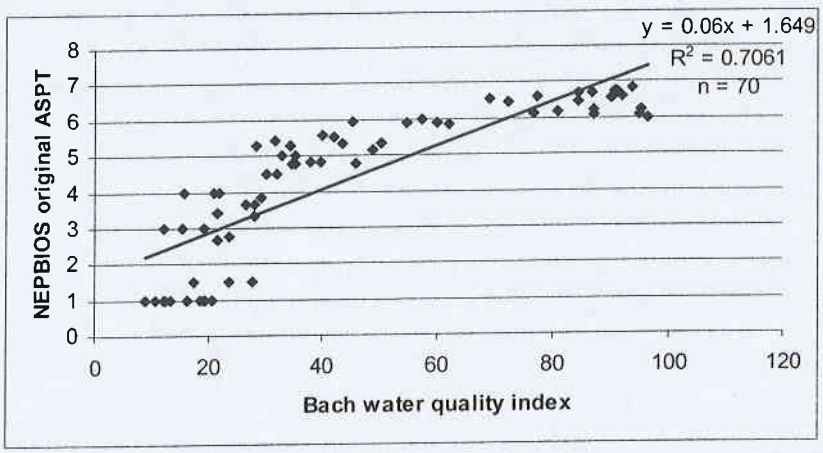


Figure 51: Regression analysis between Bach water quality index and NEPBIOS Original ASPT

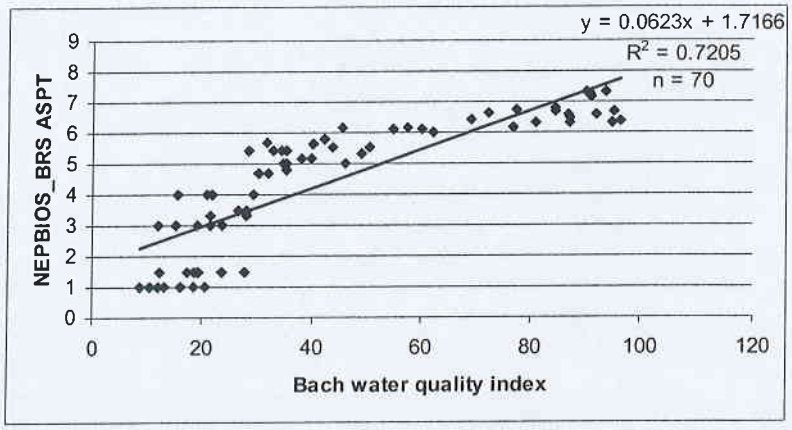


Figure 52: Regression analysis between Bach water quality index and NEPBIOS-BRS ASPT

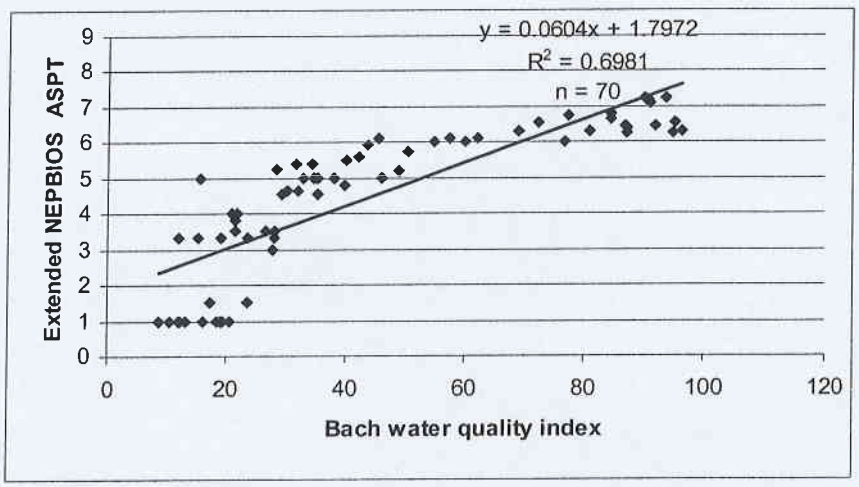


Figure 53: Regression analysis between Bach water quality index and Extended NEPBIOS ASPT

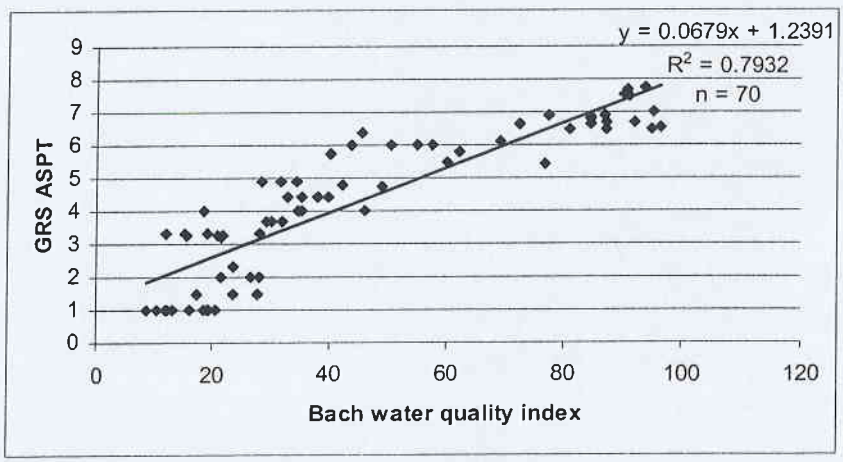


Figure 54: Regression analysis between Bach water quality index and GRS ASPT

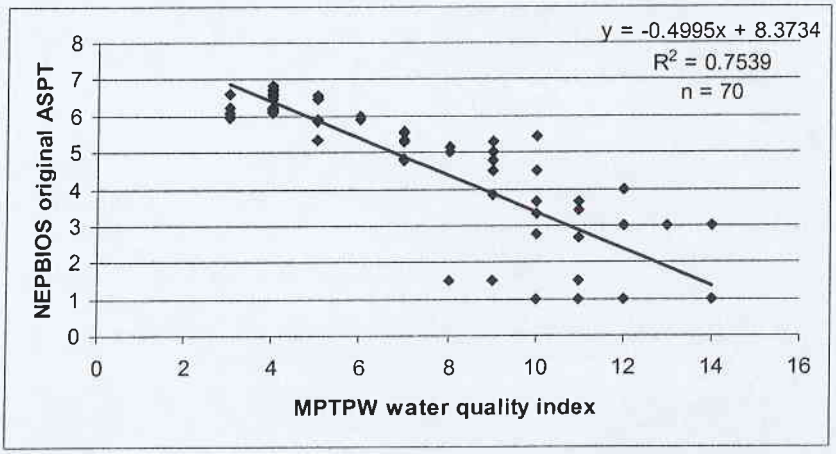


Figure 55: Regression analysis between MPTPW water quality index and NEPBIOS original ASPT

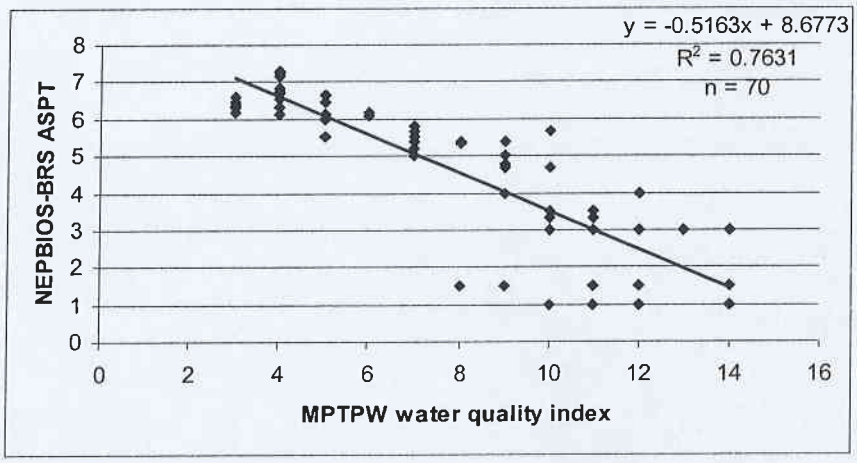


Figure 56: Regression analysis between MPTPW water quality index and NEPBIOS-BRS ASPT

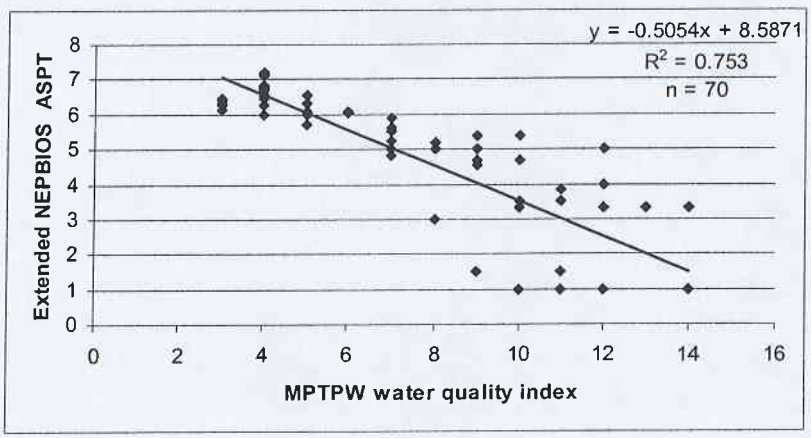


Figure 57: Regression analysis between MPTPW water quality index and Extended NEPBIOS ASPT

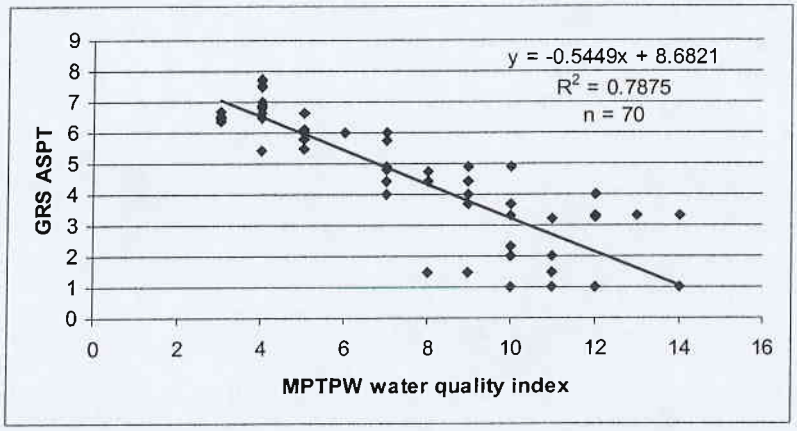


Figure 58: Regression analysis between MPTPW water quality index and GRS ASPT

These figures 51 to 58 also showed that the r^2 was improved for GRS index and Extended NEPBIOS. The r^2 value between Bach water quality index and ASPT of NEPBIOS original was 0.7061 which means the change in chemical water quality index is 71 % explained by the change in ASPT value given by NEPBIOS original. The r^2 value between Bach water quality index and ASPT of NEPBIOS-BRS was 0.7205 indicating that the change in chemical water quality index is 72 % explained by the change in ASPT value given by NEPBIOS-BRS. Similarly, the r^2 value was 0.7539 between MPTPW water quality index and ASPT of NEPBIOS original and that r^2 was 0.7631 for MPTPW water quality index and ASPT of NEPBIOS-BRS. The r^2 value is slightly increased when ASPT using NEPBIOS-BRS was applied with both chemical water quality indices (Bach index and MPTPW index). The r^2 value was more increased when GRS index was applied. The r^2 value between Bach water quality index and ASPT value of GRS index was 0.7932 and that between MPTPW index and ASPT value of GRS index was 07875. However, the r^2 value was less when NEPBIOS Extended was applied being 0.6981 between Bach water quality index and ASPT value of NEPBIOS Extended and 0.753 between MPTPW water quality index and NEPBIOS Extended. Thus, the change in chemical water quality index (Bach index) is 79 % explained by the change in ASPT value using GRS inded.

Similar result is obtained by regression analysis between chemical water quality class and saprobic water quality class which is shown in figures 59 to 66.

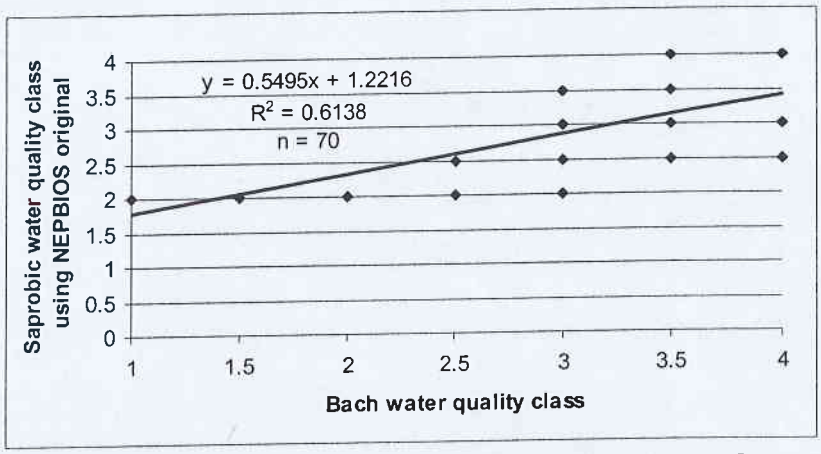


Figure 59: Regression analysis between Bach water quality class and saprobic water quality class using NEPBIOS original

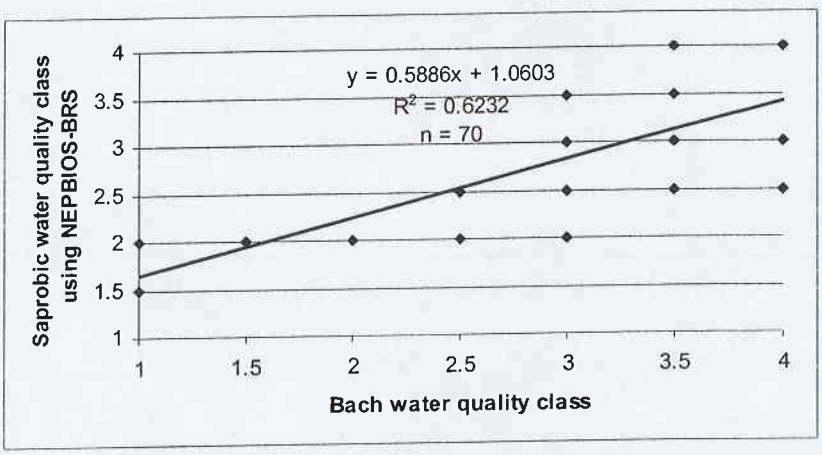


Figure 60: Regression analysis between Bach water quality class and saprobic water quality class using NEPBIOS-BRS

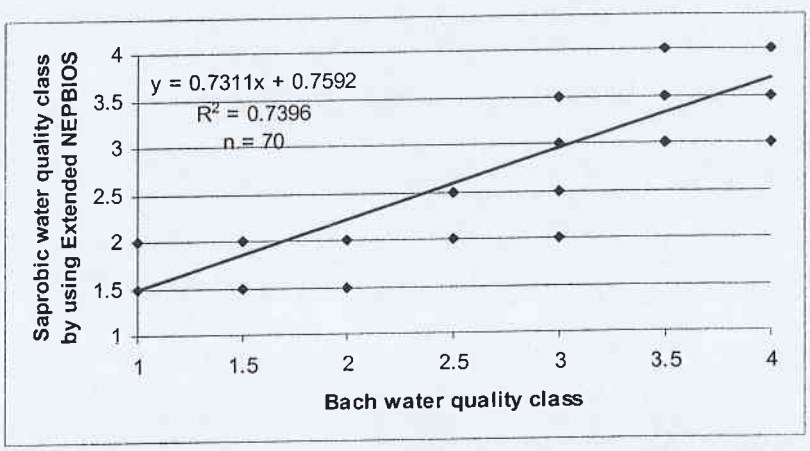


Figure 61: Regression analysis between Bach water quality class and saprobic water quality class using Extended NEPBIOS

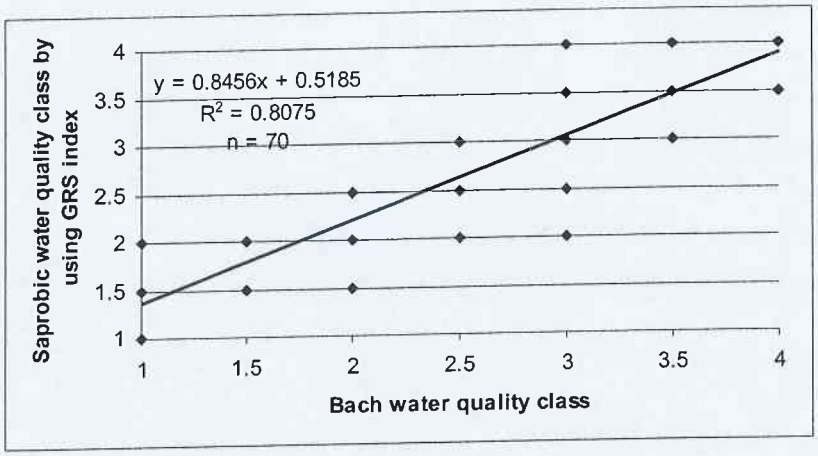


Figure 62: Regression analysis between Bach water quality class and saprobic water quality class using GRS index

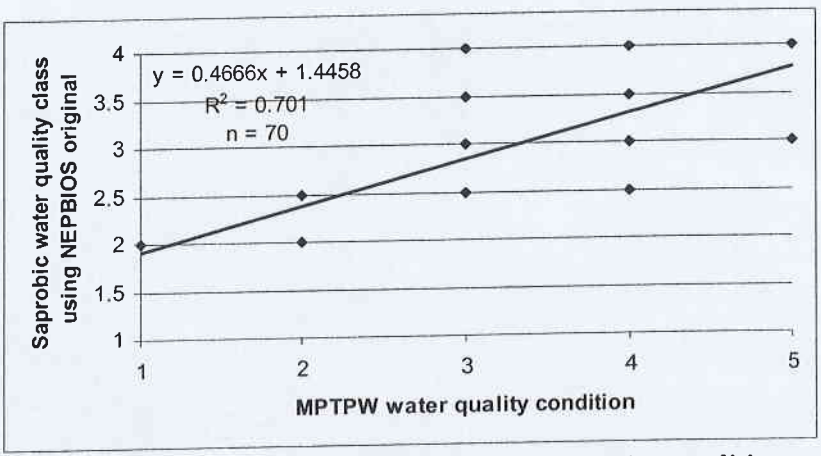


Figure 63: Regression analysis between MPTPW water quality condition and saprobic water quality class using NEPBIOS original

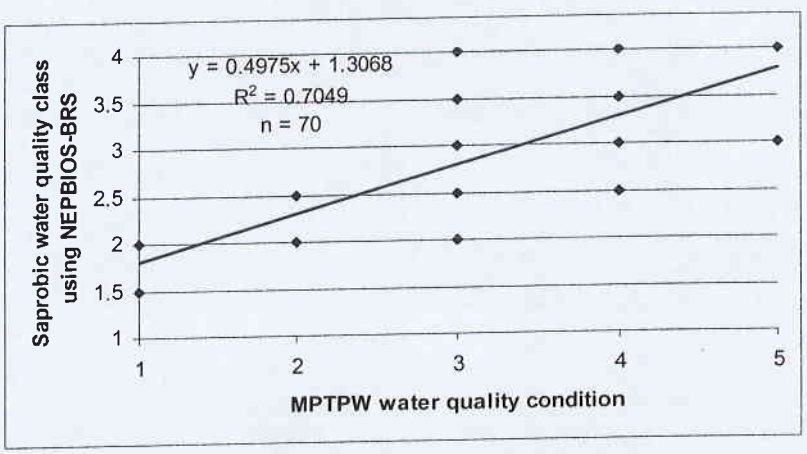


Figure 64: Regression analysis between MPTPW water quality condition and saprobic water quality class using NEPBIOS-BRS

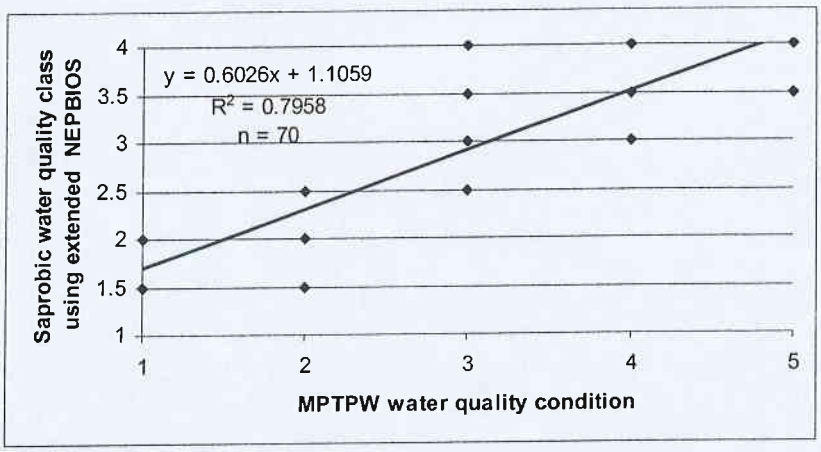


Figure 65: Regression analysis between MPTPW water quality condition and saprobic water quality class using Extended NEPBIOS

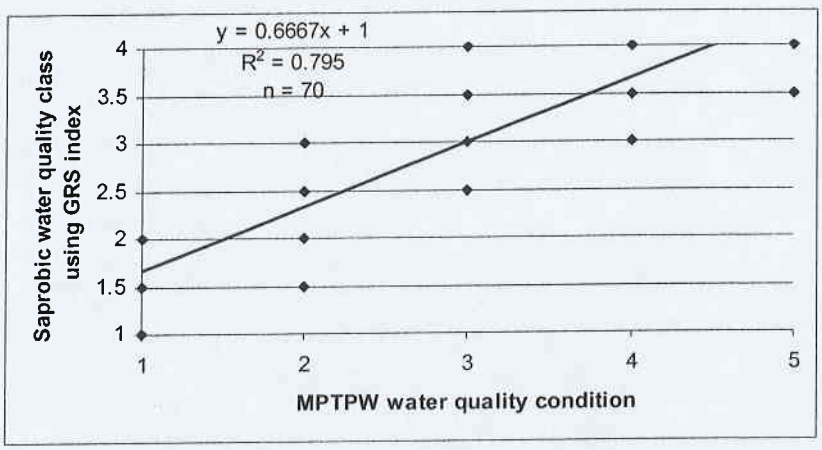


Figure 66: Regression analysis between MPTPW water quality condition and saprobic water quality class using GRS index

The r^2 value were 0.6138 and 0.6232 respectively between Bach water quality class and saprobic water quality class using NEPBIOS Original and that between Bach water quality class and saprobic water quality class using NEPBIOS-BRS. Similarly, the r^2 value were 0.701 and 0.7049 respectively between MPTPW water quality condition and saprobic water quality class (WQ class) using NEPBIOS original and that between MPTPW water quality condition and saprobic WQ class using NEPBIOS-BRS respectively. The precision value was increased when GRS and Extended NEPBIOS were applied. The r^2 value between Bach WQ class and saprobic WQ class using Extended NEPBIOS and that between Bach WQ class and saprobic WQ class using GRS were respectively 0.7396 and 0.8075. Similarly, the r^2 value

between MPTPW WQ condition and saprobic WQ class using Extended NEPBIOS and that between MPTPW WQ condition and saprobic WQ class using GRS were respectively 0.7958 and 0.7950. Thus, the change in chemical water quality class (Bach and MPTPW) is explained 80% or more by change in saprobic water quality class using GRS index. The r^2 value is more or less similar by including or excluding the monsoon data.

6.3.7 Water quality of different saprobic water quality classes of Manahara river

Based on the ten months of investigation with 210 number of water samples and 700 number of macroinvertebrates samples in the Manahara river from October 2005 to July 2006, the saprobic water quality class has following important physico-chemical features as shown in tables 25 and 26.

Table 25: Dissolved oxygen, BOD and free co_2 of different saprobic water quality classes of Manahara river

SWQC	DO			BOD			Free CO_2		
	$\bar{x}$	Min-Max	SD	$\bar{x}$	Min-Max	SD	$\bar{x}$	Min-Max	SD
I	8.92	8.25-9.59	0.67	1.53	1.13-1.92	0.40	7.69	7.47-8.04	0.31
I-II	8.28	6.7-9.59	0.95	2.15	1.2-3.82	0.82	9.46	6.16-13.35	2.40
II	7.52	6.2-8.92	0.93	5.51	1.8-10.49	3.25	10.06	6.89-13.87	2.41
II-III	6.86	6.99-9.12	1.20	13.30	6.78-18.36	4.98	12.24	9.29-14.11	1.66
III	7.19	5.57-8.67	1.17	15.90	10.1-22.04	3.86	13.12	6.13-18	3.75
III-IV	4.37	2.27-5.82	1.19	68.76	36.92-113.6	29.12	29.76	7.11-65.33	18.76
IV	4.02	0 - 6.85	1.88	90.77	24.78-167.25	44.18	41.28	9.24-107.45	29.75

Table 26: Nitrate, phosphate and ammonia of different saprobic water quality classes of Manahara river

SWQC	NO3			PO4			Ammonia		
	$\bar{x}$	Min-Max	SD	$\bar{x}$	Min-Max	SD	$\bar{x}$	Min-Max	SD
I	0.12	0.09-0.16	0.04	0.09	0.08-0.1	0.01	0.07	0.06-0.07	0.01
I-II	0.19	0.04-0.32	0.10	0.12	0.04-0.18	0.06	0.12	0.02-0.22	0.07
II	0.38	0.13-0.7	0.20	0.20	0.04-0.32	0.11	0.18	0.03-0.28	0.09
II-III	0.53	0.13-0.75	0.24	0.32	0.12-0.44	0.12	0.36	0.16-0.66	0.21
III	0.45	0.19-0.72	0.20	0.36	0.13-0.69	0.19	0.39	0.15-0.61	0.15
III-IV	1.40	0.26-3.02	0.84	1.57	0.2-3.25	0.88	1.56	0.42-3.25	1.04
IV	2.13	0.4-3.83	1.18	1.98	0.56-3.52	1.40	2.22	0.38-8.84	2.13

Table 27: Total alkalinity, hardness and chloride of different saprobic water quality classes of Manahara river

SWQC	Total alkalinity			Haardness			Chloride		
	$\bar{x}$	Min-Max	SD	$\bar{x}$	Min-Max	SD	$\bar{x}$	Min-Max	SD
I	23.94	18.83-30.5	5.97	23.94	18.83-30.5	5.97	23.94	18.83-30.5	5.97
I-II	29.11	22-38.67	7.59	29.11	22-38.67	7.59	29.11	22-38.67	7.59
II	33.73	25.74-45.83	6.26	33.73	25.74-45.83	6.26	33.73	25.74-45.83	6.26
II-III	42.92	24-42.915	16.25	42.92	24-42.915	16.25	42.92	24-42.915	16.25
III	42.72	24.83-66.61	15.01	25.95	19.67-33.79	4.14	10.97	9.01-14.09	1.51
III-IV	112.73	25.83-276	69.78	66.79	22.75-127.33	31.95	28.69	9.92-68.73	16.85
IV	173.73	59.83-379	94.28	92.62	38.89-150.55	33.84	36.80	12.45-78.48	19.03

The table 25 shows that the dissolved oxygen decreased gradually from saprobic water quality class I to IV whreas BOD and free carbondixide increased gradually from saprobic water quality class I to IV with very less overlapping chemical values between two consecutive classes. Similalry, the tables 26 and 27 showed that nitrate, phosphate, ammonia, total alkalinity, hardness and chloride gradually increased from saprobic water quality class I to IV.

6.4 Water quality map

The water quality class determined using the data of the entire investigation period is presented in the form of water quality map. The water quality map is prepared for Bach water quality class (chemical) which is shown in figure 67 as well as for Saprobic water quality class based on GRS index is shown in figure 68.

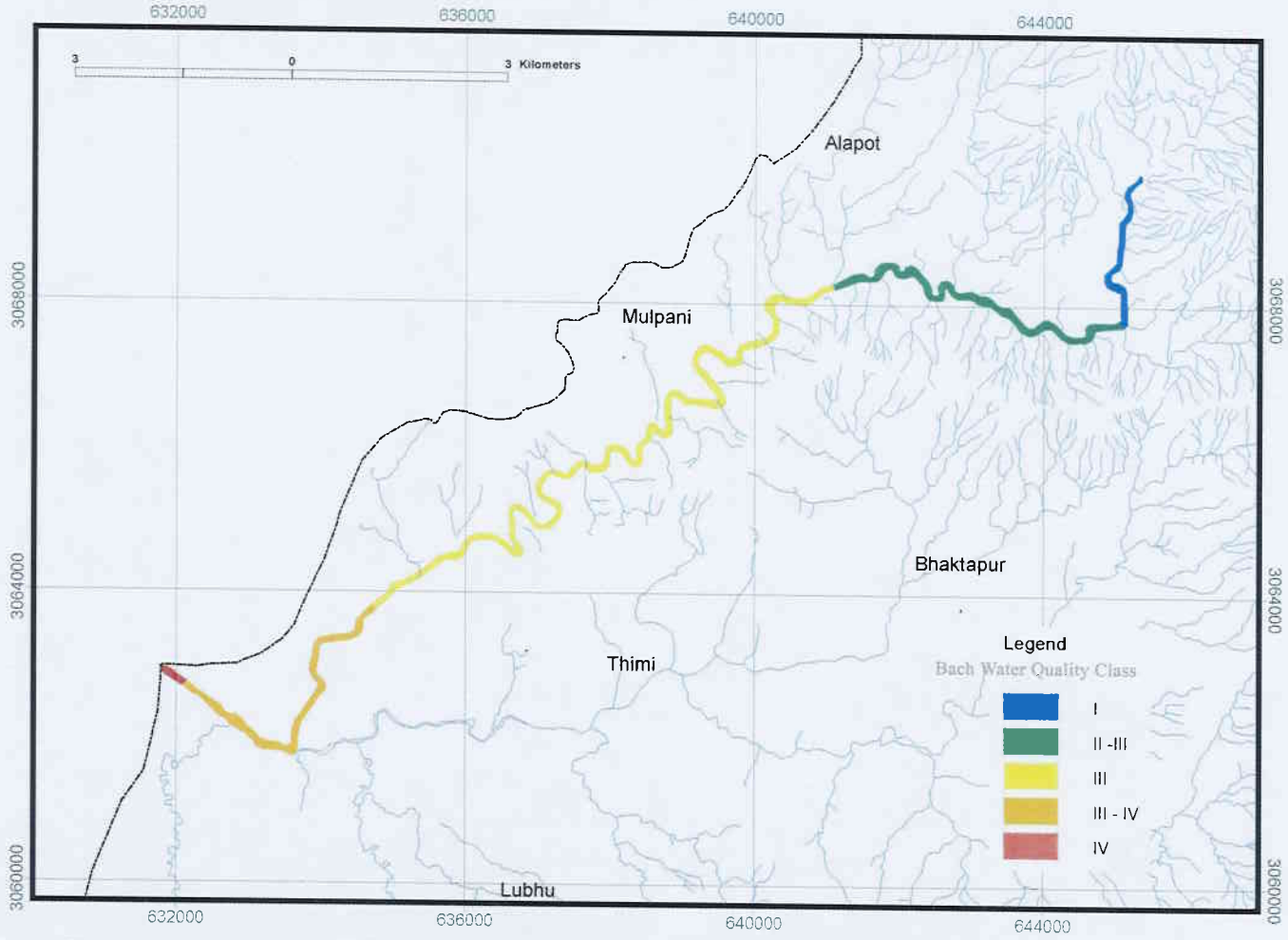


Figure ८: Water quality map of Manahara river of 2005/2006 using Bach Water Quality Index

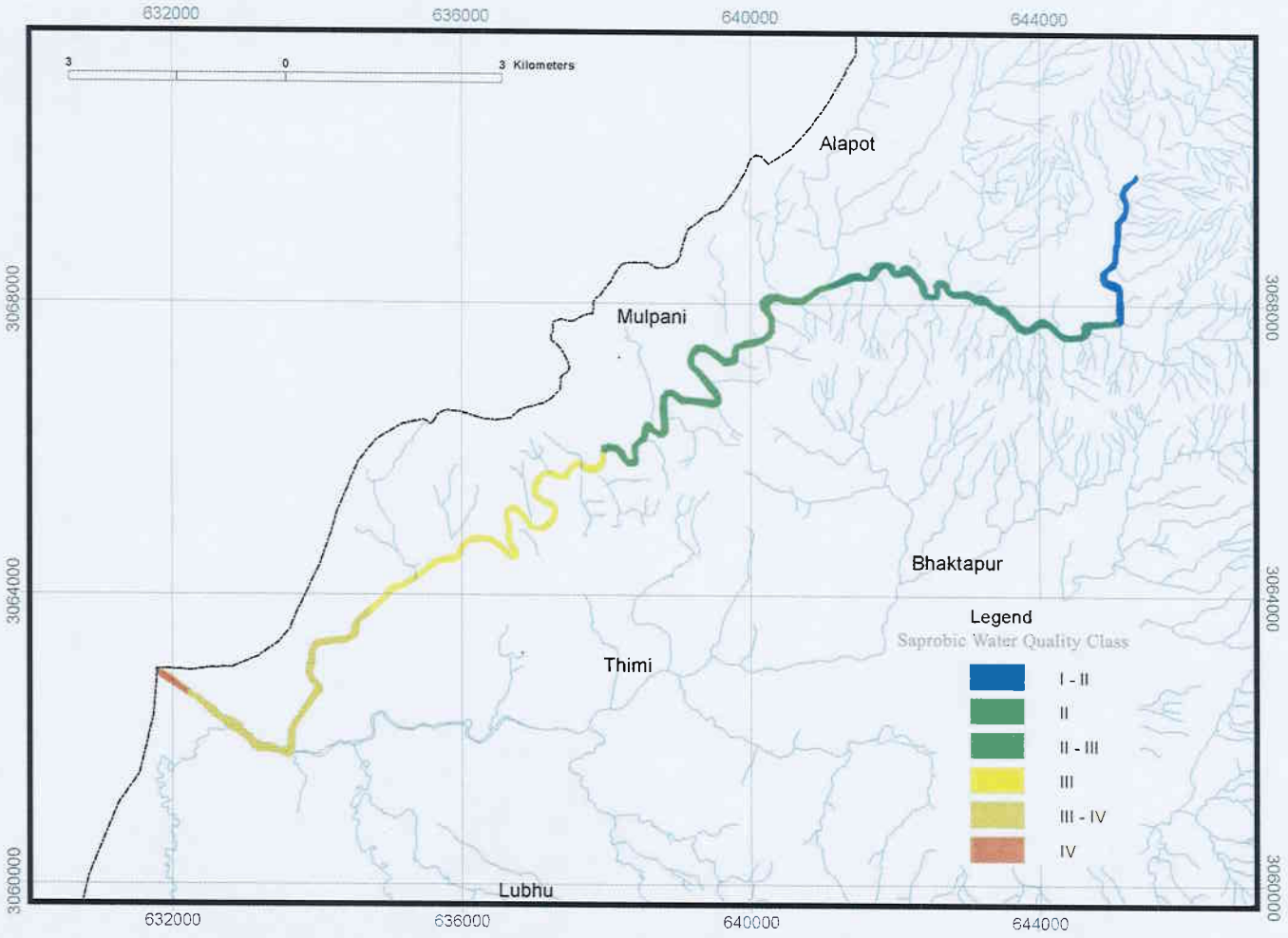


Figure 68: Water Quality map of Manahara River of 2005/2006 based on Saprobic Water Quality class using GRS index

6.5 Effluent quality

There were many sewage (effluent) outfall points observed in the Manahara river as shown in figure 69. Among them quality of two effluent outfalls were studied.

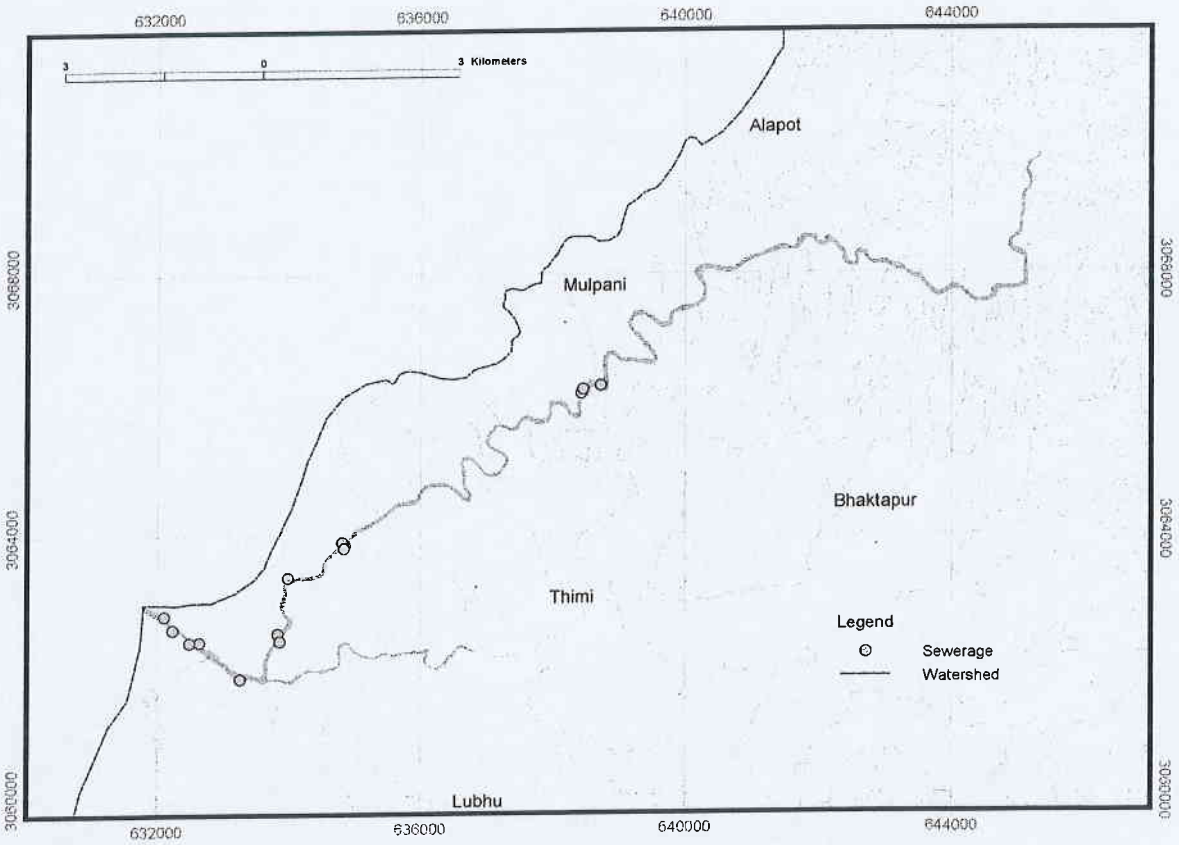


Figure 69: Sewage outfall points observed to the Manahara river

The characteristics of effluents one at the right bank ot the river at about 10 metres upstream of Sanothimi-Sinamangal bridge which contained the industrial effluent from Varun Beverages Private limited and domestic wastewater discharged by the nearby community and another sewage outfall at the right bank at about 5 metres downstream of Seti Opi Marg – Chyasal suspension bridge, containing sewage from settlements were analyzed. The effluent quality is shown in table 28 in compared to the National effluent standards.

Table 28: Quality of two effluents discharges into the Manahara River

Parameters	Industrial effluent		Sewage outfall		Effluent standard for industrial effluent entering into rivers #
	A*	B*	C*	D*	
Temperature(°c)	15.0	16.0	18.0	18.5	<40
pH	7.2	7.1	7.2	6.1	5.5-9
Free CO2(mg/L)	8.4	114.4	35.0	112.0	-
DO(mg/L)	6.8	0.4	4.8	0.6	-
BOD(mg/L)	65.0	240.0	58.0	196.0	30-100
COD(mg/L)	180.0	674.0			250
Conductivity(µs/cm)	110.0	2824	426.0	1562	-
TDS(mg/L)	72.0	1836.0	277.0	1015.0	-
TSS(mg/L)	2.8	746	4.2	634.0	30-200
Hardness (mg/Las aCO_3)	38.2	122.0	-	-	-
Tot.alkalinity(as $CaCO_3$)	61.6	342.0	-	-	-
Ca(mg/L)	8.2	21.2	-	-	-
Mg(mg/L)	4.31	16.79	-	-	-
Cl (mg/L)	11.2	172.0	42.0	172.0	-
N-NO_3(mg/L)	1.2	3.8	2.4	4.32	-
P-PO_4(mg/L)	0.9	5.2	2.5	3.94	-
N-NH_3(mg/L)	0.82	10.2	-	-	50

* Note: A: River at 1 metre upstream of point of industrial effluent discharge
B: Point of industrial effluent discharge D: Point of sewage outfall
C: River at 2 metres upstream of sewage outfall point

Source: Upreti, 2003

The industrial effluent at Sinamangal into Manahara river had high chemical concentration and organic load with respective to the water of the river just 1 metre upstream of the effluent outfall point. The temperature and pH of the industrial effluent were 16° C and 7.1 respectively whereas that of the river water just 1 metre upstream was 15 °C and 7.2 respectively. Similarly, the free CO_2 was 144.4 mg/L and dissolved oxygen was 0.4 mg/L for the industrial effluent whereas that for the river water, free CO_2 was 8.4 mg/L and dissolved oxygen was 6.8 mg/L. The BOD_5 and COD were 240.0 mg/L and 674.0 mg/L respectively for the effluent whereas that for the river water, BOD_5 was 65.0 mg/L and COD was 180.0 mg/L. Similarly, the electrical conductivity was 2824 µS/cm in the effluent and 110µS/cm in the river

water; the TDS was 1836 mg/L in the effluent and 72 mg/L in the river water and TSS was 746 mg/L in the effluent and 2.8 mg/L in the river water.

The industrial effluent had the hardness of 122 mg/L as $CaCO_3$ and total alkalinity/bicarbonate alkalinity of 342.0 mg/L as $CaCO_3$ whereas the river water had the hardness of 38.2 mg/L as $CaCO_3$ and total alkalinity/ bicarbonate alkalinity of 61.6 mg/L as $CaCO_3$. The calcium and magnesium concentration was 21.2mg/L and 16.79 mg/L respectively in the effluent whereas the river water had calcium concentration of 8.2 mg/L and magnesium concentration of 4.31mg/L. The chloride content was 172.0 mg/L, nitrate-nitrogen content was 3.8 mg/L, ortho-phosphate concentration was 5.4 mg/L and ammoniacal-nitrogen was 10.2 mg/L in the industrial effluent whereas in the river water, chloride content was 11.2 mg/L, nitrate-nitrogen content was 1.2 mg/L, ortho-phosphate concentration was 0.9 mg/L and ammoniacal-nitrogen was 0.82 mg/L.

Similarly, the concentration of chemicals and organic load was also high in the sewage outfall at Seti-Opi Marg. The temperature and pH of the sewage was 18.5 °C and 6.1 respectively whereas the temperature was 18 °C and pH was 7.2 in the river water just 2 metres upstream from the sewage outfall. Sewage had electrical conductivity of 1562 µS/cm, TDS of 1015 mg/L, TSS of 634 mg/L and free CO_2 content of 112 mg/L whereas for the river water at just 2 metres upstream, the electrical conductivity was 426 µS/cm, TDS was 277 mg/L, TSS was 4.2 mg/L and free CO_2 was 35 mg/L. The dissolved oxygen content was 0.6 mg/L and BOD_5 content was 196 mg/L in the sewage whereas dissolved oxygen content was 4.8 mg/L and BOD_5 was 58.0 mg/L in the river water. The sewage had the chloride content of 170.0 mg/L, nitrate-nitrogen of 4.32 mg/L and ortho-phosphate of 3.94 mg/L whereas the river water had chloride of 42.0 mg/L, nitrate-nitrogen of 2.4 mg/L and ortho-phosphate of 2.5 mg/L.

6.6 Wastewater generation and existing treatment facilities

The wastewater is produced by the households as well as by the industries. A total of 14.4 million litres/day is generated from the urban region of the Manahara watershed (CBS, 2001; NWSC, 2001; ICIMOD, 2007) which is presented in the table 29.

Table 29: Wastewater generation in urban region of the Manahara watershed, 2001

Municipality	Wastewater generation (MLD)
Bhaktapur	3.7
Madhyapur Thimi	2.4
Lalitpur	8.3
Total	**14.4**

(Source: CBS, 2001; NWSC, 2001; ICIMOD, 2007)

For the control or reducing water pollution, limited infrastructures are constructed in the Manahara watershed. These infrastructures are both wastewater treatment plants and ECOSAN toilets. Wastewater treatment plant removes or reduces pollutants below the acceptable limit whereas ECOSAN toilet prevents generation of wastewater during defecation and urination. Such toilet converts faeces into humus anaerobically within 6 months and the collected urine in the urine tank is used in the kitchen garden and also for composting. This type of toilet is also called by Composting toilet, Dehydrating toilet or Zero discharge toilet. The status of wastewater treatment plants in the watershed are shown in table 30 and its location is presented in figure 69.

Table 30: Existing wastewater treatment plants in the Manahara watershed

WWTP	Location, District	Operation year	Treatment type	Capacity (MLD)	Area/ Population served	Ownership	Current status
1.Hanumanghat WWTP	Hanumanghat, Bhaktapur	1975	Oxidation pond	0.5	South-eastern part of Bhaktapur city	Govt	Not operational
2.Sallaghari WWTP	Sallaghari, Bhaktapur	1983	Aerated lagoon	2	Eastern, western, northern part of Bhaktapur city	Govt	Not operational
3.Kodku WWTP	Kodku, Lalitpur	1981	Stabilization pond	1.1	15,500 HH of eastern part of Patan	Govt	Partially operational
4. Sunga Community WWTP	Thimi, Bhaktapur	2005	Reed Bed	0.05	1200 persons	Community	Operational
5. SKMPRSH* CW	Sakhu, Ktm.	2000	Reed Bed	0.01	Hospital complex	Private	Operational
Total				**3.66**			
Total Operational				**1.16**			

(Source: Shrestha, 2001; ENPHO, 2006 and Field visit)

*SKMPRSH= Susma Koirala Memorial Plastic and Reconstructive Surgery Hospital

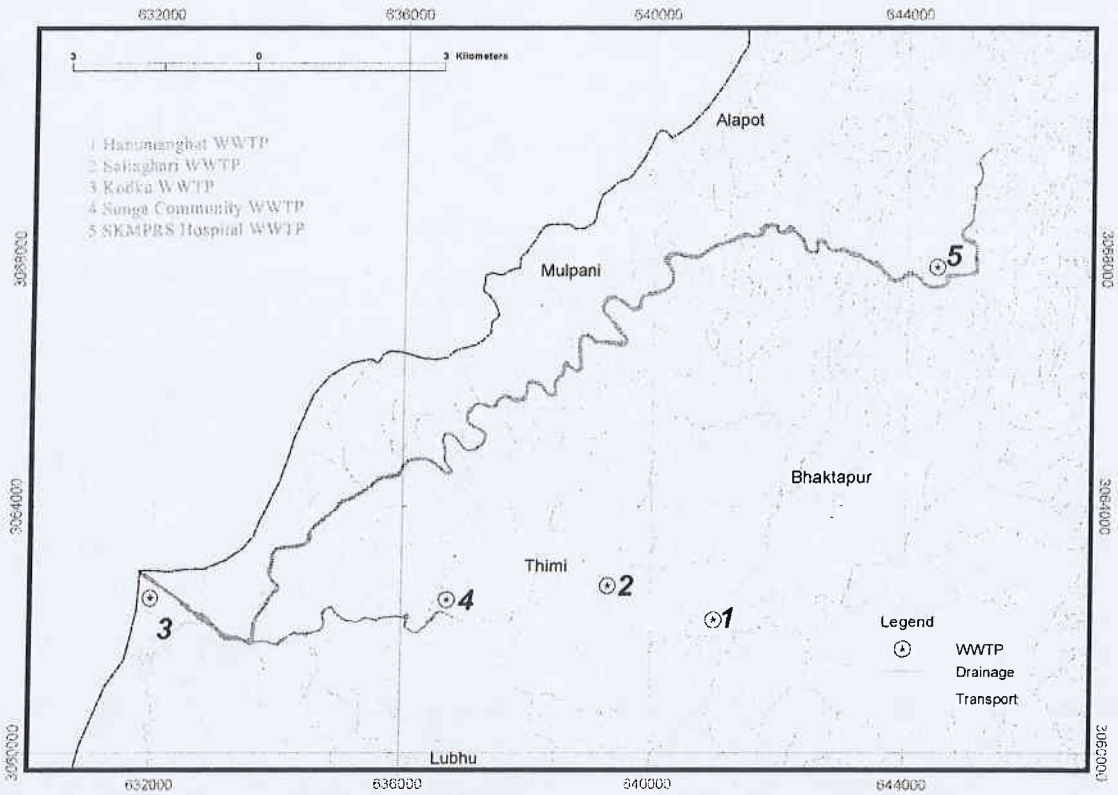


Figure 70: Location of wastewater treatment plants in the Manahara watershed

Similarly, altogether there are 221 ECOSAN units in the Manahara watershed. In Lalitpur disctrict of the watershed, 162 ECOSAN units are in operation. There are 93 ECOSAN units in Siddhipur VDC, 6 units in Lubhu VDC, 13 units in Imadol VDC and 50 units in Thecho VDC of Lalitpur district. Similarly, there were 59 ECOSAN units in different VDCs and municipality of Bhaktpur district. There were 49 units in Madhyapur Thimi municipality and 10 units in Duwakot VDC of Bhaktapur district. (Source: Compiled from LUMANTI, DNET, NEWAH, ENPHO and CIUD in 2006).

Therefore out of 14.4 MLD of wastewater generation, only 1.16 MLD i.e. about 8 % is being treated and the remaining is discharged directly or indirectly into the Manahara river.

6.7 Existing legislation for control of water pollution

In Nepal, various water and environment related legislations are existing that address the deteriorating water quality and conservation of water resources. They are explained below by mentioning their provisions in chronological order.

6.7.1 Aquatic Animals Protection Act 1961

The Aquatic Animals Protection Act 1961 (with 1999 first ammendation) requires the preservation of aquatic life and wetlands. The Act establishes punishment to persons using explosives in or poisoning any water source with the intention of catching or killing aquatic life. The Act also empowers the Government to prohibit catching, killing and harming certain aquatic species.

6.7.2 Solid Waste (Management and Resource Mobilization) Act 1987

Solid Waste (Management and Resource Mobilization) Act 1987 contains provisions which control the adverse impact on the environment caused by solid waste pollution. It establishes the Solid Waste Management and Resource Mobilization Centre (SWMRMC) as the body responsible for the collection, transportation and disposal of municipal solid waste in safe and environmental friendly manner. In case of the air, soil or water pollution resulting from solid wastes affects, or is likely to adversely affect, human beings, birds, animals, plants and other living creatures in any area or public place or any inhabited area, the SWMRMC may make necessary arrangements for the eradication of such pollution. The act allows no one to throw, keep or dump solid, liquid or gaseous wastes in any public places other than in pots, containers or any prescribed places and it may fine a maximum of NRs 5000 for undertaking water and environment polluting activities due to wastes.

6.7.3 Nepal Water Supply Corporation Act 1989

Nepal Water Supply Corporation Act 1989 prohibits the pollution of drinking water and also creates a duty in the Nepal Water Supply Corporation to control the pollution of drinking water. It further provides a penalty of up to NRs.10000 for the pollution of drinking water.

6.7.4 Water Resources Act 1992

Water Resources Act 1992 is the umbrella legislation governing the water resource management. It declares the order of priority of water use and vests the ownership of the entire water resources in the State. It provides the system of licensing and prohibits water pollution. Under this Act three separate regulations namely Water Resource Regulation 1993, Drinking Water Regulation 1998 and Irrigation

Regulation 2000 have been promulgated. The Water Resources Act 1992 allows no one to pollute water resources by placing litter, industrial waste, poisons, chemicals or other toxicants to the effect that it exceeds the pollution tolerance limit. The pollution tolerance limit for water resources shall be prescribed by GoN. It further provides that, while utilizing water resources, the user must ensure that there is no substantial adverse effect on the environment such as soil erosion, flood, landslide or other effect. This act also provides that any body who pollutes water resources shall be fined up to NRs.5000 and must pay compensation for the damage due to pollution if it is caused to anybody.

6.7.5 Electricity Act 1992

Electricity Act 1992 prohibits any substantial adverse effect on environment by way of soil erosion, flood, landslide, air pollution etc. while generating, transmitting or distributing electricity.

6.7.6 Industrial Enterprises Act 1992

Industrial Enterprises Act 1992 requires that certain industries that may cause a significant adverse impact on the security, public health and environment, are required to obtain permission for their establishment, extension and diversification such as cigarette, beer and alcohol production etc. It also provides that a reduction of up to 50% from the taxable income will be granted for an industry that invests on process or equipment which has the objective of controlling pollution or which may have a minimum effect on the environment.

6. 6.7 Water Resources Regulation 1993

Water Resources Regulation 1993 promulgated under Water Resources Act 1992 requires an Environment Impact Assessment (EIA) report to be submitted with the application for obtaining a license for the utilization of water resources. Thus, it requires to preserve water resources and aquatic species.

6.7.8 Electricity Regulation 1993

Electricity Regulation 1993 promulgated under Electricity Act 1992 requires an Environmental Impact Assessment (EIA) to be submitted with the application for a license for utilization of water resource for hydropower generation.

6.7.9 Environment Protection Act (EPA) 1997

Environment Protection Act 1997 is an umbrella act for all kinds of pollution control. It contains provisions relating to the control of pollution and environmental standards. It allows no body to create pollution in such a manner as to cause significant adverse impacts on the environment or likely to be hazardous to public life and people's health contrary to the prescribed standards. If it appears that anyone has carried out any act contrary to above mentioned activities and caused significant adverse impacts on the environment, the concerned agency may prescribe necessary terms in regard thereto or may prohibit the carrying out of such an act.

EPA 1997 requires that a proponent of a proposed development project must conduct IEE/EIA study to ascertain as to whether, in implementing a proposal, the proposal does have significant adverse impacts on the environment or not, whether such impacts could be avoided or mitigated by any means or not. This provides an important mechanism for the prevention and control of pollution.

There is a unique feature of provisions for compensation and penalty. In case, in consequence of the creation or disposal of pollution, sound, heat or wastes by anybody contrary to this Act or Rules, any person or organization happens to suffer any loss or damage, the affected person or organization may have compensation recovered from the person or institution or proponent doing such act through the submission of an application to prescribed authority (CDO of concerned district) and after such damage is proved to be done by the body as mentioned in the application. Similarly, if any person or organization does any activities against this act or its rules, he shall be punished according to the degree of the offence with a fine up to NRs.50,000 (except in EIA/IEE related activities where the fine is up to NRs. 100,000).

This act provides Environmental Inspector in order to effectively carry out or cause to be carried out the acts of the mitigation, avoidance or control of pollution or the acts required to be carried out in accordance with the IEE or EIA report.

6.7.10 Environment Protection Regulation (EPR) 1997

Environment Protection Regulation 1997 framed under Environment Protection Act 1997 also allows no person to emit, or cause the emission of noise, heat, radio-active

material and waste from any mechanical means, industrial establishment or any other place in contravention of the prescribed standards set by the MoEST by notice published in the Nepal Gazette. It requires certain industries to obtain a Pollution Control Certificate which is of two types, Provisional Certificate and Permanent Certificate. All industries as listed in Schedule 7 of the EPR 1997 are required to obtain Provisional Pollution Control Certificate which is valid for one year. Similarly, EPR provides that a Permanent Pollution Control Certificate is required in cases where the standards of sound, heat, nuclear radiation and waste disposal for any industry have been prescribed by notice published in the Nepal Gazette which is valid for three years.

6.7.11 Drinking Water Regulation 1998

Drinking Water Regulation 1998 promulgated under Water Resources Act 1992 prohibits a drinking water supplier from doing any work or constructing any structure which will pollute the source of the water resource or have a substantial adverse impact on the environment. Similarly, it imposes a duty on a water supplier to maintain a determined quality of water supplied.

6.7.12 Local Self Governance Act 1999

Local Self Governance Act 1999 establishes environment protection and water resource conservation (including the preservation of water sources as an important duty of local bodies (VDCs, Municipalities and DDCs). Particularly, it allows local bodies to impose a fine up to NRs.15000 for the dumping of solid waste in a water body (other than in a designated place) plus expenses incurred in removing the wastes.

6.7.13 Irrigation Regulation 2000

Irrigation Regulation 2000 promulgated under Water Resources Act 1992 prohibits all people including irrigation service users from the pollution of water resource in the irrigation structure in addition to the protection measures of the irrigation structure.

CHAPTER SEVEN

7. DISCUSSION

7.1 Physico-chemical features

The depth, velocity and discharge of a river are interrelated and the discharge is directly proportional to depth, velocity and width (Whitton, 1975). The stream water velocity is a function of the slope of the channel, "roughness" of the bed and banks and the hydralulic radius (cross sectional area divided by wetted perimeter) (Manning's formuala as cited by Whitton, 1975). The decrease in mean depth of the river water gradually from post-monsoon season (October) to late winter season (February) or early pre-monsoon (March) season may be related to the precipitation which didn't occur in the watershed from November 2005 to February 2006 as shown in figure 7. The increase in the mean depth of river water during monsoon season (June/July) indicates the relationship with the occurrence of precipitation in the watershed which occurred in March, April May, June and July in the watershed as shown in figure 7. This seasonal variation of precipitation observed in 2005/2006 (figure 7) may be the cause of minimum level of mean depth in February/March and maximum level of mean depth in June/July. Such seasonal variation of mean depth of river water in different seasons (months) is significant probably because of high seasonal fluctuations in the precipitation as it is the major source of water for the spring fed river like Mahanara. Similarly, the seasonal variation of velocity and discharge of the river is also significant. In addition, the minimum level of velocity and discharge recorded in February/March and their maximum level recorded in June/July may also be related to the seasonal fluctuation of precipation with no precipitaton in November 2005 to February 2006 and high precipitation in June/July 2006 (figure 7).

The spatial variations of mean depth and discharge at different stations along the river stretch was found significant at 0.05 probability level and not significant at 0.01 probability level. Compared to the downstream region of the river, the mean depth was minimum in upstream region and maximum in downstream (station 7) in late pre-monsoon season (May), monsoon season (June and July) and post-monsoon season (October, November) probably because as the water flows to downstream, more and

more tributaries contribute water volume to the river and in these months high water is available in agricultural fields due to which water abstraction for irrigation was less or negligible and didn't affect the water volume in the river. However the mean depth, discharge and velocity fluctuated from upstream to downstream in winter and early and mid pre-monsoon (March and April) mostly because these are dry seasons during which high abstraction of water from the river for irrigation and also for city supply through the dug wells at the banks (below station 4 at Bode and above station 6 at Lokanthali) may cause so. The river section below station 4 i.e. downstream of location of dug wells of NWSC for city supply was completely dry for about 500 metres in the month of February/March 2006. In addition, the river velocity was also affected by the gradient of the river. Probably due to these factors, the spatial variation of mean depth and discharge at different stations along the river stretch is not significant at 0.01 and significant at 0.05 probability level as well as the spatial variation of velocity from stations 1 to 7 in not significant. As per the classification of rivers by UNESCO, 1996 (table 1), the Manahara river falls in "small streams" with respect to discharge. However, with respect to drainage area (256 sq. Km), stream order (6^{th} order) and river width, the Manahara falls in "streams" category.

The river water at stations 1, 2,3 and 4 was transparent during the entire investigation period probably because these stations had the least human disturbance such as this stretch has no to less sewage outfalls in the river as shown in the sewage map in figure 69. In these waters, light penetrate up to the river bed providing light and heat to the substrate and biota. But, the variable Secchi disc transparency was observed at station 5 during the present investigation period. Based on classification of water bodies of the Asian Wetland Inventory (AWI) Manual (not dated), the water was transparent from November to March whereas it was "very turbid" (since within 5cm - 25cm) in April to July (pre-monsoon and monsoon season) and "turbid" (since within 25 cm – 250 cm) in October (post-monsoon season) at station 5. At stations 5, 6 and 7, the minimum level of Secchi disc transparency value was observed in May during the present study period probably because it was the most polluted month as indicated by Bach water quality class and MPTPW water quality condition (tables 14 and 15 respectively). The water at stations 6 and 7 was never transparent, i.e. river-bed was never seen through the water during the present investigation period. It may be because of high suspended load and dark colour of river water as they were the

most polluted stations as indicated by Bach water quality class and MPTPW water quality condition (tables 14 and 15 respectively). The water of the river at stations 6 and 7 occured in "very turbid" category except in November at stations 6 and 7 and in October at station 6 based AWI manual as the Secchi disc transparencies were within 5 cm-25 cm at these stations. Similarly, the river water in November at station 6 and 7 and in October at station 6 falls in "turbid category" as the Secchi disc transparencies were within 25 cm - 250 cm. The Secchi disc transparency was decreased from stations 6 to 7 in different months of investigation period except in March. It was probably because the station 7 was more polluted than station 6 due to more sewage discharge as shown by sewage outfall points in figure 69.

Temperature is considered as a very important factor in stream ecology (Hynes, 1979). The temperature is basically important for its effect on the chemistry and biological reactions in the organisms in waters. A rise in temperature of the water leads to the speeding up of the chemical reactions in water, reduces the solubility of gases and amplifies the tastes and odours (Trivedi and Goel, 1986). The temperature of surface water of the Manahara river was observed with low in winter season (December/ January) i.e. 8.5 °C to 10.5 °C and high in summer (July) i.e. 21.5 °C to 28.5 °C which followed more or less the fluctuation trend of air temperature as shown in figures 71 and 72. It may be so because the major factor in the warming of stream water is direct solar radiation and the water temperature varies with the season in temperate climates (Hynes, 1979).

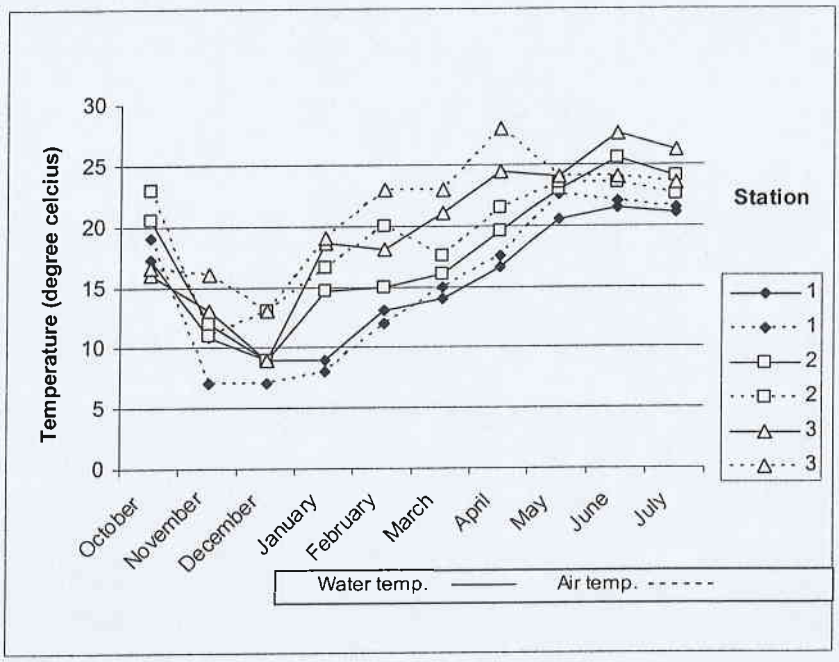


Figure 71: Fluctuation trend of water and air temperature from stations 1 to 3 in Manahara river

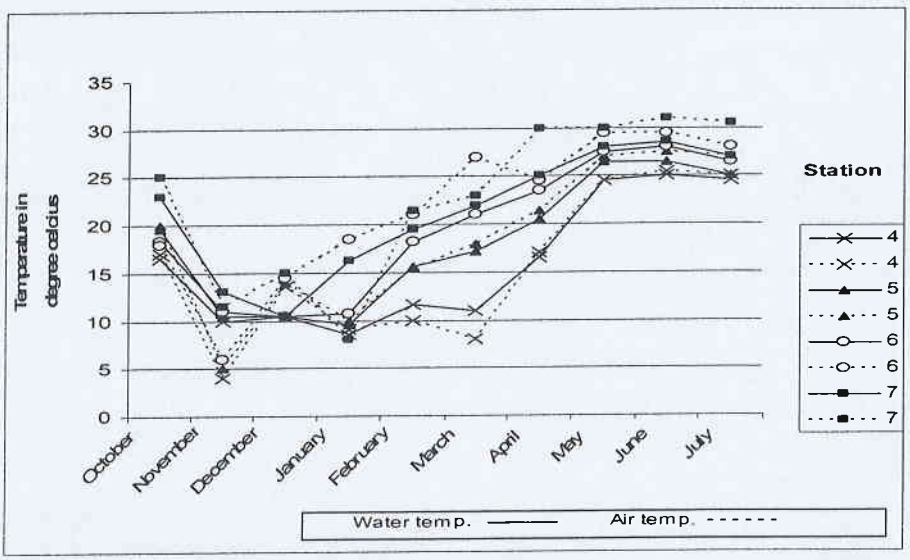


Figure 72: Fluctuation trend of Water and Air temperature from stations 4 to 7 in Manahara river

Several scholars such as Mosley, 1982; Towns, 1979, Ward, 1985 and Yadav, 1989 have indicated that there is close relationship between surface water temperature and air temperature. Such temperature variation of the river water in different months of the investigation period is significant probably because Manahara watershed has

temperate climate where there is high fluctuation in seasonal air temperature that in turn fluctuates the surface water temperature.

Similarly, the diurnal variation of water temperature also followed more or less the fluctuation pattern of air temperature. The water temperature and air temperature was equal at 7:00 am at the diurnal observation station 4 as shown in figure 43. Both of them gradually increased due to warming by solar radiation but the rate of increase of air temperature was higher than that of water probably because specific heat capacity of air is lower than that of water (Shrestha, 1995). Both of them decreased after 12:00 noon but the rate of decrease of air temperature was higher than that of water temperature probably because of lower specific heat capacity of air than water as mentioned above.

The spatial variation of temperature of surface water along the river also followed more or less the fluctuation trend of air temperature which is determined by the time of a day. The temperature is lower at station 1 and station 4 (except in May) because sampling was done early in the morning (6:00 to 9:00 am) at these stations and the water temperature was higher at station 7 (except in November and December) because sampling was done usually in noon or afternoon at this station. While in December, sampling was done at the same time (9:00 am) in all the stations. The temperature gradually decreased from headwaters i.e. station 1 (9.0 °C) to station 7 (10.5 °C) in December (winter). It is reverse to Hynes, 1979 which states that the headwaters are relatively cool in spring-fed streams in summertime and may be warm in winter. It may be because the source of the Manahara river is Manichud pond, not the deep underground water as explained by Hynes, 1979. The amplitude of variation of diurnal temperature at station 4 was 7.17 °C ranging 17.5 °C at 7:00 a.m. to 24.67 °C at 12:00 noon. This may be because of solar radiation that also changed the air temperature from 17.5 °C to 26 °C on that day. The diurnal variation of water temperature is slightly higher than 6 °C although Hynes, 1979 mentioned 6 °C as the probable variation of diurnal temperature in streams in summertime. It may be because of intense sunlight which can be predicted from high air temperature of 26.0 °C at the time of highest water temperature (as shown in figure 43).

Dissolved oxygen is considered as one of the most important parameters in water quality assessment and reflects the physical and biological process prevailing in the waters. Its presence is essential to maintain the higher forms of biological life in the water (Trivedi and Goel, 1986) whereas Biochemical Oxygen Demand (BOD) is an empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirement in wastewaters, effluents and polluted waters during a specified incubation period (5 days) for the biochemical degradation of organic materials (carbonaceous compound) and the oxygen used to oxidize inorganic material such as sulfides and ferrous ions (APHA,1995). The dissolved oxygen in general increased from post-monsoon season to winter (except at stations 5, 6 and 7) which then decreased till late pre-monsoon and then again increased in monsoon season. The dissolved oxygen content increased at stations 1 to 4 from post-monsoon to winter probably because of decrease in temperature. The temperature has inverse relationship with oxygen solubility (Cole, 1975; Saxena, 1987). The diurnal variation of dissolved oxygen at station 4 shown in figure 45 although didn't match exactly with the change in water temperature, the coefficient of correlation between them is r = - 0.949 (significant at 0.01 probability level, two tailed) indicating negative correlation. Similar result was also obtained by Pradhan, 1998 with r = - 0.81 in diurnal variation of dissolved oxygen and water temperature. However at stations 5, 6 and 7, such decrease of dissolved oxygen during that duration was not observed probably because the discharge of untreated sewage dominate such changes as the points of sewage outfall were found in downstream region i.e. in urbanized parts as shown in figure 69 which is also indicated by high BOD at these stations. The dissolved oxygen decreased from winter till late pre-monsoon season at all stations probably because of increasing concentration of the chemical load (pollution) that was caused by decrease in river discharge due to lack of sufficient dilution. This is also reflected by degrading water quality class at station 4, 5, 6 and 7 by MPTPW water quality condition (Table 15) and station 3, 6 and 7 by Bach water quality class (Table 14).

Again the dissolved oxygen was increased from late pre-monsoon season to monsoon season probably due to the increasing precipitation that caused dilution of organic load decreasing the oxygen demand for biodegradation. Similar results were observed by ENPHO, 1997; Shrestha, 2005 and Poudel, 2005. Although variation in dissolved

oxygen content in the water at different stations along the river was observed in different months, such variation is not significant at 0.01 and 0.05 probability level and such variation may be due to temporary causes such as variation in water temperature, river discharge or sewage discharge varying in time and space etc. In the river water, the possible sources of dissolved oxygen are diffusion from air (physical phenomena) and photosynthetic activity within the water (biological phenomena).

The oxygen saturation % was recorded maximum level in late winter season and early pre-monsoon season in upstream region probably due to low temperature and low BOD. However in downstream (polluted) stretch, the maximum oxygen saturation % was observed in monsoon season probably due to dilution of organic load which is similar to the result obtained by Poudel, 2005. Such monthly variation of oxygen saturation % is not significant at 0.01 and 0.05 probability level but the spatial variation of oxygen saturation % from stations 1 to 7 is significant probably because of less variation of water quality in different seasons and high variation of water quality from upstream to downstream in the river as indicated by seasonal variation of Bach and MPTPW water quality class as shown in tables 14 and15.

The BOD_5 was maximum in February/May in downstream stretch (stations 5 to 7) of the Manahara river which may be due to low discharge value of the river that increased the concentration of organic load. This is also reflected by the river water quality class such that the month of May was found to be the most polluted month as shown in table 14 and 15. In upper stretch (stations 1, 2 , 3 and 4), the maximum BOD_5 was observed in June (monsoon) which may be due to high surface runoff input sweeping off the organic materials from the land surface to the river. The observed monthly variation of BOD_5 in the river water is not significant at 0.01 and 0.05 probability level. Unpolluted waters typically have BOD values of 2 mg/L or less (UNESCO, 1996). Therefore, it shows that the station 1 with mean BOD_5 1.74 ± 0.09 mg/L was unpolluted. The optimum BOD_5 range for fisheries and aquatic life is 3 - 6mg/L (CEC, 1978). Therefore, only the stations 1 and 2 are suitable for fisheries and aquatic life.

The dissolved oxygen (DO) of the surface water of the Manahara river decreased from upstream (station 1) to downstream (station 7) in general including December.

In reverse, BOD_5 of the river water increased from upstream (station 1) to downstream (station 7) in all the months during the investigation period. Such variation of dissolved oxygen and BOD_5 along the river from stations 1 to 7 is significant. This is so because as the river flows downstream, it entered gradually the urban area receiving the greater quantity of untreated sewage as shown in figure 69. 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). Similar results were also observed by Pradhan, 1998; Shrestha, 2005, Poudel, 2005 and GWRDP, 2001.

During the entire study period, the upper stations (1, 2, 3 and 4) had dissolved oxygen concentration well above 5 mg/L which is suitable to support aquatic life including fishes (Trivedi and Goel, 1986; HMG/FDD, 1998; CEC, 1978; UNESCO, 1996; Environment Canada, 1987). However, in the lower stations (5, 6 and 7) the dissolved oxygen fluctuated up and down 5 mg/L resulting low diversity of biota. This observation is true as the higher Shannon diversity index of macroinvertebrates (greater than 2) was recorded at stations (1, 2, 3 and 4) and the lower Shannon diversity index of macroinvertebrates (less than 1) was recorded at stations 5 to 7 which was shown in figure 48.

Carbon dioxide in the water is usually found as free carbon dioxide (CO_2) and combined CO_2 (i.e. carbonate & bicarbonate) (APHA, 1995). The concentration of free carbondioxide in the surface water of the Manahara river showed moderate negative correlation of $r = -0.3649$ with pH at stations 1, 2, 3, 4 and 5 during the present study period. Similarly, the diurnal variation of free carbondioxide and pH of water at station 4 as shown in figure 44, there is reverse fluctuation trend of free carbondioxide and pH. The correlation coefficient $r = -0.700$ between them indicates negative correlation. This is similar to Saxena, 1987 and Cole, 1975 as the pH observed in the river water was always less than 8.3. However, this negative correlation between CO_2 and pH, was not observed at polluted stations (6 and 7). It may be due to unpredicted pH change caused by various kinds of chemical substances present in the untreated wastewater of industries and households. The maximum free CO_2 recorded in late winter (February) at moderately to extremely polluted stations (stations 4, 5, 6 and 7) was probably due to low discharge value that increased the

concentration of organic load (as untreated sewage discharge doesn't vary so much in season wise) increasing the production of CO_2 during breakdown of the organic materials. However, at cleaner stations (stations 1, 2 and 3), the maximum free CO_2 was recorded in May (pre-monsoon)/June (early monsoon) probably due to increase in organic load in these months caused by increased surface runoff input to the river sweeping off the organic materials from the land surface. The observed monthly variation of free carbondioxide in the river water is not significant at 0.01 and 0.05 significance level.

The probable sources of free CO_2 in the Manahara river are respiratory activity of aquatic organisms, process of decomposition and atmospheric air. The free CO_2 concentration of the surface water of the Manahara river increased from stations 1 to 7 in all the months including December during the investigation period (except in station 4 and 5 in October) probably due to increasing organic load from upstream to downstream (as reflected by the variation of BOD_5 in figure 21) that undergo microbial degradation producing CO_2. Thus observed spatial variation of free carbondioxide in the river water is significant at 0.01 probability level. The surface water of the river was always saturated with CO_2 (ranging from 6.16 to 107.45 mg/L during the entire investigation period) as the free CO_2 concentration was always above 1.09 mg/L, the solubility of dissolved CO_2 in water at 0 °C (HMG/FDD, 1998). The optimum range of free CO_2 of water for fishes is 15 – 20 mg/L (HMG/FDD, 1998). The free CO_2 of surface water of upper stations i.e. stations 1 to 4 had always the free CO_2 below 20 mg/L (as shown in figure 22.) showing the good water quality for fishes and also other aquatic animals in view of free CO_2.

The pH of the river water varied between 6.2 and 7.37 throughout the investigation period. Among all the stations, the outlet station i.e. station 7 had the most variable pH from 6.2 to 7.37 probably due to the fact that it is the most polluted station (as shown in table 14 and table 15) that received the untreated sewage of different nature. The observed monthly variations of pH in the river water is significant at 0.01 probability level whereas the spatial variation of pH from stations 1 to 7 is significant at 0.05 probability level and not significant at 0.01 probability level. The drinking water quality standard for pH in WHO standard is below 8 (WHO, 1993) and Nepal Drinking Water Quality Standard is between 6.5 to 8.5. Thus, all the waters are

suitable for drinking from pH view point. However in fisheries point of view, the water of stations 1 to 6 is within the optimum pH range 6.5 to 9 for fishes (HMG/FDD, 1998) although other factors such as dissolved oxygen and free CO_2 are not suitable for fishes at station 5 and 6. Due to this, fishes were not observed at these stations.

Alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titrable bases such as carbonates, bicarbonates, hydroxides, phosphates, nitrates, silicates, borates etc. However, in natural waters carbonates, bicarbonates and hydroxide are considered to be the predominant bases. Thus, the total alkalinity (combining carbonates, bicarbonates and hydroxides) or alkalinity due to individual bases can be expressed (APHA, 1995; Saxena, 1987 and Trivedi and Goel., 1986). In the Manahara river water, the total alkalinity was solely due to bicarbonate (HCO_3^-) ions. Bicarbonate is dominant ion in most of the surface water (UNESCO,1996). Carbonate (CO_3^{--}) and hydroxide (OH^-) alkalinity were not observed. The absence of carbonate is obvious because the pH of water was always below 8.3 where carbonate ions must be absent (Saxena, 1987; Cole, 1975.). Carbonate is uncommon in natural surface waters because they rarely exceed pH 9 (UNESCO, 1996). Moreover, hydroxide alkalinity was also absent because the phenolphthalein alkalinity was zero at all the stations due to the presence of free CO_2 at these stations during the entire investigation period. Thus, the total alkalinity is equal to the bicarbonate alkalinity (individual alkalinity). The seasonal fluctuations in the level of bicarbonates (HCO_3^-) content over the period of ten months followed the fluctuation trends of bicarbonate alkalinity (total alkalinity) because bicarbonate alkalinity has linear relationship with bicarbonate content (APHA, 1995).

The higher level of total alkalinity and bicarbonate content were observed in spring months in the cleanest station i.e. station 1 than other months. Kushlan and Hunt, 1979 observed the similar behavior pattern of total alkalinity in the freshwater body (Yadav, 1989). However, at the most polluted stations (stations 6 and 7), the maximum total alkalinity and bicarbonate content were observed in late winter (February). This may be due to lower discharge value where untreated sewage was concentrated. However, such monthly variation of total alkalinity and bicarbonate content in the river water is not significant at 0.01 and 0.05 significance level. The

total alkalinity and bicarbonate content of surface water of the Manahara river increased from stations 1 to 7 in general in all the months including December (except from stations 2 to 3 in December) probably due to increasing pollution from upstream to downstream because of discharge of untreated sewage. The untreated sewage outfall at Seti Opi Marg, had high total alkalinity of 342 mg/L as $CaCO_3$ (as shown in table 27) that contributed to total alkalinity in the river. The spatial variation of total alkalinity and bicarbonate content in the river water is significant at 0.01 significance level.

The optimum range of total alkalinity for fishes has been recommended as 100 to 200 mg/L as $CaCO_3$ by HMG/FDD, 1998. Therefore, the station 5 can be considered as suitable for fishes from alkalinity point of view whereas stations 6 and 7 had high total alkalinity (in some months) that is not good for fishes and stations 1 to 4 had low total alkalinity. Similarly, alkalinity in itself is not harmful to human beings, still the water supplies less than 100 mg/L are desirable for domestic use (Trivedi and Goel, 1986). Thus the water from stations 1 to 4 can be used for drinking from alkalinity point of view.

Hardness refers to the sum of calcium and magnesium concentrations both expressed as calcium carbonate, in mg/L. Polyvalent ions of some other metals like strontium, iron, aluminum, zinc and manganese etc. are also capable of precipitating the soap and thus contributing to the hardness. However, the concentration of these ions is very low in natural waters, therefore, hardness is generally measured as concentration of only calcium and magnesium (as calcium carbonate), which are far higher in quantities over other hardness producing ions (Trivedi and Goel, 1986).

The hardness was solely due to carbonates of calcium and magnesium in the water of the Manahara river since the non-carbonate hardness was never appeared at any station in any month during the investigation period. Thus, the hardness is equal to carbonate hardness. The hardness (carbonate hardness) was recorded maximum in March (spring) in polluted stations (stations 6 and 7) probably because of minimum discharge in this month for both stations where the pollutants got concentrated. Similarly, in the cleanest station i.e. station 1, the hardness was recorded maximum in winter (January) which may be again due to lower discharge value. The observed

monthly variation of hardness in the river water is not significant at 0.01 and 0.05 significant level. The hardness increased from stations 1 to 7 i.e. upstream to downstream in all the months including December during the investigation period except station 3 to 4 in February probably because of increasing discharge of untreated sewage from upper stretch to downstream (urban area). Similar result was obtained by ENPHO, 1997 and Pradhan, 1998. The observed spatial variation of hardness from stations 1 to 7 in the river is significant at 0.01 significant level.

The WHO guidelines value of hardness for drinking water is 500 mg/L as $CaCO_3$ (WHO, 1993) whereas the optimum hardness of water for fishes is 50 – 300 mg/L as $CaCO_3$. (HMG/FDD, 1998). The hardness of the river water ranges from 10.73 to 150.55 mg/L as $CaCO_3$ throughout the study period. Thus, all the stations can be used for the source of drinking water from hardness point of view whereas from fisheries point of view the stations 5, 6 and 7 are suitable for fishes and stations 1 to 4 had low hardness. This is reverse to the view point from dissolved oxygen and free carbondioxide. Although, the stations 5, 6 and 7 are most suitable for fishes from hardness point of view, they were worst water due to very low dissolved oxygen and high free carbondioxide content which are the most important requirement for survival of the fishes than the hardness.

The calcium content of the river water had the similar trend of fluctuations as that of calcium hardness because calcium hardness is due to the presence of calcium and they have linear relationship (APHA, 1995). The calcium concentration and calcium hardness were higher in late winter (February)/ early spring (March) in polluted stations (stations 5 to 7) probably due to the lower value of discharge where the untreated sewage discharge concentrated in the river. Similarly, in the cleanest station i.e. station 1, the maximum calcium concentration and calcium hardness were observed in mid-winter (January) which may be due to lower discharge value of the river. The observed monthly variation of calcium hardness and calcium content in the river water is not significant at 0.01 and 0.05 significant level. The calcium content and calcium hardness increased from stations 1 to 7 (upstream to downstream) in all the months including December during the present investigation period. This spatial variation of calcium content and calcium hardness along the river water is significant at 0.01 significance level. This may be due to increasing discharge of untreated

sewage from upstream to downstream as the river entered gradually to urban area having high population density. The important source of calcium in the headwaters (upstream) may be the rocks containing calcium minerals such as limestone, gypsum etc. from which calcium is leached. The river receiving agricultural runoff may also obtain calcium that is applied in the agricultural land as agricultural lime. However, the sewage and industrial wastewater also contribute to large amount of calcium as seen from sewage quality (table 28) specially in lower reaches where it received more sewage disposal.

Magnesium is a common constituent of natural water and its concentration is generally lower than calcium (Trivedi and Goel, 1986 and Saxena, 1987). Because of this, lower magnesium content was recorded in every station during the investigation period. The monthly variation of magnesium content of the river water is not significant at 0.05 and 0.01 probability level. The magnesium content usually increased from upstream to downstream i.e. stations 1 to 7. Such spatial variation of magnesium content in the river water is significant at 0.01 probability level. It may be because more and more untreated sewage were received as the river flowed downstream. The degree of pollution increased as the river entered urban core. The possible sources of magnesium in the headwaters are various kinds of rocks containing ferromagnesium minerals from where magnesium is leached. However, in the lower reaches, the disposal of sewage adds more magnesium as sewage has high magnesium content (table 28)

Chloride occurs naturally in all types of waters. In natural freshwaters, however, its concentration remains quite low and is generally less than that of sulphates and bicarbonates. The chloride content of the water of the Manahara river varied between 6.2 mg/L and 78.48 mg/L and since the WHO guideline value as well as Nepal Drinking water standard for chloride is 250 mg/L, the water along the Manahara river had the chloride content far below the standard. Therefore, the water is not polluted from chloride point of view and safe for drinking with respect to chloride content. However, other parameters such as total coliforms, BOD_5 etc were out of the standard usually in the downstream part.

The chloride content was observed maximum in March (spring) in the polluted stations (stations 5 to 7) probably because of the low discharge value in this month due to less rainfall. Similarly, the maximum chloride content in the water of the cleanest station (station 1) was also observed in spring (May). This may be also due to lower discharge value due to low rainfall. The monthly variation of chloride content of the river water is not significant at 0.05 and 0.01 probability level. In pristine freshwater, chloride concentrations are usually lower than 10 mg/L and sometimes below 2 mg/L. Thus stations 1 and 2 i.e. headwaters were in pristine state. However, just like the other parameters, the chloride content increased gradually from upstream to downstream i.e. stations 1 to 7 and this spatial variation of chloride content is significant at 0.01 probability level. It may be due to the fact that more and more untreated sewage was received as it flows downstream. Similar result was also observed by ENPHO, 1997 and Pradhan, 1998. The probable sources of chloride are weathering of some sedimentary rocks, industrial and sewage effluents, and agricultural and road run-off as indicated by table 28.

Nitrogen is essential for living organisms as an important constituent of proteins, including genetic material. Nitrogen is present in organic and inorganic form in the water. Inorganic nitrogen, in the order of decreasing oxidation states are nitrate (NO_3), nitrite (NO_2^-), ammonium ion (NH_4^+) and molecular/elemental nitrogen (N_2). (UNESCO, 1996; APHA, 1995). Nitrate is the common form of combined nitrogen found in natural waters. The nitrate-nitrogen content of the water of the Manahara river was usually maximum in pre-monsoon (March/May). This may be due to low discharge value observed in the season. However, the minimum nitrate content was observed in monsoon (June/July) in all the stations in the Manahara river. It may be due to higher discharge value in the river as shown in the figure 16 as a result of high rainfall in the season. The monthly variation of nitrate-nitrogen content of the river water is not significant at 0.05 and 0.01 probability level. Similar results were obtained by ENPHO, 1997; Pradhan, 1998 and Poudel, 2005.

In natural conditions, the NO_3-N concentration seldom exceeds 0.1 mg/L (UNESCO, 1996). Thus, it can be said that the station 1 was more or less in natural condition. The minimum nitrate content was observed in the upstream (station 1) and the maximum nitrate content was observed in downstream (station 7) and it was increased gradually

from stations 1 to 7. Such spatial variation of nitrate-nitrogen from stations 1 to 7 is significant at 0.01 probability level. It was probably due to the fact that the more and more untreated sewage was received by the river as it flowed downstream. Similar result was obtained by ENPHO, 1997, Pradhan, 1998 and Poudel, 2005.

The possible natural sources of nitrate to waters of Manahara river include igneous rocks, land drainage and plant debris, specially in headwaters. However, in lower reaches, the major sources of nitrate-nitrogen were human waste, animal waste, industrial wastewater and fertilizer runoff. The nitrite ion is also rapidly oxidized to nitrate under aerobic condition. Throughout the investigation period, the nitrate-nitrogen content fluctuated between 0.04 to 3.83 mg/L. The WHO guideline value of nitrate for drinking water is 50 mg/L (WHO, 1993) whereas the Canada standard of Nitrate-nitrogen for drinking water is 10 mg/L. Therefore, the nitrate-nitrogen content of the river water was far below the standard and can be used for drinking purpose from nitrate point of view. However, from microbial point of view, it needs treatment to be used for drinking.

Phosphorus is an essential nutrient for living organisms and exists in water bodies as both dissolved and particulate species. In natural waters and wastewaters, phosphorus occurs mostly as dissolved orthophosphates and polyphosphates, and organically bound phosphates (UNESCO, 1996 and APHA, 1995).The Orthophosphate content of the Manahara river was recorded maximum in winter/pre-monsoon season. Similar to the other parameters, the cause may be the low discharge observed in these seasons. The minimum level of ortho-phosphate concentration was observed in monsoon (June/July) throughout the stretch of the Manahara river (stations 1 to 7) probably because of the higher discharge value in the river in the monsoon (as shown in figure 16) as a result of higher precipitation. Similar result was observed by ENPHO, 1997; Shrestha, 2005 and Poudel, 2005. The monthly variation of ortho-phosphate content of the river water is not significant at 0.05 and 0.01 probability level .

Natural sources of phosphorus in the river may be weathering of phosphorus-being rocks and the decomposition of organic matter. However, domestic waste waters (particularly those containing detergents), fertilizer run-off and industrial effluents contribute to elevated level of PO_4-P in the river water. The orthophosphate content

was observed minimum in upstream (station 1) and maximum in downstream (station 7) and it increased gradually from upstream to downstream. Such spatial variation of ortho-phosphate content of the river water is significant at 0.01 probability level (F = 20.991). It may be due to the discharge of untreated sewage which increased as the river flowed downstream. Similar result was also obtained by Pradhan, 1998; Shrestha, 2005; and Poudel, 2005.

In most natural surface water, phosphorus ranges from 0.005 to 0.020 mg/L PO_4-P. Since, the water of all the stations have the PO_4-P above this range, the river had PO_4-P beyond the natural condition probably because of washing and bathing in the river from upstream (station 1) to downstream. The optimum range of ortho-phosphate for fishes is 0.2 to 0.4 mg/L (HMG/FDD, 1998). Thus, the stations 1 to 3 (always) and station 4 (except May) had suitable level of ortho-phosphate for fishes indicating suitable water quality for higher fauna.

Ammonia is present naturally in surface waters. The ammonical nitrogen concentration was observed maximum in pre-monsoon/winter in the Manahara river probably because of lower discharge in these seasons (figure 16). More or less, similar results were obtained by Shrestha, 2005 and Poudel, 2005. However, the minimum ammonical nitrogen concentration was observed in monsoon (June) in all the stations. It may be due to higher discharge as a result of high precipitation in this season as similar to ENPHO, 1997; Pradhan, 1998; Shrestha, 2005 and Poudel, 2005. Such monthly variation of ammonical nitrogen content of the river water is not significant at 0.05 and 0.01 probability level. The concentration of ammonical nitrogen increased from stations 1 to 7 i.e. upstream to downstream in all the months during the investigation period. This spatial variation of the ammonical nitrogen from stations 1 to 7 is significant at 0.01 probability level. It is probably because the river received more and more untreated sewage as the river flowed downstream. The untreated sewage contained high ammonical nitrogen (table 28) probably because of low or no oxygen content that caused ammonification of nitrogenous materials of the sewage.

Unpolluted waters contain small amounts of NH_3-N usually less than 0.1 mg/L (UNESCO, 1996). Thus, it can be said that, the station 1 was unpolluted. The

optimum ammonical nitrogen of water for fishes is less than 0.2 mg/L (HMG/FDD, 1998). Based on this standard, the station 1 (0.02 to 0.08 mg/L N-NH_3) was only suitable for fishes throughout the year. However for drinking purpose, the WHO guideline value of ammonical nitrogen is 0.5 mg/L. Based on this, the water from stations 1 to 3, can be used for drinking purpose from ammonical nitrogen point of view. But, the Nepal Drinking Water Quality Standard of ammonical nitrogen is 1.5 mg/L. Based on this, the stations 1 to 5 can be used for drinking purpose from ammonical nitrogen point of view. However, these stations contained high total coliforms. In the river, ammonia may occur naturally arising from the breakdown of nitrogenous organic and inorganic matter, excretion by biota, reduction of the nitrite/ nitrate and from gas exchange with the atmosphere. However, the downstream river section may get high concentration due to sewage disposal as shown by high ammoniacal nitrogen in sewage (table 28).

Electrical conductivity or simply conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends upon the presence of ions; on their total concentration, mobility and valence; and on the temperature of measurement (APHA, 1995). The electrical conductivity and total dissolved solids (TDS) of the river water was observed maximum in pre-monsoon and winter (May/ February) probably because of low discharge value in these stations due to which the chemical ions concentrated. However, the minimum conductivity of the river was observed in monsoon and post-monsoon. It may be due to higher discharge value in these seasons causing dilution of the chemicals as a result of higher rainfall in the watershed. Shrestha, 2005 and Poudel, 2005 also observed similar result. Such seasonal variation of conductivity and total dissolved solids of the river water are not significant at 0.05 and 0.01 probability level. The conductivity and TDS increased gradually from upstream (station 1) to downstream (station 7). It may be due to more erosion and discharge of more and more untreated sewage to the river as the river entered the urban core. Similar result was also obtained by ENPHO, 1997; Pradhan, 1998; Shrestha, 2005 and Poudel, 2005. Such spatial variation of conductivity and total dissolved solids of the river water are significant at 0.01 probability level.

The TDS and conductivity of water showed the similar trends of fluctuation because conductivity and TDS have generally linear relationship as most of the salts in the

water are present in the ionic forms and capable of conducting current (Trivedi and Goel, 1986). The TDS is 0.55 to 0.9 times the conductivity of water (APHA, 1995) and as a general rule, the TDS is 0.65 times the conductivity of water because the dissolved solids in the highly mineralized water are usually more than 65 % of the conductivity. This is true within the conductivity value of 50,000 μS/cm (Trivedi and Goel, 1986). The TDS for drinking water should be within the limit 1000 mg/L as per WHO Guideline value and Nepal drinking water quality standard. It showed that the upstream (stations 1 to 4) is suitable for drinking purpose.

7.2 Microbial features

The total coliforms density was recorded maximum generally in December (winter) probably because of low discharge value of the river in this season due to less or no rainfall, where the coliforms were concentrated. However, probably because of dilution of pollutants in the post-monsoon (October), the total coliform density was minimum in that month. The monthly variation of total coliforms in the Manahara river is not significant at 0.05 and 0.01 probability level. The coliform density increased from upstream to downstream i.e. stations 1 to 7 probably because of increasing amount of untreated sewage containing human faeces, were received by the river as it flowed downstream. However, similar result was obtained by ENPHO, 1997 in the Bagmati and Bishnumati river. Such spatial variation of total coliforms from stations 1 to 7 in the Manahara river is significant at 0.01 probability level. The total coliforms density for drinking water as per WHO guideline as well as Nepal standard is 0 per 100 mL. Thus it shows that all waters are unsuitable for direct consumption for drinking water.

7.3 Macroinvertebrates

In the Manahara river, altogether 36 taxa of macroinvertebrates belonging to13 orders, 5 classes and 4 phyla were recorded. The order Ephemeroptera with various families such as Baetidae, Caenidae, Heptageniidae, Ephemerellidae and Leptophlebiidae were abundantly recorded in clean and less polluted river stretch (stations 1 to 4) as indicated by water quality class using Bach index and MPTPW water quality index and were almost absent in higly polluted river sections (station 6 and 7). It may be because Ephemeroptera are intolerant species to organic pollution (Olive, 1988, Gaufin, 1958, Wilhm, 1975).

The Plecopteran i.e. Pertidae was recorded regularly only at the stations 1 and 2 i.e. in non-polluted stations , irregularly recorded at station 3 and were never recorded from stations 4 to 7 (polluted stations). It may be so because plecopterans are pollution intolerant fauna (Olive, 1988; Gaufin, 1958; Wilhm, 1975). Similarly, Trichopterans such as Hydropsychidae, Glossosomatidae, Philopotamidae and Lepidostomatidae were abundantly present at stations 1 to 4 i.e. no pollution to moderately polluted stations as indicated by water quality class using Bach index and also MPTPW water quality index. (table 14 and 15). It was so because Trichopterans are pollution–intolerant taxa (Olive,1988; Gaufin, 1958; Wilhm,1975). All Coleopterans are intolerant of organic pollution (Olive, 1988; Gaufin, 1958) because of which Elmidae, Dytiscidae, Hydrophilidae, Gyrinidae and Psephenidae were abundantly present at cleaner stations like stations 1 to 4. Moreover, Elmidae was exclusively present only at stations 1 to 3 probably because it is more pollution sensitive as indicated by high tolerant score in NEPBIOS original (Sharma, 1996), Extended NEPBIOS (Sharma *et al.*, 2007), NEPBIOS-BRS (Pradhan, 1998) and GRS index (Nesemann, 2006) which are listed in Appendix XXII - XXV. However, the chironomids (red) were abundantly present at stations 5 to 7 probably because these stations were highly polluted stations as indicated by water quality class (tables 14 and 15) and dissolved oxygen content (figure 19) and chironomids (red) are organic pollution-tolerant organisms (Olive, 1988; Gaufin, 1958).

Blephariceridae was exclusively present at cleaner stations i.e. stations 1 and 2 because they are highly intolerant to organic pollution with the top score of 10 in GRS index (Nesemann, 2006). Similarly, Athericidae was recorded only at station 2 probably because it is pollution-intolerant as indicated by high score (9/10) in NEPBIOS original (Sharma, 1996), Extended NEPBIOS (Sharma *et al.* 2007), NEPBIOS-BRS (Pradhan, 1998) and GRS index (Nesemann, 2006). Similarly, Aphelocheiridae was exclusively present at stations 1 and 2 probably due to high sensitivity to organic pollution as indicated by higher score (7) in NEPBIOS original (Sharma, 1996), Extended NEPBIOS (Sharma *et al.* 2007), NEPBIOS-BRS (Pradhan, 1998) and GRS index (Nesemann, 2006).

Among the order Odonata, the individuals of the family Gomphidae were recorded at stations 1 to 6 (clean to polluted stations) probably due to facultative nature as indicated by medium score (4) by NEPBIOS original (Sharma, 1996) and not mentioned in Extended NEPBIOS (Sharma *et al.* 2007), NEPBIOS-BRS (Pradhan, 1998) and GRS index (Nesseman, 2006). In the order Megaloptera order, the individuals of the family Corydalidae were exclusively recorded at stations 1 and 2 probably because it is also sensitive to pollution as indicated by higher score (7) in NEPBIOS-BRS (Pradhan, 1998), Extended NEPBIOS (Sharma *et al.* 2007) and GRS index (Nesemann, 2006).

However, Hirudineans (Salifidae) and Oligochaetes (Tubificidae) were recorded only in the highly polluted river stretch (stations 6 or 7 or both) probably because they are organic pollution-tolerant (Olive, 1988; Wilhm, 1975). This is also supported by the lower score in NEPBIOS original (Sharma, 1996), NEPBIOS-BRS (Pradhan, 1998), Extended NEPBIOS (Sharma *et al.* 2007) and GRS index (Nesseman, 2006) for Salifidae and NEPBIOS original and NEPBIOS-BRS for Tubificidae. Gastropoda (*Physa mexicana*) was recorded from stations 1 to 6 probably because of facultative/intermediate in tolerance to organic pollution. But Planaridae (*Dugesia sp.*) was recorded only from stations 1 to 3 i.e. cleaner stations probably because of less tolerant to organic pollution which is also supported by high score value (9) in GRS index (Nesseman, 2006).

The density of stream macro-invertebrates in most stations increased during the autumn. It may be because of recruitment and growth of young (Hynes, 1979). However, the density of macroinvertebrates decreased during the winter. It may be so because the growth of many individuals slows down in winter and the rate of recruitment from newly hatched eggs also declines. The numbers therefore may be declined as individuals died or were eaten or they may decline steeply as a result of severe climate (low temperature) (Hynes, 1979). The model of annual cycle of insect dominated stream invertebrates given by Hynes, 1979 supports this fluctuation. However, the maximum density of the macroinvertebrates was observed in spring which didn't follow the annual cycle of stream invertebrates given by Hynes, 1979 for the spring season. Similar result was obtained by Yadav, 1989. It may be due to the increase in growth rate initiated by rise in temperature leading to catchable size of the

benthos. The minimum density of macroinvertebrates was recorded in summer i.e. monsoon in the Manahara river ecosystem. It also did not follow the annual cycle of stream invertebrates in summer given by Hynes, 1979. It may be due to high rainfall and high velocity of river water that reduced the density of the benthic macroinvertebrates by scouring the stream bed. Such seasonal variation of density of benthic macro-invertebrates of the river water is significant at 0.01 probability level. The total density of macroinvertebrates fluctuated from stations 1 to 7 and didn't show any distinct pattern along the river channel. However, such spatial of total density is significant at 0.01 probability level.

In some stations of the Manahara river, the maximum Shannon diversity index was observed during spring whereas it was observed maximum in autumn in others. It may be due to optimum temperature, water current, availability of food, catchable size of the benthos etc. The minimum Shannon diversity index was recorded in summer i.e. monsoon. It may be due to high rainfall and high velocity of river water that destroyed the habitat of the benthic fauna by scouring the stream bed and washed out the benthic macroinvertebrates. Such seasonal variation of Shannon diversity index of the benthic macroinvertebrates in the Manahara river is not significant at 0.05 and 0.01 probability level. The Shannon diversity index of headwaters i.e. stations 1 and 2 was higher than others indicating high diversity of benthic fauna. It may be because the headwater was pollution-free stations as indicated by high dissolved oxygen, good water quality class by Bach index and MPTPW water quality index. This result is similar to UNESCO, 1996.; DISVI, 1989. However, the Shannon diversity index decreased from headwaters (stations 1 and 2) to downstream (station 7). Such spatial variation of Shannon diversity index of the benthic macroinvertebrates in the Manahara river is significant at 0.01 probability level. It may be because the river received more and more untreated sewage as it flowed downstream and became more and more polluted as indicated by decreasing trend of dissolved oxygen content and deteriorating water quality as indicated by water quality class of Bach and MPTPW index. This is supported by UNESCO, 1996.

The index of dominance was recorded higher in summer (i.e. monsoon) and winter in most stations. It may be because of the high current of water as a result of high rainfall in summer (monsoon) and decrease in number of individuals due to low

growth rate and high deaths in winter. Due to this, only certain species can survive leading to higher index of dominance. However, the lower index of dominance was recorded in spring, and autumn at most stations and in winter at some stations. It was probably because optimum temperature, current, food availability and catchable size in spring and autumn increased diversity of benthic fauna decreasing index of dominance. Such seasonal variation of index of dominance of the benthic macroinvertebrates in the Manahara river is not significant at 0.05 and 0.01 probability level. More or less the observed maxima of index of dominance was accompanied by the minima of Shannon diversity index of the benthic fauna and vice versa. In addition, the Shannon diversity index (H) and index of dominance(c) had significant highly negative correlation (r = - 0.9764, significance level = 0.01, two tailed). It is so because Shannon diversity index behaves inversely to the index of dominance since high value of H indicates a low concentration of dominance (Odum, 1996). Because of the same reason, the minimum index of dominance was recorded in headwaters (stations 1 and 2) and the maximum index of dominance was recorded in downstream (station 7) with respect to entire stretch of the river in reverse to the variation of Shannon diversity index. Such spatial variation of index of dominance of the benthic macroinvertebrates in the Manahara river is significant at 0.01 probability level.

While analyzing seasonal variation of evenness index, although the maximum evenness index was recorded in summer (monsoon) or winter at most stations and at spring in other stations which seems similar to the maxima of index of dominance, there was significant high negative correlation (r = - 0.9025, significance level = 0.01, two tailed) between evenness index and index of dominance. Such seasonal variation of evenness index of the benthic macroinvertebrates in the Manahara river is not significant at 0.05 and 0.01 probability level. Moreover, the higher evenness index was recorded in upstreams i.e stations 1 to 4 and lower evenness index was recorded in downstreams i.e. stations 6 and 7, which is reverse to the trend of index of dominance. Such result was observed because the evenness index (e) behaves inversely to the index of dominance (c) since high value of e indicates low concentration of dominance (Odum, 1996). Such spatial variation of evenness index of the benthic macroinvertebrates in the Manahara river is significant at 0.01 probability level.

7.4 Biological assessment of water quality

The four biological assessment of water quality system by using macroinvertebrates, developed in this region were applied to observe their effectiveness and compare between them to obtain the best fit system. The comparison were done by regression analysis using the r^2 value as a measure of precision by assuming that higher the correlation coefficient, better the indicative value (suitability) of the method.

The r^2 value (also r) is slightly more in NEPBIOS-BRS than in NEPBIOS original for assessing chemical water quality probably because tolerance scores for some taxa are improved and some more taxa are added in NEPBIOS-BRS) and the NEPBIOS-BRS is specially modified form of NEPBIOS original for whole Bagmati River basin. However, the precision value is increased when NEPBIOS Extended is applied for determing saprobic water quality and r^2 value is improved to 0.7396. It may be because of improvement in the score value, addition of taxa (increased 92 indicators i.e. 82 family level, 8 generic level and 2 species level to 116 indicators i.e. 87 family level, 15 generic level and 14 species level); different transformation scale for midland and lowland based on altitude and score value refined more to species level. However, the r^2 value is even more improved in GRS index and reached 0.8075. The change in chemical water quality class is 81 % explained by the change in saprobic water quality class using GRS index. It may be so because it has included the highest number of taxa (420 taxa) and some of the sensitive taxa are given higher indicator value by GRS index (eg. Perlidae and Elmidae are given indicator value 8 by NEPBIOS original, NEPBIOS-BRS and NEPBIOS Extended whereas GRS indicator values are 9 and 10 respectively) and tolerant taxa are given lower indicator value (e.g. Caenidae and Hydropsychidae are given indicator value 6 by NEPBIOS original, NEPBIOS-BRS and NEPBIOS Extended whereas GRS indicator value is 3 for both; Simulidae is given indicator value 7 by NEPBIOS original, NEPBIOS-BRS and NEPBIOS Extended whereas GRS indicator value is 5; Tabanidae is given indicator value 6 by NEPBIOS-BRS whereas GRS indicator value is 4 etc.). The results are even more or less similar by including and excluding the monsoon data probably because the sampling was done by avoiding the floods.

However, Sharma, 1996 obtained a coefficient of determination (r^2) of 0.79 between calculated saprobic water quality class using NEPBIOS original/ASPT and field observed saprobic water quality class for various rivers of Nepal. Similarly, Pradhan, 1998 obtained a coefficient of determination (r^2) of 0.85 between calculated NEPBIOS index BRS and field observed saprobic water quality class for Bagmati River System. Sharma *et al.*, 2007 obtained a high coefficient of determination (r^2) of 0.96 between calculated NEPBIOS/ASPT and field observed saprobic water quality class. The higher value of these r^2 in comparison to r^2 between chemical water quality class and saprobic water quality class may be due to the fact that chemical water quality class and field observed saprobic water quality class are different ones. Chemical water quality class is based on field/laboratory measured important physico-chimical parameters such as dissolved oxygen, temperature, BOD, ammonia, phosphate, nitrate, conductivity and pH whereas field observed saprobic water quality class considers the parameters such as turbidity, colour, odour, foaming, algal composition and cover, suspended solids, wastes, anaerobic condition, microbiological and biological characters.

Thus it can be said that water quality class as determined by GRS index would be more accurate than NEPBIOS original, Extended NEPBIOS and NEPBIOS-BRS. However, final conclusions can be made only after extensive application of GRS index in many streams of different geographical region. For more accurate biological assessment of water quality, the score value should be refined to species level (as in GRS index) and the abundance factor should be considered. Particularly, in the Manahara river, the change in chemical water quality class (Bach and MPTPW) is explained more than 80% by saprobic water quality class using GRS index.

In addition, chemical water quality was gradually degraded form saprobic water quality I to IV with distinct range of chemical water quality in each biologically determined saprobic water quality class. The dissolved oxygen decreased gradually from saprobic water quality class I to IV whreas BOD, free carbondixide, phosphate, ammonia, total alkalinity, hardness and chloride gradually increased from saprobic water quality class I to IV. This is more or less similar to Pradhan, 1998.

The seasonal variation of Saprobic water quality class using GRS index in the Manahara river is not significant at 0.05 and 0.01 probability level as similar to Bach water quality class and MPTPW water quality condition. However, there is significant spatial variation in Saprobic water quality class using GRS index from stations 1 to 7 in the Manahara river as similar to Bach water quality class and MPTPW water quality condition.

7.5 Effluent quality

The industrial effluent and sewage had very high chemical concentrations and organic load. Similar results were obtained by CEDA, 1989, Stanley *et al.* 1994, ITECO, 2003 and Kafle, 2006. The temperature of 21.5 °C of the industrial effluent is within the National standard of industrial effluent entering into the river (less than 40 °C). Kafle, 2006 found the effluent temperature of 34 – 38 °C at the same site which is also above the national effluent standard. Similarly, the pH of 7.1 of the industrial effluent was also within the National industrial effluent of 5.5 to 9. But Kafle, 2006 found the pH of 10.65 – 12.3 for the effluent which was above the national effluent standard. Such variation in pH of effluent may be due to temporal variation in effluent quality in a long period of more than one and half year. The BOD_5 of 240 mg/L and COD of 674 mg/L of the industrial effluent was above the National industrial effluent standard of BOD_5 of 30 – 100 mg/L and COD of 250 mg/L. Similarly, the TSS of 746 mg/L was also above the National industrial effluent standard of 30 to 200 mg/L. Similarly, Kafle, 2006 found BOD, COD and TSS well above the National effluent standard. On the other hand, the ammoniacal nitrogen of 10.2 mg/L was within the national industrial effluent standard of 50 mg/L. Similarly, other parameters had also high value for which National standard is not prescribed till the date. Therefore, although the effluent quality crossed the National standard, there is no legal attempt to control the pollution till the date.

Similarly, the sewage from public sewer entering into the river at Seti-Opi Marg had high chemical concentration and organic load. Although, there is no National standard for quality of sewage discharge from public sewer entering into the river, the sewage entering into the river was highly polluted as the quality of sewage and industrial effluent observed don't have large difference. The high chemical concentration in the wastewater may be due to the daily need of chemicals for every person as shown in

table 31 and most of which pass into the wastewater particularly chloride from sodium chloride (NaCl), a common article (Pradhan, 1998).

Table 31: Average need of the chemicals per person per day

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 / Pradhan, 1998.

7.6 Wastewater generation and treatment facilities

In the urban region of Manahara watershed, only 1.16 MLD of wastewater out of 14.4 MLD of wastewater generated i.e. about 8 % is being treated by three operational wastewater treatment plants. The remaining was discharged directly or indirectly into the Manahara river. This enhanced the water pollution of the Manahara river. However, more than 220 ECOSAN units in the Manahara watershed were in operation which prevented the wastewater generation during the defecation and urination for more than 220 households. This may be a good option for septage specially in rural and semi-urban area.

7.7 Existing legislation for control of water pollution

Several acts and rules (laws) as well as National Effluent Standards are enforced in Nepal in order to control quality of wastewater discharged by industries that inturn helps to reduce water pollution. But the implementation of these laws are very weak. The legal attempt to control water pollution of the Manahara river is not observed till the date.

CHAPTER EIGHT

8. CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

The Manahara river, one of the major tributaries of Bagmati river flows from Manichud Lekh (ridge) and meets to Bagmati river at Chyasal draining a length of 30.0 km and catchment area of 256 sq. kms. The physico-chemical features such as Secchi disc transparency, mean depth, discharge, dissolved oxygen, oxygen saturation %, Biochemical oxygen demand, free carbondioxide, total alkalinity, bicarbonate, hardness, calcium, magnesium, chloride, ammoniacal nitrogen, nitrate nitrogen, ortho-phosphate, electrical conductivity, total dissolved solids, total coliforms and macroinvertebrates features vary significantly from stations 1 to 7 whereas the monthly variations of only the discharge, temperature, velocity, depth, pH of the river water and total density of macroinvertebrates were significant over the investigation period. Compared to other seasons, the water pollution was less in monsoon season probably as the pollutants were diluted in the season The water quality was gradually being deteriorated from the station 1 (Salinadi) to station 7 (Chyasal) which was indicated by the chemically determined water quality class using Bach index and Ministry of Public Transport and Public Works water quality index as well as biologically determined saprobic water quality class using NEPBIOS Original, NEPBIOS-BRS, Extended NEPBIOS and GRS index. The river was nearly in pristine condition with high species diversity of macroinvertebrates at station 1 (Salilnadi). Altogether, 36 families of macroinvertebrates were found in the river. The water quality was deteriorated specially when it entered into urban area i.e. Bode (Madhyapur Thimi municipality) and more severe when it reached Sinamangal (Kathmandu Metropolitan City). The river water from stations 1 to 4 was generally suitable for aquatic life including fishes as well as for drinking water but they should be treated to remove coliforms and suspended solids for drinking supply.

The major cause of the deterioration of water quality along the river from upstream to downstream may be the sewage outfalls to the river which were more in number in urban areas and also the sewage discharged into the river was untreated. The quality

of effluent which was entering into the river didn't comply the National effluent standards of Nepal. The legal measures are not utilized to control water pollution in the river in spite of several legal provisions. Among five wastewater treatment plants in this watershed, two plants at Thimi and Sakhu are fully operational and one at Balkumari is partially operational. Thus about 8 % wastewater is being treated by these plants and remainings are discharged directly or indirectly into the Manahara river enhancing the water pollution.

The GRS index was found to be more appropriate than other biotic scoring systems for bioassessment of water quality. There is highly positive significant correlation of about 0.90 between chemically determined water quality class and biologically determined saprobic water quality class specially by using newly developed GRS index. The change in chemical water quality class is explained more than 80 % by the change in saporbic water quality class using GRS index since coefficient of determination is 0.80. Thus, the water quality can be assessed by using macroinvertebrates as bioindicators and for more precise biological assessment more number of taxa should be incuded and the indicator values should be refined to genus/species level.

8.2 Recommendations

1. For the river water quality assessment in Nepal, there is lack of regular monitoring of river water quality as well as the inadequacy of physical facilities including laboratory and manpower. Thus, the government should allocate a sufficient fund for river water quality monitoring and prepare national database system including physical, chemical and biological aspects of streams and rivers with the involvement of Ministry of Environment, Science and Technology.

2. The environment related Acts and Rules (laws) should be implemented in order to control river water pollution.

3. The industries should install pollution abating devices by utilizing the grants of a reduction of up to 50 % from the taxable income for installing pollution reducing devices as per Industrial Enterprises Act 1992. It won't only reduce wastewater generation anr river pollution but also reduces their own water demand.

4. National effluent standards should be implemented strictly.

5. The existing waste water treatment plant at Hanumanghat, Sallaghari and Balkumari should be re-installed or improved and new such treatment plants should be established in dense settlement to treat all the wastewater generated before discharging into the rivers. The effluent charge from each household should be collected in conjunction with raising public awareness for the sustainability of the plants

6. The Ecological Sanitation (ECOSAN) units constructed in the area can be a good alternative in rural and semi-urban areas for prevention of wastewater generation during defecation and urination and also as a source of manure for plants.

7. Public awareness should be raised on the importance of aquatic resources and the ways for their conservation

8. The country should integrate biological assessment methods with physico-chemical assessment methods so that the entire status (health) of a river can be known.

9. Extended NEPBIOS and GRS index should be made more precise and refined to genus and species level so that more accurate assessment can be done.

10. The capacity building in benthic taxonomy is necessary for precise biological assessment. So, more trainings and researches on benthology should be conducted.

11. The upstream of the Manahara watershed is nearly in pristine condition due to the river conservation by the surrounding communities. Such communities can be encouraged to preserve the riverine environment by providing some incentives through the system of PES (Payment of Ecosystem Services) by the ecosystem servive users. So, researches should be conducted to develop the mechanism of PES in the watershed.

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APPENDICES

Appendix I

Physico-chemical and microbial water quality of Manahara river in October

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	19	-	23.0	-	16.5	-	17.0	-	20.0	-	18.0	-	25.0	-
2. Water temp.(^{0}c)	17.2	0	20.5	0	16	0	16.5	0	19.67	0.29	18.33	0.58	23	0
3. pH	7.13	0.06	7.03	0.06	6.67	0.06	6.83	0.06	7.13	0.06	7.03	0.06	6.2	0.10
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	26.00	0	30.00	0	24.00	0.82
5. Mean depth (m)	0.20	-	0.27	-	0.27	-	0.26	-	0.22	-	0.21	-	0.68	-
6. Mean velocity (m/s)	0.31	-	0.33	-	0.50	-	0.60	-	0.68	-	0.74	-	0.55	-
7. Discharge (m^3/s)	0.3742	-	0.4582	-	1.1059	-	1.9903	-	1.7183	-	5.541	-	5.892	-
8. DO (mg/L)	7.91	0.34	6.89	0.04	6.11	0.45	6.20	0.68	5.73	0.02	4.39	1.24	4.36	0.45
9. O_2 % saturation	84.81	3.65	78.65	0.46	63.95	4.72	65.54	7.24	64.42	0.34	48.06	13.18	52.03	5.33
10. BOD(mg/L)	1.84	0.07	2.98	0.31	9.12	1.11	15.20	1.10	37.04	2.37	75.99	27.41	78.35	7.32
11.Free co_2(mg/L)	9.68	1.16	10.85	0.67	11.73	1.27	6.13	0.23	7.11	0.13	16.87	11.88	19.48	0.73
12.Total alkalinity #	22.0	0.87	23.17	1.26	24	0	24.83	0.29	25.83	0.76	60.33	49.51	114.0	2.0
13. Bicarb. alkalinity #	22.0	0.87	23.17	1.26	24	0	24.83	0.29	25.83	0.76	60.33	49.51	114.0	2.0
14. Bicarbonate (mg/L)	26.84	1.06	28.26	1.54	29.28	0	30.30	0.35	31.52	0.93	73.61	60.40	139.08	2.44
15. Hardness #	13.67	1.15	14.0	2.0	18.0	2.0	19.67	0.42	22.75	0.48	56.07	44.98	81.2	1.20
16. Carbo. hardness #	13.67	1.15	14.0	2.0	18.0	2.0	19.67	0.42	22.75	0.48	56.07	44.98	81.2	1.20
17. Ca (mg/L)	3.13	0.11	3.26	0.58	4.57	0.41	5.23	0.11	6.19	0.12	17.11	17.14	25.17	0.43
18. Ca hardness #	7.80	0.27	8.13	1.45	11.39	1.03	13.04	0.28	15.44	0.29	42.69	42.75	62.81	1.07
19. Mg (mg/L)	1.43	0.22	1.43	0.19	1.61	0.24	1.61	0.08	1.77	0.12	3.26	0.55	4.48	0.54
20. Chloride (mg/L)	7.34	0.82	8.72	0.36	9.28	1.08	9.42	0.12	9.92	0.11	12.88	4.76	17.19	0.14
21. NO_3^- (mg/L)	0.08	0.02	0.21	0.04	0.33	0.02	0.39	0.04	0.52	0.03	1.37	0.34	3.23	0.04
22. PO_4^{3-}(mg/L)	0.10	0.02	0.20	0.03	0.27	0.03	0.32	0.03	0.68	0.09	1.47	0.25	1.81	0.13
23. Ammonia (mg/L)	0.05	0.01	0.12	0.03	0.16	0.02	0.31	0.06	0.42	0.04	0.83	0.15	1.31	0.10
24.Conductivity(µS/cm)	33.33	0.72	42.1	0.20	57.4	0.56	62.43	0.15	71.93	0.85	122.03	11.00	276.4	10.38
25.TDS(mg/L)	22.09	0.45	33.56	7.39	38.00	0.43	41.29	0.25	47.64	0.57	80.51	7.31	182.35	7.22
26.Tot. coliform(cfu/100ml)	$9.03x10^2$	70	1617	111	2703	225	5333	1150	40,667	9074	148667	131439	131667	33501
Date of sampling	19 Oct 2005		19 Oct 2005		24 Oct 2005		25 Oct 2005		25 Oct 2005		26 Oct 2005		26 Oct 2005	
Time of sampling	08:40		12:30		07:40		06:10		09:25		08:42		11:00	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix II

Physico-chemical and microbial water quality of Manahara river in November

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	7.0	-	11.0	-	16.0	-	4.0	-	5.0	-	6.0	-	11.5	-
2. Water temp.(^{0}c)	10.83	0.29	12.0	0	13	0	10	0	10.5	0	11	0	13	0
3. pH	7.27	0.06	7.23	0.06	6.73	0.06	6.7	0.10	7.1	0.10	7.23	0.06	7.17	0.6
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	T	-	27.00	2.12	25.67	2.08
5. Mean depth (m)	0.16	-	0.13	-	0.14	-	0.14	-	0.18	-	0.14	-	0.62	-
6. Mean velocity (m/s)	0.31	-	0.30	-	0.39	-	0.40	-	0.64	-	0.96	-	0.24	-
7. Discharge (m^3/s)	0.3893	-	0.4676	-	0.4877	-	0.7502	-	0.8513	-	2.415	-	2.613	-
8. DO (mg/L)	8.25	0.06	8.16	0.25	8.17	0.22	8.20	0.33	6.88	0.212	5.82	4.65	4.19	0.42
9. O_2 % saturation	77.01	0.20	77.83	2.36	80.13	2.16	75.17	2.81	63.74	1.97	54.58	43.6	41.05	4.14
10. BOD(mg/L)	1.13	0.09	1.97	0.16	6.03	0.32	14.52	0.53	22.04	1.72	74.4	84.79	74.79	8.48
11. Free co_2(mg/L)	8.04	0.20	13.05	0.64	13.42	0.22	13.71	0.13	14.63	0.51	42.17	36.22	65.33	1.15
12.Total alkalinity #	18.83	0.57	24.07	0.19	26.17	0.29	27.4	1.22	33.57	0.71	107.67	83.27	127.17	1.89
13. Bicarb. alkalinity #	18.83	0.57	24.07	0.19	26.17	0.29	27.4	1.22	33.57	0.71	107.67	83.27	127.17	1.89
14. Bicarbonate (mg/L)	22.97	0.69	29.36	1.10	31.92	0.35	33.43	1.48	40.96	0.86	131.35	101.59	155.14	2.31
15. Hardness #	14.10	0.27	15.53	0.50	19.07	1.01	23.53	1.36	26.14	0.42	87.67	46.52	90.67	1.15
16. Carbo. hardness #	14.10	0.27	15.53	0.50	19.07	1.01	23.53	1.36	26.14	0.42	87.67	46.52	90.67	1.15
17. Ca (mg/L)	2.73	0.27	3.26	0.25	4.69	0.31	6.47	0.18	7.24	0.13	21.12	14.71	25.08	1.25
18. Ca hardness #	6.82	0.66	8.14	0.63	11.77	0.68	16.15	0.46	18.06	0.32	52.69	36.70	62.57	3.11
19. Mg (mg/L)	1.77	0.13	1.79	0.04	1.79	0.07	1.8	0.38	1.96	0.03	8.53	2.40	8.86	0.87
20. Chloride (mg/L)	8.66	0.15	9.94	0.43	10.32	1.19	10.25	0.75	10.33	0.05	24.61	15.64	32.1	2.15
21. NO_3^-(mg/L)	0.09	0.02	0.25	0.03	0.34	0.04	0.40	0.03	0.55	0.03	1.92	0.10	3.02	0.09
22. PO_4^{3-}(mg/L)	0.09	0.01	0.16	0.02	0.30	0.02	0.31	0.03	0.69	0.03	1.62	1.38	1.81	0.16
23. Ammonia (mg/L)	0.06	0.02	0.14	0.02	0.22	0.03	0.30	0.03	0.45	0.03	0.68	0.24	1.91	0.15
24.Conductivity(µS/cm)	42.37	0.31	52.33	0.21	60.63	0.51	72.67	0.58	82.93	0.45	252.7	224.83	336.0	9.54
25.TDS(mg/L)	28.08	0.11	34.61	0.04	40.19	0.46	48.17	0.56	54.85	0.35	167.66	149.48	222.24	6.71
26.Tot. coliform(cfu/100ml)	1247	87	2287	176	2893	49	7500	566	67667	8327	192000	152735	234333	157
Date of sampling	28 Nov 2005		28 Nov 2005		28 Nov 2005		29 Nov 2005		29 Nov 2005		30 Nov 2005		30 Nov 2005	
Time of sampling	07:40		09:30		11:10		6:10		7:35		06:15		09:15	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix III

Physico-chemical and microbial water quality of Manahara river in December

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	7.0	-	13.0	-	13.0	-	13.5	-	14	-	14.5	-	15.0	-
2. Water temp.(^{0}c)	9	0	9	0	9	0	10.5	0	10.5	0	10.5	0	10.5	0
3. pH	7.33	0.02	7.27	0.05	7.13	0.05	7.13	0.03	7.08	0.10	7.26	0.06	7.37	0.02
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	T	-	21.00	1.82	20.67	4.93
5. Mean depth (m)	0.35	-	0.17	-	0.12	-	0.11	-	0.16	-	0.15	-	0.25	-
6. Mean velocity (m/s)	0.22	-	0.19	-	0.22	-	0.24	-	0.60	-	0.62	-	0.39	-
7. Discharge (m^3/s)	0.3850	-	0.3339	-	0.2983	-	0.2636	-	0.4975	-	2.082	-	1.2344	-
8. DO (mg/L)	9.59	0.24	8.95	0.13	8.65	0.46	8.67	0.3	8.38	0.23	5.54	0.47	4.86	0.41
9. O_2 % saturation	85.73	2.11	79.95	1.18	77.39	4.19	80.28	3.07	77.56	2.14	51.3	4.33	45.03	3.75
10. BOD(mg/L)	1.53	0.42	2.05	0.10	7.17	0.22	13.67	0.41	21.80	1.52	81.02	14.92	83.86	10.34
11. Free co_2(mg/L)	7.47	0.58	9.33	0.61	9.68	0.22	14.4	1.11	18.00	0.69	24.2	3.81	36.00	1.39
12.Total alkalinity #	22.5	2.50	46.07	1.85	45.83	1.44	52.67	0.76	61.67	2.89	113.33	12.58	143.33	2.89
13. Bicarb. alkalinity #	22.5	2.50	46.07	1.85	45.83	1.44	52.67	0.76	61.67	2.89	113.33	12.58	143.33	2.89
14. Bicarbonate (mg/L)	27.45	3.05	56.20	2.25	55.92	1.76	64.25	0.24	75.23	3.52	138.27	15.35	174.87	3.52
15. Hardness #	16.16	1.15	17.32	0.18	20.71	1.07	23.73	1.27	28.0	0	72.0	2.00	103.67	3.06
16. Carbo. hardness #	16.16	1.15	17.32	0.18	20.71	1.07	23.73	1.27	28.0	0	72.0	2.00	98.67	3.06
17. Ca (mg/L)	4.03	0.37	4.36	0.20	4.83	0.08	5.54	0.37	7.12	0.05	22.19	0.47	26.39	1.23
18. Ca hardness #	10.06	0.93	10.88	0.61	12.04	0.25	13.82	0.92	17.76	0.25	55.37	1.17	65.83	3.06
19. Mg (mg/L)	1.48	0.09	1.57	0.11	2.10	0.32	2.41	0.53	2.49	0.05	4.06	0.57	9.19	0.28
20. Chloride (mg/L)	8.34	0.41	9.73	0.82	10.64	0.51	11.43	0.08	11.59	0.37	26.51	2.17	35.5	2.84
21. NO_3^- (mg/L)	0.11	0.02	0.28	0.04	0.45	0.0100	0.44	0.03	0.68	0.06	2.01	0.73	3.39	0.03
22. PO_4^{3-}(mg/L)	0.08	0.02	0.16	0.02	0.29	0.02	0.32	0.04	0.67	0.58	1.44	0.60	1.83	0.05
23. Ammonia (mg/L)	0.07	0.02	0.16	0.02	0.24	0.04	0.38	0.03	0.58	0.05	1.07	0.49	1.72	0.11
24.Conductivity(µS/cm)	47.33	4.51	55.33	11.24	61.67	1.15	84.67	0.58	92.33	3.06	328	108.51	393	8.54
25.TDS(mg/L)	31.37	2.88	36.69	7.56	40.87	0.61	56.12	0.59	61.06	1.82	217.22	70.98	260.49	6.46
26.Tot. coliform(cfu/100ml)	1547	152	2477	258	2910	143	11,600	557	78,333	12,220	150000	136,836	$3x10^5$	-
Date of sampling	18 Dec 2005		18 Dec 2005		18 Dec 2005		18 Dec 2005		18 Dec 2005		18 Dec 2005		18 Dec 2005	
Time of sampling	09:00		09:00		09:00		09:00		09:00		09:00		09:00	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix IV

Physico-chemical and microbial water quality of Manahara river in January

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	8.0	-	16.5	-	19.0	-	8.0	-	9	-	10.0	-	18.5	-
2. Water temp.(^{0}c)	9	0	14.67	.0.29	18.57	0.12	8.5	0	9.5	0	10.67	0.29	16.33	0.29
3. pH	7.29	0.02	7.21	0.02	7.35	0.08	7.28	0.05	7.27	0.02	7.22	0.03	7.36	0.04
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	T	-	14.67	4.04	9.67	2.52
5. Mean depth (m)	0.14	-	0.10	-	0.10	-	00..09	-	0.1	-	0.27	-	0.13	-
6. Mean velocity (m/s)	0.25	-	0.30	-	0.32	-	0.32	-	0.33	-	0.45	-	0.35	-
7. Discharge (m^3/s)	0.2438	-	0.2093	-	0.2018	-	0.1832	-	0.1690	-	1.1118	-	0.6933	-
8. DO (mg/L)	8.91	0.11	8.74	0.13	7.61	0.10	7.16	0.06	6.85	0.32	4.62	2.25	2.93	0.09
9. O_2 % saturation	79.59	1.61	88.88	0.94	83.72	1.15	63.23	0.57	61.93	2.87	42.89	20.74	30.90	1.08
10. BOD(mg/L)	1.92	0.10	2.61	0.45	7.94	0.15	14.6	1.09	24.78	3.32	68.04	34.82	72.70	11.59
11. Free co_2(mg/L)	7.55	1.21	7.62	0.34	7.7	0.58	9.15	1.01	9.24	0.66	32.27	22.58	38.87	3.36
12.Total alkalinity #	30.5	1.80	32.33	3.06	35	0.50	53.54	1.48	59.83	0.76	160	93.41	220	5.00
13. Bicarb. alkalinity #	30.5	1.80	32.33	3.06	35	0.50	53.54	1.48	59.83	0.76	160	93.41	220	5.00
14. Bicarbonate (mg/L)	37.21	2.20	39.45	3.73	42.70	0.61	65.32	1.80	73.00	0.93	195.20	113.96	268.4	6.10
15. Hardness #	18.13	0.83	19.2	1.06	19.87	0.12	22.64	0.43	45.47	3.95	110.53	55.69	126.67	1.15
16. Carbo. hardness #	18.13	0.83	19.2	1.06	19.87	0.12	22.64	0.43	45.47	3.95	110.53	55.69	126.67	1.15
17. Ca (mg/L)	5.61	0.70	6.12	0.21	5.85	0.52	6.48	0.25	11.50	0.24	29.68	14.85	33.01	0.23
18. Ca hardness #	14.01	1.75	15.28	0.51	14.59	1.31	16.17	0.63	28.69	0.61	74.04	37.05	82.37	0.57
19. Mg (mg/L)	1.01	0.23	1.23	0.79	1.29	0.29	1.57	0.15	4.09	1.10	8.9	4.96	10.80	0.37
20. Chloride (mg/L)	8.09	0.29	8.19	0.09	9.56	0.91	10.34	0.16	12.45	0.36	43.55	23.52	51.97	0.75
21. NO_3^-(mg/L)	0.16	0.02	0.27	0.02	0.55	0.03	0.68	0.04	0.75	0.03	2.2	0.60	3.33	0.14
22. PO_4^{3-}(mg/L)	0.10	0.02	0.17	0.02	0.30	0.02	0.35	0.01	0.68	0.03	1.74	1.45	3.52	0.30
23. Ammonia (mg/L)	0.07	0.01	0.18	0.02	0.24	0.04	0.55	0.03	0.77	0.04	1.36	1.37	1.83	0.04
24.Conductivity(µS/cm)	59.33	0.58	64.33	2.08	75.67	0.58	85.67	0.58	148.67	0.47	417	236.14	550.3	2.08
25.TDS(mg/L)	39.33	0.24	42.55	1.43	50.15	0.57	56.78	0.59	98.54	0.74	276.53	157.14	364.76	2.69
Date of sampling	12 Jan 2006		12 Jan 2006		12 Jan 2006		13 Jan 2006		13 Jan 2006		13 Jan 2006		13 Jan 2006	
Time of sampling	08:45		11:15		14:30		06:50		08:15		10:00		12:30	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix V

Physico-chemical and microbial water quality of Manahara river in February

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	12	-	20	-	23.0	-	10.0	-	15.0	-	21.0	-	21.5	-
2. Water temp.(^{0}c)	13	0	15	0	18	0	11.67	0.29	15.67	0.29	18.17	0.29	19.5	0.5
3. pH	7.33	0.03	7.31	0.01	7.21	0.06	7.08	0.06	6.84	0.06	7.21	0.12	7.24	0.04
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	T	-	12.5	0.82	9.33	0.58
5. Mean depth (m)	0.09	-	0.07	-	0.075	-	0.127	-	0.08	-	0.16	-	0.11	-
6. Mean velocity (m/s)	0.19	-	0.28	-	0.24	-	0.16	-	0.27	-	0.19	-	0.22	-
7. Discharge (m^3/s)	0.0511	-	0.0915	-	0.1020	-	0.0959	-	0.077	-	0.2598	-	0.3976	-
8. DO (mg/L)	9.15	0.50	9.20	0.19	9.12	0.10	8.51	0.81	6.22	0.24	2.20	2.13	Nil	Nil
9. O_2 % saturation	89.74	4.93	94.23	1.89	99.39	1.09	80.82	7.44	64.57	2.28	24.00	23.25	0	0
10. BOD(mg/L)	1.22	0.13	1.28	0.03	6.78	0.06	14.93	0.54	27.54	1.66	154.94	51.94	153.01	22.11
11. Free co_2(mg/L)	7.12	0.16	9.24	0.44	12.54	0.22	17.82	0.22	48.25	0.25	106.76	36.65	107.45	15.12
12.Total alkalinity #	25.67	0.29	38.67	1.26	38.83	1.26	66.61	1.16	102.83	3.01	352.0	135.60	379.0	2.0
13. Bicarb. alkalinity #	25.67	0.29	38.67	1.26	38.83	1.26	66.61	1.16	102.83	3.01	352.0	135.60	379.0	2.0
14. Bicarbonate (mg/L)	31.31	0.35	47.17	1.54	47.38	1.54	81.26	1.41	125.46	3.68	429.44	165.43	462.38	2.44
15. Hardness #	12.13	0.23	16.20	0.16	35.87	0.23	23.87	0.23	62.93	5.68	123.33	44.03	148.53	3.23
16. Carbo. hardness #	12.13	0.23	16.20	0.16	35.87	0.23	23.87	0.23	62.93	5.68	123.33	44.03	148.53	3.23
17. Ca (mg/L)	4.85	0.03	5.90	0.05	6.23	0.05	5.25	0.11	15.19	0.09	34.97	8.61	42.61	3.63
18. Ca hardness #	12.10	0.1	14.73	0.12	15.55	0.12	13.11	0.28	37.89	0.23	87.24	21.48	106.32	9.07
19. Mg (mg/L)	0.05	0.05	2.56	1.29	4.96	0.02	2.61	0.12	6.11	1.33	11.79	10.13	10.30	1.80
20. Chloride (mg/L)	6.34	0.08	6.72	0.36	7.24	0.14	9.01	0.08	22.15	0.14	57.60	21.09	71.61	1.14
21. NO_3^- (mg/L)	0.18	0.01	0.32	0.03	0.64	0.03	0.72	0.02	0.83	0.02	2.00	0.43	3.37	0.10
22. PO_4^{3-}(mg/L)	0.08	0.01	0.18	0.01	0.32	0.03	0.37	0.02	0.88	0.04	4.24	1.54	5.28	0.47
23. Ammonia (mg/L)	0.07	0.02	0.20	0.02	0.26	0.02	0.61	0.03	1.16	0.16	4.42	1.01	4.62	0.13
24.Conductivity(µS/cm)	60.33	0.58	71	0	82	0	94	0	281.33	1.15	925	76.32	857.73	2.08
25.TDS(mg/L)	39.99	0.24	47.16	0	54.46	0	62.43	0	186.47	1.44	613.04	49.67	567.04	3.19
Date of sampling	11 Feb 2006		11 Feb 2006		11 Feb 2006		10 Feb 2006		10 Feb 2006		10 Feb 2006		10 Feb 2006	
Time of sampling	07:45		08:30		10:15		07:40		09:45		11:35		13:30	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix VI

Physico-chemical and microbial water quality of Manahara river in March

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	15	-	17.5	-	23.0	-	8.0	-	18.0	-	27.0	-	23	-
2. Water temp.(^{0}c)	14.0	0	16.0	0	21.0	0	11.0	0	17.17	0.29	21	0	22	0
3. pH	737	0.02	7.36	0.02	6.8	0.03	6.35	0.04	6.67	0.04	7.2	0.32	7.04	0.02
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	T	-	9.71	0.72	10.5	0.68
5. Mean depth (m)	0.17	-	0.06	-	0.05	-	0.22	-	0.07	-	0.08	-	0.10	-
6. Mean velocity (m/s)	0.19	-	0.37	-	0.20	-	0.21	-	0.31	-	0.16	-	0.15	-
7. Discharge (m^3/s)	0.0842	-	0.0909	-	0.0174	-	0.1841	-	0.0802	-	0.0855	-	0.1005	-
8. DO (mg/L)	9.59	0.59	8.92	0.41	7.89	0.21	7.26	0.04	4.30	0.04	5.75	0.02	2.51	0.34
9. O_2 % saturation	96.13	5.96	93.27	4.24	90.9	2.38	68.04	0.28	46.04	0.24	66.21	0.27	29.39	4.04
10. BOD(mg/L)	1.20	0.16	1.83	0.17	8.71	0.80	16.75	0.55	36.92	1.32	83.78	5.14	75.31	20.79
11. Free co_2(mg/L)	6.16	0.44	6.89	0.34	13.37	0.72	14.11	0.55	32.63	0.64	55.88	5.72	59.53	1.56
12.Total alkalinity #	24.83	1.04	30.83	0.58	40.17	0.22	73.33	7.64	151.17	1.26	276	48.03	276.57	2.12
13. Bicarb. alkalinity #	24.83	1.04	30.83	0.58	40.17	0.22	73.33	7.64	151.17	1.26	276	48.03	276.57	2.12
14. Bicarbonate (mg/L)	30.30	1.27	37.62	0.70	49.02	1.23	89.47	9.32	184.42	1.54	336.72	58.60	337.41	2.59
15. Hardness #	12.4	0.20	16.05	0.17	19.07	0.23	32.47	0.50	85.13	1.63	127.33	15.28	150.55	2.00
16. Carbo. hardness #	12.4	0.20	16.05	0.17	19.07	0.23	32.47	0.50	85.13	1.63	127.33	15.28	150.55	2.00
17. Ca (mg/L)	4.14	0.41	5.16	0.12	6.01	0.23	10.21	0.55	25.96	0.26	36.14	2.41	42.34	1.10
18. Ca hardness #	10.34	1.02	12.87	0.31	15.01	0.73	25.48	1.37	64.77	0.65	90.18	6.02	105.65	2.75
19. Mg (mg/L)	0.50	0.29	0.78	0.12	1.01	0.15	1.71	0.42	4.97	0.55	9.02	2.32	10.91	0.29
20. Chloride (mg/L)	7.48	0.30	8.43	0.36	9.04	0.16	13.21	0.38	38.72	0.36	68.73	2.14	78.48	0.56
21. NO_3^-(mg/L)	0.19	0.02	0.35	0.03	0.70	0.02	0.75	0.04	0.88	0.02	1.82	0.76	3.26	0.12
22. PO_4^{3-}(mg/L)	0.08	0.01	0.18	0.02	0.31	0.31	0.39	0.02	1.05	0.07	3.25	1.21	2.96	0.16
23. Ammonia (mg/L)	0.08	0.01	0.22	0.02	0.28	0.03	0.66	0.05	1.21	0.04	3.25	0.13	8.84	1.23
24.Conductivity(µS/cm)	58.33	0.58	70.0	0	81.67	1.15	116.33	0.58	405.33	1.53	719.33	81.93	796.0	4.58
25.TDS(mg/L)	38.66	0.24	46.49	0	54.13	0.57	76.78	0.38	267.52	1.01	474.76	54.07	474.76	54.07
Date of sampling	29 Mar 2006		29 Mar 2006		29 Mar 2006		29 Mar 2006		29 Mar 2006		29 Mar 2006		29 Mar 2006	
Time of sampling	08:10		09:40		11:45		07:10		09:25		11:00		12:40	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Physico-chemical and microbial water quality of Manahara river in April

`n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	17.5	-	21.5	-	28.0	-	17.0	-	21.5	-	24.5	-	30.0	-
2. Water temp.(^{0}c)	16.5	0	19.5	0	24.5	0	16.5	0	20.5	0	23.5	0	25	0
3. pH	7.10	0.02	6.87	0.02	6.81	0.01	6.68	0.22	6.67	0.01	6.71	0.06	6.66	0.01
4. Secchi disc transparency (cm)	T	-	T	-	23.0	0	T	-	21.27	1.80	13.0	0	9.5	0
5. Mean depth (m)	0.17	-	0.11	-	0.15	-	0.15	-	0.18	-	0.11	-	0.1	-
6. Mean velocity (m/s)	0.28	-	0.45	-	0.37	-	0.40	-	0.34	-	0.31	-	0.35	-
7. Discharge (m^3/s)	0.2157	-	0.3988	-	0.4323	-	0.3684	-	0.3599	-	0.5671	-	1.0798	-
8. DO (mg/L)	8.57	0.16	7.22	0.03	6.82	0.09	6.47	0.04	4.29	0.21	3.27	1.18	2.01	0.20
9. O_2 % saturation	90.63	1.69	80.81	0.36	83.41	1.04	68.43	0.43	49.01	2.42	39.26	14.15	24.83	2.49
10. BOD(mg/L)	1.80	0.20	2.77	0.13	9.83	0.21	17.85	0.47	39.25	1.19	113.60	20.20	149.20	9.74
11. Free co_2(mg/L)	8.51	0.25	8.73	0.12	9.17	0.20	9.29	0.67	17.31	0.25	37.11	29.44	77.0	2.20
12.Total alkalinity #	31.67	0.76	32.67	1.40	36.67	0.58	40.67	0.61	63.46	0.57	166.7	124.62	278.83	3.40
13. Bicarb. alkalinity #	31.67	0.76	32.67	1.40	36.67	0.58	40.67	0.61	63.46	0.57	166.7	124.62	278.83	3.40
14. Bicarbonate (mg/L)	38.63	0.93	39.85	1.72	44.73	0.70	49.62	0.75	77.40	0.70	203.33	152.03	340.18	4.15
15. Hardness #	10.73	0.31	11.53	0.31	13.87	0.31	23.13	0.23	42.0	2.0	89.33	58.29	116.13	1.80
16. Carbo. hardness #	10.73	0.31	11.53	0.31	13.87	0.31	23.13	0.23	42.0	2.0	89.33	58.29	116.13	1.80
17. Ca (mg/L)	3.62	0.21	3.93	0.14	4.20	0.05	6.87	0.17	8.71	0.24	21.56	14.74	27.24	0.20
18. Ca hardness #	9.03	0.53	9.81	0.34	10.47	0.12	17.15	0.41	21.74	0.61	53.80	36.79	67.97	0.50
19. Mg (mg/L)	0.41	0.06	0.42	0.06	0.83	0.05	1.46	0.05	4.94	0.63	8.67	5.25	11.74	0.32
20. Chloride (mg/L)	6.20	0.22	7.43	0.06	8.57	0.29	11.83	0.82	26.46	0.14	43.22	18.46	48.42	1.49
21. NO_3^- (mg/L)	0.18	0.02	0.25	0.05	0.60	0.03	0.63	0.02	0.79	0.03	1.79	0.49	3.09	0.07
22. PO_4^{3-}(mg/L)	0.06	0.01	0.12	0.03	0.29	0.02	0.35	0.03	1.27	0.06	2.41	0.58	2.22	0.12
23. Ammonia (mg/L)	0.07	0.01	0.22	0.02	0.24	0.02	0.39	0.03	1.32	0.20	2.86	0.64	3.22	0.12
24.Conductivity(µS/cm)	49.67	2.08	75.33	0.58	78.0	0	91.0	5.29	192.67	4.04	473.0	226.46	544.67	10.69
25.TDS(mg/L)	32.84	1.30	49.93	0.20	51.81	0	60.32	3.66	127.35	2.52	278.39	194.88	359.05	7.13
Date of sampling	29 Apr 2007		29 Apr 2007		29 Apr 2007		29 Apr 2007		29 Apr 2007		29 Apr 2007		29 Apr 2007	
Time of sampling	08:05		09:20		10:50		07:20		09:00		10:15		11:55	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix VIII

Physico-chemical and microbial water quality of Manahara river in May

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	22.5	-	23.5	-	24.0	-	24.5	-	27.0	-	29.5	-	30.0	-
2. Water temp.(^{0}c)	20.5	0	23.0	0	24.0	0	24.5	0	26.5	0	27.5	0	28.0	0
3. pH	6.82	0.02	6.78	0.03	6.73	0.02	6.72	0.02	6.71	0.02	7.09	0.06	7.02	0.02
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	20.0	0	9.0	0	7.0	0
5. Mean depth (m)	0.19	-	0.18	-	0.17	-	0.15	-	0.22	-	0.22	-	0.48	-
6. Mean velocity (m/s)	0.47	-	0.42	-	0.35	-	0.38	-	0.51	-	0.48	-	0.33	-
7. Discharge (m^3/s)	0.3587	-	0.4912	-	0.5144	-	0.5109	-	1.2592	-	1.7194	-	1.7662	-
8. DO (mg/L)	7.16	0.24	6.70	0.06	6.20	0.29	5.99	0.01	2.84	0.04	2.27	0.24	1.81	0.06
9. O_2 % saturation	81.77	2.70	79.99	0.73	75.19	3.46	73.19	0.28	35.1	0.82	29.07	3.08	23.31	0.32
10. BOD(mg/L)	2.16	0.14	3.82	0.10	10.49	0.92	18.36	0.32	56.15	2.59	119.01	14.01	167.25	5.09
11. Free co_2(mg/L)	8.57	0.13	13.35	0.25	13.87	0.68	12.39	0.13	12.87	0.74	24.93	5.54	25.23	0.46
12.Total alkalinity #	32.21	0.86	32.90	1.35	40.83	0.76	41.33	0.29	61.67	0.76	129.67	28.38	139.33	0.76
13. Bicarb. alkalinity #	32.21	0.86	32.90	1.35	40.83	0.76	41.33	0.29	61.67	0.76	129.67	28.38	139.33	0.76
14. Bicarbonate (mg/L)	39.30	1.05	40.14	1.65	49.82	0.93	50.43	0.35	75.23	0.93	158.19	34.62	169.99	0.93
15. Hardness #	15.53	0.31	23.53	1.68	28.93	0.12	32.93	0.23	33.47	0.31	63.53	19.29	97.0	0.6
16. Carbo. hardness #	15.53	0.31	23.53	1.68	28.93	0.12	32.93	0.23	33.47	0.31	63.53	19.29	97.0	0.6
17. Ca (mg/L)	3.53	0.08	6.58	0.28	8.65	0.05	9.59	0.08	9.76	0.05	20.77	9.05	32.13	0.05
18. Ca hardness #	8.81	0.2	16.42	0.69	21.58	0.12	23.93	0.2	24.36	0.12	51.82	22.59	80.17	0.12
19. Mg (mg/L)	1.64	0.10	1.74	0.24	1.79	0.03	2.19	0.02	2.21	0.05	2.86	1.00	4.11	0.15
20. Chloride (mg/L)	9.28	0.08	9.71	0.08	10.89	0.22	13.25	0.22	17.42	0.33	25.01	4.19	29.34	0.87
21. NO_3^- (mg/L)	0.20	0.01	0.26	0.02	0.62	0.04	0.67	0.03	0.75	0.03	2.24	0.15	3.83	0.10
22. PO_4^{3-}(mg/L)	0.07	0.02	0.12	0.02	0.32	0.00	0.44	0.03	1.22	0.03	1.81	0.39	1.82	0.14
23. Ammonia (mg/L)	0.07	0.01	0.22	0.02	0.25	0.03	0.55	0.01	1.15	0.13	3.04	0.99	3.10	0.08
24.Conductivity(µS/cm)	58.33	0.58	97.33	1.15	114.33	1.53	122.33	1.53	181.33	1.53	296.0	109.83	389.33	3.51
25.TDS(mg/L)	38.45	0.42	64.16	0.69	75.37	1.00	80.64	1.00	119.53	1.13	195.09	72.26	256.65	2.56
Date of sampling	27 May 2006		27 May 2006		27 May 2006		27 May 2006		27 May 2006		27 May 2006		27 May 2006	
Time of sampling	07:35		08:20		09:10		10:20		12:55		13:35		14:25	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix IX

Physico-chemical and microbial water quality of Manahara river in June

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	22	-	23.5	-	24.0	-	25.5	-	27.5	-	29.5	-	28.5	-
2. Water temp.(^{0}c)	21.5	0.5	25.5	0	27.5	0	25	0	26.5	0	28	0	28.5	0
3. pH	6.78	0.03	6.73	0.02	6.70	0.02	6.71	0.01	6.67	0.01	7.10	0.05	6.69	0.02
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	22.00	0	15.00	0	12	0
5. Mean depth (m)	0.25	-	0.16	-	0.21	-	0.25	-	0.29	-	0.38	-	0.92	-
6. Mean velocity (m/s)	0.56	-	0.56	-	0.58	-	0.62	-	0.72	-	0.66	--	0.63	-
7. Discharge (m^3/s)	0.916	-	0.6771	-	0.8966	-	2.2140	-	3.1242	-	8.8016	-	9.540	-
8. DO (mg/L)	7.54	0.02	6.35	0.24	6.22	0.24	5.57	0.10	4.57	0.05	4.08	2.20	3.80	0.06
9. O_2 % saturation	87.65	0.80	78.92	2.94	79.6	3.03	68.64	12.12	57.66	0.58	36.9	28.34	51.17	0.82
10. BOD(mg/L)	2.71	0.10	4.41	0.12	10.92	0.20	19.07	0.24	45.4	1.71	106.44	30.41	108.68	6.60
11. Free co_2(mg/L)	10.73	0.46	11.83	0.34	13.35	0.25	14.08	0.28	15.2	0	22.88	12.58	28.01	1.41
12.Total alkalinity #	26.0	1.0	27.0	2.65	39.33	1.15	42.0	0.5	70.33	0.58	119.67	54.50	148.33	1.15
13. Bicarb. alkalinity #	26.0	1.0	27.0	2.65	39.33	1.15	42.0	0.5	70.33	0.58	119.67	54.50	148.33	1.15
14. Bicarbonate (mg/L)	31.72	1.22	32.94	3.23	47.99	1.41	51.24	0.61	85.81	0.70	145.99	66.49	180.97	1.41
15. Hardness #	11.27	1.14	15.67	2.08	27.07	1.01	27.67	0.23	36.73	0.42	74.0	52.33	95.47	1.29
16. Carbo. hardness #	11.27	1.14	15.67	2.08	27.07	1.01	27.67	0.23	36.73	0.42	74.0	52.33	95.47	1.29
17. Ca (mg/L)	3.10	0.12	3.8	0.51	7.75	1.23	7.98	0.27	9.51	0.09	21.37	17.60	29.45	0.51
18. Ca hardness #	7.74	0.31	9.47	1.28	19.34	3.06	19.92	0.66	23.73	0.23	53.33	43.90	73.47	1.28
19. Mg (mg/L)	0.86	0.32	1.51	0.81	1.88	0.50	1.90	0.11	3.17	0.05	5.04	2.06	5.36	0
20. Chloride (mg/L)	8.80	0.49	9.65	0.98	10.60	0.71	12.55	0.16	16.49	0.30	26.22	6.84	28.93	0.18
21. NO_3^-(mg/L)	0.05	0.02	0.13	0.04	0.13	0.03	0.19	0.03	0.26	0.04	0.40	0.30	0.93	0.04
22. PO_4^{3-}(mg/L)	0.04	0.02	0.04	0.01	0.12	0.03	0.13	0.04	0.20	0.02	0.48	00.35	1.28	0.09
23. Ammonia (mg/L)	0.02	0.01	0.03	0.01	0.16	0.05	0.28	0.05	0.54	0.04	0.90	0.37	1.39	0.13
24.Conductivity(µS/cm)	37.33	0.58	38	5.57	78.67	0.58	84.0	8.19	165.33	1.15	260.00	112.62	331.67	1.53
25.TDS(mg/L)	24.61	0.40	25.05	3.65	51.86	0.33	55.38	5.45	108.92	0.76	171.36	74.13	218.63	1.08
Date of sampling	27 Jun 2006		27 Jun 2006		27 Jun 2006		28 Jun 2006		28 Jun 2006		28 Jun 2006		28 Jun 2006	
Time of sampling	08:30		11:55		14:20		08:15		10:30		11:45		13:40	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix X

Physico-chemical and microbial water quality of Manahara river in July

n=3

Parameters/Sites	1		2		3		4		5		6		7	
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.
1.Air temp (^{0}c)	21.5	0	22.5	0	23.5	0	25	0	27	0	28	0	30.5	0
2. Water temp.(^{0}c)	21	0	24	0	26.17	0.29	24.5	0	25	0	26.5	0	27.0	0
3. pH	7.02	0.02	6.91	0.04	6.87	0.05	6.77	0.04	6.64	0.03	7.03	0.04	7.0	0.02
4. Secchi disc transparency (cm)	T	-	T	-	T	-	T	-	21.00	0	16.00	0	13.00	0.42
5. Mean depth (m)	0.24	-	0.23	-	0.35	-	0.28	-	0.36	-	0.48	-	1.04	-
6. Mean velocity (m/s)	0.88	-	0.83	-	0.62	-	0.63	-	0.72	-	0.63	-	0.61	-
7. Discharge (m^3/s)	1.6204	-	1.7812	-	1.8142	-	2.7212	-	3.7214	-	9.2045	-	9.8321	-
8. DO (mg/L)	8.29	0.20	6.67	0.20	6.16	0.69	6.13	0.07	6.06	0.18	5.84	0.36	5.27	0.04
9. O_2 % saturation	95.47	2.31	80.81	2.47	77.30	8.25	74.98	0.83	74.76	2.24	73.74	4.51	67.09	0.45
10. BOD(mg/L)	1.92	0.09	2.99	0.07	10.10	0.28	13.03	0.13	32.18	2.61	79.16	4.01	80.56	1.09
11. Free co_2(mg/L)	6.95	0.57	8.92	0.20	9.87	0.20	13.40	1.28	15.61	0.58	24.79	12.50	26.19	1.09
12.Total alkalinity #	24.53	0.58	25.74	0.62	28.45	0.51	36.47	0.70	70.91	1.05	125.77	30.70	149.64	0.65
13. Bicarb. alkalinity #	24.53	0.58	25.74	0.62	28.45	0.51	36.47	0.70	70.91	1.05	125.77	30.70	149.64	0.65
14. Bicarbonate (mg/L)	29.93	0.70	31.4	0.76	34.71	0.63	44.49	0.85	86.51	1.29	153.45	37.45	182.56	0.79
15. Hardness #	12.51	0.20	17.17	0.18	30.46	2.18	33.79	0.47	38.89	0.68	54.25	13.13	73.84	1.15
16. Carbo. hardness #	12.51	0.20	17.17	0.18	30.46	2.18	33.79	0.47	38.89	0.68	54.25	13.13	73.84	1.15
17. Ca (mg/L)	3.84	0.08	4.24	0.07	8.48	0.06	9.33	1.05	10.60	0.12	13.55	2.50	19.18	0.84
18. Ca hardness #	9.59	0.20	10.57	0.18	21.17	0.16	23.28	2.62	26.46	0.29	33.8	10.59	47.85	2.10
19. Mg (mg/L)	0.71	0.08	1.60	0.07	2.26	0.54	2.55	0.73	3.02	0.12	4.97	0.69	6.32	0.51
20. Chloride (mg/L)	9.02	0.10	10.08	0.22	10.68	0.19	14.09	0.25	18.55	0.32	27.12	5.57	30.08	0.76
21. NO_3^- (mg/L)	0.04	0.01	0.18	0.02	0.22	0.03	0.25	0.02	0.52	0.09	1.56	0.15	1.55	0.07
22. PO_4^{3-}(mg/L)	0.04	0.01	0.09	0.02	0.13	0.04	0.34	0.11	0.56	0.04	0.71	0.19	1.18	0.35
23. Ammonia (mg/L)	0.03	0.01	0.10	0.02	0.15	0.02	0.31	0.05	0.38	0.04	0.82	0.44	0.88	0.05
24.Conductivity(µS/cm)	39.33	0.58	42.67	0.58	86.0	1.0	92.67	1.15	178.0	0	231.0	28.83	284.67	2.52
25.TDS(mg/L)	25.93	0.41	28.13	0.35	56.69	0.66	61.09	0.83	117.27	0	152.27	18.88	187.77	1.51
Date of sampling	27 Jul 2006		27 Jul 2006		27 Jul 2006		28 Jul 2006		28 Jul 2006		28 Jul 2006		28 Jul 2006	
Time of sampling	08:20		09:45		11:45		09:30		11:40		13:10		14:20	

Note: $\bar{x}$.=Mean value of a parameter S.D. = Standard Deviation #(mg/L as $CaCO_3$) Bicarb.=Bicarbonate Carbo.= Carbonate T = Transparent

Appendix XI

Macroinvertebrates recorded in the Manahara river in October

n=10

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Baetidae(*Baetis sp.*)	28.89	23.33	112.22	75.56	143.33	127.78	0.00
Caenidae	31.11	23.33	51.11	38.89	0.00	0.00	0.00
Heptageniidae	8.89	11.11	0.00	0.00	0.00	0.00	0.00
Ephemerellidae	5.56	7.78	31.11	13.33	0.00	0.00	0.00
Leptophlebiidae	4.44	5.56	0.00	0.00	0.00	0.00	0.00
Philopotamidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	12.22	12.22	8.89	0.00	0.00	0.00	0.00
Hydropsychidae	13.33	16.67	36.67	11.11	15.56	17.78	0.00
Lepidostomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	6.67	7.78	6.67	1.11	0.00	0.00
Elmidae	47.78	60.00	0.00	0.00	0.00	0.00	0.00
Gyrinidae	0.00	2.22	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	3.33	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limoniidae	0.00	10.00	0.00	0.00	0.00	0.00	0.00
Simuliidae	0.00	51.11	16.67	0.00	0.00	0.00	0.00
Chironomidae	0.00	0.00	5.56	10.00	8.89	297.78	302.22
Blephariceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	0.00	2.22	7.78	6.67	0.00	0.00	0.00
Stratiomyidae	0.00	2.22	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	2.22	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	5.56	0.00	0.00	0.00	0.00
Aphenocheiridae	4.44	3.33	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	0.00	3.33	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	5.56	3.33	0.00	0.00	0.00
Vellidae	2.22	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	3.33	4.44	0.00	0.00	0.00	0.00	0.00
Gomphidae	14.44	14.44	26.67	6.67	6.67	2.22	0.00
Corydalidae	3.33	3.33	0.00	0.00	0.00	0.00	0.00
Salifidae	0.00	0.00	0.00	0.00	0.00	4.44	0.00
Tubificidae	0.00	0.00	0.00	0.00	3.33	17.78	0.00
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae(*Physa mexicana*)	0.00	0.00	0.00	4.44	0.00	26.67	0.00
Planaridae (*Dugesia sp.*)	2.22	2.22	0.00	0.00	0.00	0.00	0.00

Appendix XII

Macroinvertebrates recorded in the Manahara river in November

n = 10

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Baetidae(*Baetis sp.*)	44.44	31.11	107.78	72.22	86.67	0	0.00
Caenidae	46.67	31.11	47.78	12.22	0.00	0	0.00
Heptageniidae	11.11	12.22	0.00	0.00	0.00	0	0.00
Ephemerellidae	7.78	11.11	26.67	0.00	0.00	0	0.00
Leptophlebiidae	5.56	7.78	0.00	0.00	0.00	0	0.00
Philopotamidae	3.33	4.44	0.00	0.00	0.00	0	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Glossosomatidae	17.78	10.00	8.89	0.00	0.00	0	0.00
Hydropsychidae	18.89	18.89	74.44	21.11	15.56	10	0.00
Lepidostomatidae	0.00	3.33	0.00	0.00	0.00	0	0.00
Psephenidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Dytiscidae	0.00	0.00	7.78	6.67	0.00	0	0.00
Elmidae	73.33	60.00	24.44	0.00	0.00	0	0.00
Gyrinidae	4.44	4.44	0.00	0.00	0.00	0	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Limoniidae	0.00	10.00	7.78	0.00	0.00	0	0.00
Simuliidae	0.00	55.56	20.00	0.00	0.00	0	0.00
Chironomidae	0.00	16.67	14.44	23.33	31.11	423.33	537.78
Blephariceridae	3.33	3.33	0.00	0.00	0.00	0	0.00
Tabanidae	0.00	3.33	4.44	6.67	0.00	0	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Nepidae	0.00	0.00	3.33	0.00	0.00	0	0.00
Aphenocheiridae	0.00	0.00	0.00	0.00	0.00	0	0.00
Gerridae	0.00	0.00	0.00	0.00	0.00	0	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Macromiidae	0.00	2.22	0.00	0.00	0.00	0	0.00
Gomphidae	27.78	20.00	31.11	10.00	8.89	0	0.00
Corydalidae	0.00	0.00	0.00	0.00	0.00	0	0.00
Salifidae	0.00	0.00	0.00	0.00	0.00	4.44	0.00
Tubificidae	0.00	0.00	0.00	0.00	0.00	27.78	26.67
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0	1.11
Physidae*(Physa mexicana)*	0.00	0.00	0.00	0.00	0.00	0	0.00
Planaridae *(Dugesia sp.)*	3.33	2.22	0.00	0.00	0.00	0	0.00

Appendix XIII

Macroinvertebrates recorded in the Manahara river in December

n=10

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Perlidae	3.33	3.33	0.00	0.00	0.00	0.00	0.00
Baetidae(*Baetis sp.*)	30.00	24.40	68.90	24.40	57.80	0.00	0.00
Caenidae	14.40	14.40	20.00	6.67	0.00	0.00	0.00
Heptageniidae	7.78	3.33	0.00	0.00	0.00	0.00	0.00
Ephemerellidae	5.56	2.22	12.20	0.00	0.00	0.00	0.00
Leptophlebiidae	4.44	4.44	0.00	0.00	0.00	0.00	0.00
Philopotamidae	3.33	2.22	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	8.89	4.44	5.56	0.00	0.00	0.00	0.00
Hydropsychidae	7.78	15.60	41.10	16.70	7.78	4.44	0.00
Lepidostomatidae	0.00	2.22	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	0.00	4.44	4.44	0.00	0.00	0.00
Elmidae	16.70	38.90	18.90	0.00	0.00	0.00	0.00
Gyrinidae	0.00	3.33	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limoniidae	0.00	5.56	4.44	0.00	0.00	0.00	0.00
Simuliidae	0.00	43.30	13.30	0.00	0.00	0.00	0.00
Chironomidae	0.00	26.70	38.90	31.10	63.30	734.00	626.00
Blephariceridae	2.22	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	0.00	2.22	3.33	4.44	0.00	0.00	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aphenocheiridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	0.00	1.11	0.00	0.00	0.00	0.00	0.00
Gomphidae	13.30	13.30	13.30	8.89	5.56	0.00	0.00
Corydalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tubificidae	0.00	0.00	0.00	0.00	0.00	22.20	18.90
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae*(Physa mexicana)*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planaridae *(Dugesia sp.)*	2.22	2.22	0.00	0.00	0.00	0.00	0.00

Appendix: XIV

Macroinvertebrates recorded in the Manahara river January

n=10

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Perlidae	3.33	2.22	0.00	0.00	0.00	0.00	0.00
Baetidae(*Baetis sp.*)	18.90	22.20	57.80	21.10	0.00	0.00	0.00
Caenidae	12.20	12.20	23.30	5.56	0.00	0.00	0.00
Heptageniidae	5.56	2.22	0.00	0.00	0.00	0.00	0.00
Ephemerellidae	4.44	1.11	0.00	0.00	0.00	0.00	0.00
Leptophlebiidae	3.33	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	3.33	1.11	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	7.78	3.33	4.44	0.00	0.00	0.00	0.00
Hydropsychidae	7.78	14.40	21.10	13.30	8.89	0.00	0.00
Lepidostomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	0.00	2.22	0.00	0.00	0.00	0.00
Elmidae	7.78	17.80	32.20	0.00	0.00	0.00	0.00
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limoniidae	0.00	3.33	4.44	0.00	0.00	0.00	0.00
Simuliidae	0.00	50.00	13.30	0.00	0.00	0.00	0.00
Chironomidae	0.00	23.30	45.60	35.60	55.60	724.00	802.00
Blephariceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	0.00	2.22	2.22	3.33	0.00	0.00	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aphenocheiridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphidae	8.89	12.20	8.89	7.78	6.67	0.00	0.00
Corydalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tubificidae	0.00	0.00	0.00	0.00	0.00	12.20	0.00
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae(*Physa mexicana)*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planaridae *(Dugesia sp.)*	2.22	1.11	0.00	0.00	0.00	0.00	0.00

Appendix: XV

Macroinvertebrates recorded in the Manahara river February

n=10

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Perlidae	2.22	1.11	0.00	0.00	0.00	0.00	0.00
Baetidae(*Baetis sp.*)	11.11	21.11	31.11	18.89	0.00	0.00	0.00
Caenidae	17.78	10.00	15.56	6.67	0.00	0.00	0.00
Heptageniidae	4.44	2.22	0.00	0.00	0.00	0.00	0.00
Ephemerellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptophlebiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	2.22	1.11	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	6.67	3.33	5.56	0.00	0.00	0.00	0.00
Hydropsychidae	6.67	14.44	22.22	14.44	8.89	0.00	0.00
Lepidostomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	4.44	0.00	0.00	0.00	0.00	0.00
Elmidae	7.78	13.33	0.00	0.00	0.00	0.00	0.00
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limoniidae	0.00	2.22	4.44	0.00	0.00	0.00	0.00
Simuliidae	0.00	38.89	15.56	0.00	0.00	0.00	0.00
Chironomidae	5.56	30.00	66.67	40.00	66.67	396.70	1.11
Blephariceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	0.00	2.22	2.22	2.22	0.00	0.00	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aphenocheiridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphidae	5.56	11.11	7.78	6.67	5.56	0.00	0.00
Corydalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tubificidae	0.00	0.00	0.00	0.00	0.00	15.56	0.00
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae*(Physa mexicana)*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Planaridae *(Dugesia sp.)*	2.22	1.11	0.00	0.00	0.00	0.00	0.00

Appendix: XVI

Macroinvertebrates recorded in the Manahara river March

n=10

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Perlidae	3.33	2.22	28.89	0.00	0.00	0.00	0.00
Baetidae(*Baetis sp.*)	40.00	25.56	12.22	24.44	40.00	18.89	0.00
Caenidae	15.56	10.00	6.67	7.78	0.00	0.00	0.00
Heptageniidae	6.67	8.89	0.00	5.56	0.00	0.00	0.00
Ephemerellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptophlebiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	4.44	2.22	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	17.78	11.11	6.67	0.00	0.00	0.00	0.00
Hydropsychidae	10.00	23.33	16.67	34.44	18.89	0.00	0.00
Lepidostomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	3.33	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	3.33	2.22	0.00	0.00	0.00	0.00
Elmidae	113.30	42.22	57.78	0.00	0.00	0.00	0.00
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limoniidae	5.56	3.33	3.33	4.44	0.00	0.00	0.00
Simuliidae	0.00	38.89	21.11	17.78	0.00	0.00	0.00
Chironomidae	17.78	37.78	92.22	35.56	105.60	354.40	92.22
Blephariceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	5.56	4.44	3.33	3.33	0.00	0.00	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aphenocheiridae	2.22	2.22	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	2.22	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphidae	16.67	22.22	8.89	28.89	12.22	14.44	0.00
Corydalidae	2.22	0.00	0.00	0.00	0.00	0.00	0.00
Salificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tubificidae	0.00	0.00	1.11	0.00	0.00	18.89	0.00
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae*(Physa mexicana)*	28.89	72.22	168.90	17.78	10.00	21.11	0.00
Planaridae *(Dugesia sp.)*	3.33	1.11	1.11	0.00	0.00	0.00	0.00

Appendix: XVII

Macroinvertebrates recorded in the Manahara river April

n=70

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Perlidae	4.44	2.22	0.00	0.00	0.00	0.00	0.00
Baetidae(*Baetis sp.*)	40.00	33.33	28.89	32.22	41.11	24.44	0.00
Caenidae	17.78	11.11	16.67	11.11	0.00	0.00	0.00
Heptageniidae	6.67	3.33	4.44	6.67	0.00	0.00	0.00
Ephemerellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptophlebiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	2.22	2.22	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	18.89	11.11	7.78	0.00	0.00	0.00	0.00
Hydropsychidae	33.33	20.00	21.11	43.33	21.11	0.00	0.00
Lepidostomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	3.33	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	2.22	1.11	2.22	0.00	0.00	0.00
Elmidae	107.80	44.44	54.44	0.00	0.00	0.00	0.00
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	1.11	0.00	0.00	0.00	0.00	0.00
Limoniidae	5.56	3.33	5.56	4.44	0.00	0.00	0.00
Simuliidae	0.00	46.67	24.44	27.78	0.00	0.00	0.00
Chironomidae	44.44	38.89	172.20	43.33	134.40	337.80	308.90
Blephariceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	4.44	3.33	3.33	3.33	0.00	0.00	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aphenocheiridae	2.22	2.22	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	2.22	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphidae	38.89	34.44	12.22	33.33	17.78	17.78	0.00
Corydalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tubificidae	0.00	0.00	1.11	0.00	0.00	11.11	0.00
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae*(Physa mexicana)*	22.22	51.11	130.00	27.78	6.67	15.56	0.00
Planaridae *(Dugesia sp.)*	3.33	1.11	1.11	0.00	0.00	0.00	0.00

Appendix: XVIII

Macroinvertebrates recorded in the Manahara river in May

n=10

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Perlidae	3.33	2.22	0.00	0.00	0.00	0.00	0.00
Baetidae(*Baetis sp.*)	35.56	28.89	27.78	37.78	31.11	23.33	0.00
Caenidae	17.78	7.78	13.33	12.22	0.00	0.00	0.00
Heptageniidae	8.89	2.22	2.22	3.33	0.00	0.00	0.00
Ephemerellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptophlebiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	2.22	2.22	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	20.00	16.67	0.00	0.00	0.00	0.00	0.00
Hydropsychidae	24.44	34.44	25.56	36.67	22.22	0.00	0.00
Lepidostomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	2.22	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	1.11	2.22	2.22	0.00	0.00	0.00
Elmidae	121.11	37.78	44.44	0.00	0.00	0.00	0.00
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limoniidae	3.33	4.44	4.44	3.33	0.00	0.00	0.00
Simuliidae	0.00	36.67	24.44	18.89	0.00	0.00	0.00
Chironomidae	62.22	48.89	156.67	46.67	168.89	256.67	497.78
Blephariceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	3.33	2.22	2.22	4.44	0.00	0.00	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aphenocheiridae	2.22	2.22	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gomphidae	38.89	35.56	11.11	27.78	23.33	14.44	0.00
Corydalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tubificidae	0.00	0.00	0.00	0.00	0.00	4.44	0.00
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae*(Physa mexicana)*	16.67	33.33	90.00	13.33	4.44	13.33	0.00
Planaridae *(Dugesia sp.)*	2.22	1.11	1.11	0.00	0.00	0.00	0.00

Appendix: XIX

Macroinvertebrates recorded in the Manahara river in June

n=3

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Perlidae	2.22	1.11	0.00	0.00	0.00	0.00	0.00
Baetidae(*Baetis sp.*)	12.22	10.00	7.78	5.56	5.56	0.00	0.00
Caenidae	11.11	2.22	4.44	0.00	0.00	0.00	0.00
Heptageniidae	4.44	2.22	0.00	0.00	0.00	0.00	0.00
Ephemerellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptophlebiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydropsychidae	6.67	7.78	2.22	7.78	0.00	0.00	0.00
Lepidostomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elmidae	13.33	0.00	0.00	0.00	0.00	0.00	0.00
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limoniidae	2.22	2.22	0.00	0.00	0.00	0.00	0.00
Simuliidae	0.00	6.67	4.44	0.00	0.00	0.00	0.00
Chironomidae	0.00	0.00	0.00	0.00	36.67	78.89	140.00
Blephariceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aphenocheiridae	1.11	1.11	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	1.11	1.11	0.00	0.00	0.00	0.00	0.00
Gomphidae	0.00	0.00	4.44	4.44	0.00	0.00	0.00
Corydalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tubificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae*(Physa mexicana)*	4.44	3.33	11.11	6.67	4.44	14.44	0.00
Planaridae *(Dugesia sp.)*	2.22	0.00	0.00	0.00	0.00	0.00	0.00

Appendix: XX

Macroinvertebrates recorded in the Manahara river in July

n=18

Macroinvertebrates species	Densities (no./sq.m) at station						
	1	2	3	4	5	6	7
Perlidae	2.22	0.00	0.00	0.00	0.00	0.00	0.00
Baetidae(*Baetis sp.*)	6.67	5.56	8.89	4.44	0.00	0.00	0.00
Caenidae	8.89	2.22	0.00	0.00	0.00	0.00	0.00
Heptageniidae	2.22	1.11	0.00	0.00	0.00	0.00	0.00
Ephemerellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Leptophlebiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psychomyiidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glossosomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydropsychidae	6.67	7.78	6.67	7.78	0.00	0.00	0.00
Lepidostomatidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psephenidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dytiscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elmidae	11.11	0.00	0.00	0.00	0.00	0.00	0.00
Gyrinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrophilidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Athericidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limoniidae	3.33	0.00	0.00	0.00	0.00	0.00	0.00
Simuliidae	0.00	4.44	0.00	0.00	0.00	0.00	0.00
Chironomidae	0.00	0.00	0.00	0.00	30.00	42.22	37.78
Blephariceridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tabanidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stratiomyidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muscidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aphenocheiridae	1.11	1.11	0.00	0.00	0.00	0.00	0.00
Gerridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corixidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vellidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macromiidae	1.11	0.00	0.00	0.00	0.00	0.00	0.00
Gomphidae	0.00	0.00	5.56	3.33	0.00	0.00	0.00
Corydalidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tubificidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Megascolecidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Physidae*(Physa mexicana)*	4.44	3.33	10.00	4.44	3.33	20.00	0.00
Planaridae *(Dugesia sp.)*	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Value of q_i^{wi} of each chemical parameter to calculate Bach water quality index (Source: Pradhan, 1998)

O2 -. 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	2.392	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	1.441	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									

BOD_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	2.255	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	1.331	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	1.451	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	.	.	.	.	.	.	.	.	.

0	1.346	1.356	1.363	1.360	1.371	1.373	1.375	1.376	1.377	1.378
										0
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	1.320	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	2.247	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									

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
										pH
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	1.560	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									

	0.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	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	.	.	.	.	.	.	.	.	.

	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
										$O - PO_4$
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	1.156	1.155	1.153	1.152
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

Appendix: XXII

Original NEPBIOS (Nepalese Biotic Score) taxa list and its scores

(Sharma, 1996)

Macroinvertebrates taxa	Score
Athericidae, Capniidae, Epiophllebiidae, Helicopsychidae, Helodidae, Heptageniidae(*Epeorus rhithralis*), Heptageniidae(*Rhithrogena nepalensis*), Hydrobiosidae, Lepidostomatidae, Leuctridae, Peltoperlidae, Perlidae(*Acroneuria sp.*), Perlidae(*Calicneuria sp.*), Siphlonuridae, Taeniopterygidae, Uenoidae.	10
Chloroperlidae, Goeridae, Limnephilidae, Limnocentropodidae, Nemouridae, Neoephemeredae, Periodidae.	9
Elmidae, Euphaeidae, Heptageniidae(*Rhithrogena sp.*), Limoniidae, Perlidae,Phyacophilidae, Stenopsychidae, Tipilidae.	8
Aphelocheiridae, Baetidae(*Baetiella sp.*), Baetidae(*Baetis sp.*), Brachicentridae, Ephemerellidae, Gammaridae, Glossosomatidae, Heptageniidae,Hydraenidae,Leptophlebiidae, Philopotamidae, Polycentropodidae, Potamidae, Psephinidae, Simuliidae.	7
Aeshnidae, Caenidae, Corydalidae, Ecnomidae, Ephemerellidae(*torleya sp.*), Ephemeredae, Gyrinidae, Hydraenidae(*Ochthebius sp.*), Hydrophilidae, Hydropsychidae, Hydroptilidae, Libellulildae, Lymnaeidae, Psychomyiidae, Scirtidae, Viviparidae.	6
Bithyniidae, Chlorocyphidae, Coenagrionidae, Cordullidae, Dryopidae, Leptophlebiidae(*Euthraulus sp.*), Odontoceridae, Protoneuridae, Sphaeriidae, Unionidae.	5
Calopterygidae, Corbiculidae, Corixidae, Dytiscidae, Gerridae, Glossiphoniidae, Gomphidae, Naucoridae, Nepidae, Noteridae, Palaemonidae, Planorbidae, Pleuroceridae, Ranatridae, Thiaridae.	4
Notonectidae, Salifidae.	3
Culicidae, Physidae	2
Chironomidae [*Chironomous* group riparius (= *thummi*) and group *plumosus*] Tubificidae	1

Appendix: XXIII

NEPBIOS-BRS (Nepalese Biotic Score-Bagmati River System) taxa list and its scores (Pradhan, 1998)

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

Cinctieostella sp.	7
Drunella sp.	10
Torleya nepalica	6
Ephemeridae	7
Ephydridae	x
Epiophlebiidae	10
Euphaeidae	8
Gammaridae	7
Gerridae	4
Glossiphoniidae	4
Glossosomatidae	8
Goeridae	9
Gomphidae	0
Gyrinidae	7
Hebridae	x
Helicopsychidae	10
Helodidae (Scirtidae)	10
Heptageniidae	7
Cinygmina sp.	7
Electrogena sp.	6
Epeorus bispinosus	8
Epeorus rhithralis	10
Iron sp.	8
Notacantburus cristatus	7
Rhitbrogena sp.	8
Rhitbrogena nepalensis	10
Hydraenidae	7
Hydrobiosidae	8
Hydrometridae	6
Hydrobiidae	x
Hydrophilidae	5
Hydropsychidae	6
Lepidosmatidae	8
Leptophlebiidae	7
Eutbraulus sp.	5
Habropblebiodes sp.	9
Leuctridae	10
Libellulidae	3
Limnephilidae	8
limnocentropodidae	9
Limoniidae	7
Lumbricidae	3
lumbriculidae	x
Lymnaeidae	5
Micronectidae	4
Muscidae	x
Naucoridae	4
Nemouridae	8
Neoephemeridae	9
Nepidae	4
Noteridae	3
Notonectidae	3

Odontoceridae	5
Palaemonidae	4
Peltoperlidae	10
Perlidae	8
Acroneuria sp.	10
Calicneuria sp.	10
Perlodidae	9
Philopotamidae	8
Phrygnaidae	x
Physidae	2
Planorbidae	4
Pleurocentridae	7
Polycentropodidae	9
Potamidae	6
Protoneuridae	5
Psephenidae	8
Psychodidae	8
Psychomyiidae	7
Ranatridae	4
Rhyacophilidae	8
Salifidae	3
Barbronia sp.	7
Barbronia cf. weberi	4
Scirtidae (Helotidae)	6
Simuliidae	7
Siphlonuridae	10
Sphaeriidae	4
Stenopsychidae	9
Stratiomyidae	x
Synlestidae	8
Syrphidae	2
Tabanidae	6
Taeniopterygidae	10
Thiaridae	4
Tipulidae	7
Tubificidae	2
Uenoidae	10
Unionidae	5
Veliidae	x
Viviparidae	6

Appendix XXIV

Ganga River System (GRS) index taxa list and its scores (Nesemann, 2006)

Taxon Name	Value
Acroneuria sp. (Perlidae)	10
Aeshnidae	6
Agriolimacidae (*Deroceras* spec.)	6
Alboglossiphonia heteroclita (Linnaeus, 1761)	4
Alboglossiphonia hyalina (O.F.Muller, 1774)	5
Alboglossiphonia pahariensis n. sp.	5
Alboglossiphonia shillongensis n. sp.	5
Alboglossiphonia weberi (Blanchard, 1897)	4
Allonais gwaliorensis (Stephenson, 1920)	5
Allonais inaequalis (Stephenson, 1911)	5
Allonais paraguayensis (Michaelsen, 1905)	5
Amblemidae	7
Amphiterygidae	N.A.
Ampullariidae	4
Amynthas corticis (Kienberg, 1867)	7
Apataniidae	9
Aphelocheiridae	7
Arcidae	8
Asiaticobdella birmanica birmanica (Blanchard, 1894)	5
Asiaticobdella fuscolineata (Moore, 1924)	5
Asiaticobdella punyamataensis n. sp.	7
Assiminea francesiae (Wood, 1828)	6
Assimineidae	6
Athericidae	9
Atyidae	6
Aulodrilus limnobius Bretscher, 1899	9
Aulodrilus pigueti Kowalewski, 1914	6
Aulodrilus pluriseta (Piguet, 1906)	4
Aulophorus carteri Stephenson, 1931	7
Aulophorus flabelliger Stephenson, 1931	8
Aulophorus furcatus (O. F. Müller, 1773)	7
Aulophorus hymanae Naidu, 1963	8
Aulophorus indicus Naidu, 1963	7
Aulophorus michaelseni Stephenson, 1923	7
Aulophorus tonkinensis Vejdovsky, 1894	8
Baetidae	6
Baetiella sp. (Baetidae)	7
Baetis sp. (Baetidae)	7
Barbronia nepalensis meghalayaensis n. ssp.	3
Barbronia nepalensis nepalensis n. sp.	3
Barbronia weberi (Blanchard, 1897)	4
Barythelphusa lugubris (Wood-Mason, 1871)	5
Batracobdelloides reticulatus (Kaburaki, 1921)	4
Bellamya (Filopaludina) bengalensis (Lamarck, 1822)	6
Belostomatidae	7
Bithyniidae	5
Blephariceridae	10
Bothrioneurum iris Beddard, 1901	7
Bothrioneurum vejdovskyanum Stolc, 1888	10
Brachycentridae	8
Branchiodrilus hortensis (Stephenson, 1910)	5
Branchiodrilus semperi (Bourne, 1890)	6
Branchiura sowerbyi Beddard, 1892	2
Brotia costula (Rafinesque, 1833)	7
Caenidae	3
Calamoceratidae	8
Calicneuria sp. (Perlidae)	10
Calopterygidae	7
Camptoceras lineatum Blanford, 1871	7
Capniidae	10
Caridina (cf. *nilotica)*	7
Carychiidae (Freshwater)	10
Carychium minusculum Gredler, 1887	10
Centroptilum sp. ((Baetidae)	8
Ceratopogonidae	5
Chaetogaster cristallinus Vejdovsky, 1883	5
Chaetogaster diaphanus (Gruithuisen, 1828)	5
Chaetogaster diastrophus (Gruithuisen, 1828)	5
Chaetogaster langi Bretscher, 1896 (? syn: *C. spongillae* Annandale, 1905)	6
Chaetogaster limnaei bengalensis Annandale, 1905	5
Chaetogaster limnaei limnaei Von Baer, 1827	5
Chironomidae (red)	1
Chlorocyphidae	N.A.
Chlorolestidae	N.A.
Chloroperlidae	9
Cincticostella sp. (Ephemerellidae)	7
Cinygmina sp. (Heptageniidae)	7

Cirolana parva Hansen, 1890	7
Cirolanidae	7
Clavidae	6
Cloedodes sp. (Baetidae)	7
Coenagrionidae	5
Corbicula assamensis Prashad, 1928	6
Corbicula bensoni Deshayes, 1854	8
Corbicula cashmiriensis Deshayes, 1854	5
Corbicula striatella Deshayes, 1854	4
Corbiculidae	5
Cordulegasteridae	9
Corduliidae	5
Corixidae	2
Corydalidae	7
Culicidae	2
Cyclestheria hislopi (Baird, 1859)	7
Cyclestheriidae	7
Dendrodrilus rubidus Savigny, 1826	5
Dendronereides heteropoda Southern, 1921	6
Dero cooperi Stephenson, 1932	5
Dero digitata (O. F. Müller, 1773)	5
Dero dorsalis Ferroniere, 1899	5
Dero nivea Aiyer, 1930	6
Dero pectinata Aiyer, 1930	6
Dero phewatalensis n. sp.	6
Dero sawayai Marcus, 1943	5
Diamesinae (Chironomidae)	8
Digoniostoma cerameopoma (Benson, 1830)	5
Digoniostoma lithoglyphoides n. sp.	5
Digoniostoma pulchella (Benson, 1836)	5
Dinobdella ferox (Blanchard, 1896)	N.C.
Dixidae	7
Dolichopodidae	N.A.
Dorylaimiodea	N.C.
Drawida nepalensis Michaelsen, 1907	6
Drunella sp. (Ephemerellidae)	10
Dryopidae	10
Dytiscidae	N.A.
Ecnomidae	3
Eisenia fetida (Savigny, 1826)	5
Eiseniella tetraedra (Savigny, 1826)	8
Electrogena sp. (Heptageniidae)	6

Ellobiidae (Brackish water)	6
Elmidae	10
Empididae	4
Enchytraeidae	9
Enchytraeus indicus Stephenson, 1912	N.A.
Epeorus bispinosus (Heptageniidae)	8
Epeorus rhithralis (Heptageniidae)	10
Ephemerellidae	6
Ephemeridae	7
Epiophlebiidae	10
Erhaia banepaensis n. sp.	10
Erhaia chandeshwariensis n. sp.	10
Erpobdella bhatiai n. sp.	7
Erpobdellidae	7
Euphaeidae	8
Euthraulus sp. (Leptophlebiidae)	5
Ferrissia baconi (Bourguignat, 1853)	6
Ferrissia verruca (Bourguignat, 1859)	6
Fredericella indica Annandale, 1909	8
Fredericellidae	8
Fridericia perrieri (Vejdovsky, 1877)	9
Gabbia orcula (Frauenfeld, 1862)	5
Gabbia stenothyroides (Dohrn, 1857)	5
Galba truncatula (O.F. Müller, 1774)	8
Gammaridae	8
Gammarus aff. *lacustris*	8
Gangemysis assimilis (W.M. Tattersall, 1908)	8
Gangetia miliacea (Nevill, 1880)	9
Gerridae	4
Glossiphonia complanata (Linnaeus, 1758)	4
Glossiphoniidae	4
Glossosomatidae	9
Glyphidrilus gangeticus Gates, 1958	7
Goeridae	7
Gomphidae	N.A.
Gordiidae	10
Grapsidae	4
Gyraulus convexiusculus (Hutton, 1849)	4
Gyraulus euphraticus (Mousson, 1874)	4
Gyraulus labiatus (Benson, 1850)	5
Gyrinidae	7
Habrophleboides sp. (Leptophlebiidae)	9

Haemadipsa sylvestris Blanchard, 1894	8
Haemadipsa zeylanica agilis Moore, 1927	8
Haemadipsa zeylanica montevindicis Moore, 1927	8
Haemadipsidae	8
Haemonais waldvogeli Bretscher, 1900	7
Haemopidae	8
Hebridae	N.A.
Helicopsychidae	9
Helobdella stagnalis (Linnaeus, 1758)	7
Helophoridae	N.A.
Hemiclepsis marginata asiatica Moore, 1924	4
Heptageniidae	7
Heteroceridae	N.A.
Himalayapotamon atkinsonianum (Wood-Mason, 1871)	9
Himalayapotamon emphysetum (Alcock, 1809)	9
Himalayapotamon sunkoshiense Brandis & Sharma, 2005	9
Hippeutis umbilicalis (Benson, 1836)	4
Hirudinaria manillensis (Lesson, 1842)	8
Hirudinidae	7
Hydracarina	7
Hydraenidae	7
Hydrobiosidae	9
Hydrometridae	6
Hydrophilidae	N.A.
Hydropsychidae	3
Hydroptilidae	4
Hydroscaphidae	N.A.
Hymenicoides carteri Kemp, 1916	8
Hymenosomatidae	8
Idiopoma dissimilis (O.F. Müller, 1774)	6
Ilyodrilus templetoni (Southern, 1909)	5
Indoplanorbis exustus (Deshayes, 1834)	4
Isonychiidae	5
Isotomidae	N.A.
Lamellidens phenchooganjensis Preston, 1912	6
Lamellidens consobrinus (Lea, 1859)	7
Lamellidens corrianus (Lea, 1834)	7
Lamellidens jenkinsianus jenkinsianus (Benson, 1862)	6
Lamellidens jenkinsianus daccaensis (Benson, 1912)	N.C.
Lamellidens lamellatus (Lea, 1838)	8
Lamellidens mainwaringi Preston, 1912	7

Lamellidens marginalis (Lamarck, 1819)	6
Lamellidens narainporensis Preston, 1912	6
Lamellidens rhadineus Annandale & Prashad, 1919	6
Lepidostomatidae	7
Leptophlebiidae	8
Lestidae	8
Leuctridae	10
Libellulidae	3
Limnephilidae	5
Limnichidae	N.A.
Limnocentropodidae	9
Limnodrilus claparedeanus Ratzel, 1868	4
Limnodrilus hoffmeisteri Claparede, 1862	2
Limnodrilus profundicola (Verill, 1871)	3
Limnodrilus udekemianus Claparede, 1862	4
Limoniidae	8
Lophopodella carteri (Hyatt, 1866)	7
Lophopodidae	7
Lumbricidae	5
Lumbriculidae	7
Lumbriculus variegatus (O.F.Muller, 1774)	8
Lymnaea kashmiriensis Annandale & Rao, 1925	6
Lymnaea acuminata (Lamarck, 1822)	4
Lymnaea andersoniana simulans (Preston, 1912)	8
Lymnaeidae	4
Macrobrachium spec.	8
Marionina riparia Bretscher, 1899	10
Megascolecidae	7
Mekongia crassa (Benson, 1836)	6
Melanoides pyramis (Hutton, 1850)	4
Melanoides tuberculatus (O.F. Müller, 1774)	4
Mermithidae	8
Mesopodopsis orientalis (W.M. Tattersall, 1908)	N.C.
Metaphire houlleti (Perrier, 1872)	7
Microchaetidae	7
Micronectidae	N.A.
Microtendipes sp. (Chironomidae)	4
Monoligastridae	6
Muscidae	N.A.
Musculium goshaithanensis Nesemann & Sharma 2005	4
Musculium indicum (Deshayes, 1854)	4
Mysidae	8

Myxobdella annandalei Oka, 1917	10
Myxobdella nepalica Nesemann & Sharma, 2001	10
Naididae	7
Nais alpina Sperber, 1948	10
Nais bretscheri Michaelsen, 1899	6
Nais communis Piguet, 1906	6
Nais elinguis (O. F. Müller, 1773)	N.A.
Nais pardalis Piguet, 1906	7
Nais simplex Piguet, 1906	5
Nais variabilis Piguet, 1906	N.A.
Namalycastis fauveli Rao, 1981	6
Namalycastis indica (Southern, 1921)	6
Naucoridae	4
Nemouridae	8
Neoephemeridae	9
Neoniphargus indicus (Chilton, 1923)	10
Neorhynchoplax nasalis (Kemp, 1916)	8
Nephthydae	8
Nephthys oligobranchia Southern, 1921	8
Nephthys polybranchia Southern, 1921	8
Nepidae	4
Nereididae	6
Nereis chilkaensis Southern, 1921	6
Neritidae	8
Neritina (Dostia) violacea (Gmelin, 1791)	8
Neritina smithi Wood, 1828	8
Niphargidae	10
Noteridae	N.A.
Notocanthurus cristatus (Heptageniidae)	7
Notonectidae	3
Novaculina gangetica Benson, 1831	8
Octochaetidae	N.C.
Odontoceridae	8
Onchidiidae	8
Onchidium typhae Buchannan, 1800	8
Oosthuizobdella garoui (Oosthuizen, 1981)	7
Ozobranchidae	8
Ozobranchus shipleyi Harding, 1909	8
Palaemonidae	7
Paludinella (Schuettiella) daengswangi Brandt, 1968	6
Paludomus blanfordiana Nevill, 1877	7
Paludomus conica (Gray, 1834)	7

Paraclepsis praedatrix Harding, 1924	7
Parathelphusa martensi (Wood-Mason, 1871)	6
Parathelphusa panningi Bott, 1966	6
Parathelphusidae	6
Parreysia corrugata laevirostris (Benson, 1862)	7
Parreysia favidens favidens (Benson, 1862)	7
Parreysia favidens chrysis (Benson, 1862)	7
Parreysia favidens deltae (Benson, 1862)	N.C.
Parreysia favidens pinax (Benson, 1862)	7
Parreysia sikkimensis (Lea, 1859)	7
Parreysia triembolus (Benson, 1855)	7
Parreysia viridula (Benson, 1862)	7
Peltoperlidae	10
Perionyx excavatus Perrier, 1872	7
Perionyx fluviatilis n. sp.	7
Perlidae	9
Perlodidae	9
Philopotamidae	8
Phryganeidae	8
Physa (Haitia) mexicana (Phillipi, 1889)	2
Physidae	2
Phytia plicata (Gray, 1825)	8
Pila globosa (Swainson, 1822)	4
Piscicolidae	N.C.
Pisidium annandalei Prashad, 1925	9
Pisidium atkinsonianum Theobald, 1876	8
Pisidium casertanum (Poli, 1795)	10
Pisidium clarkeanum dhulikhelensis Nesemann & Sharma, 2005.	6
Pisidium clarkeanum G. & H. Nevill, 1871	4
Pisidium ellisi Dance, 1967	10
Pisidium kuiperi Dance, 1967	9
Pisidium nevllianum Theobald, 1876	5
Pisidium prasongi Kuiper, 1974	9
Placobdelloides fulvus (Harding, 1924)	4
Placobdelloides multistriatus (Johansson, 1909)	7
Planariidae	9
Planorbidae: Planorbinae	4
Planorbidae: Bulininae (former: Ancylidae)	6
Platorchestia platensis (Kröyer, 1868)	8
Platycnemididae	8
Platystictidae	N.A.
Pleidae	4

Pleuroceridae	7
Plumatella casmiana Oka, 1907	7
Plumatellidae	7
Poecilobdella granulosa (Savigny, 1822)	8
Polycentropodidae	3
Polypedilum sp. (Chironomidae)	4
Pomatiopsidae	10
Potamidae	9
Potamiscus sikkimensis (Rathbun, 1905)	N.C.
Pristina breviseta (Bourne, 1891)	
Pristina cf. *biserrata* Chen, 1940	6
Pristina longiseta (Ehrenberg, 1828)	
Pristina macrochaeta Stephenson, 1936	
Pristina synclites Stephenson, 1925	6
Pristinella acuminata Liang, 1958	6
Pristinella jenkinae (Stephenson, 1931)	
Pristinella menoni (Aiyer, 1929)	
Protoneuridae	8
Psephenidae	8
Psychodidae (black)	6
Psychodidae (white)	1
Psychomyiidae	N.A.
Pyralidae	8
Quickia spec.	5
Radiatula andersoniana (Nevill, 1877)	8
Radiatula bonneaudi (Eydoux, 1838)	8
Radiatula caerulea (Lea, 1831)	6
Radiatula gaudichaudi (Eydoux, 1838)	6
Radiatula keraudreni (Eydoux, 1838)	7
Radiatula lima (Simpson, 1900)	7
Radiatula occata (Lea, 1860)	7
Radiatula olivaria (Lea, 1831)	8
Radiatula pachysoma (Benson, 1862)	7
Radiatula shurtleffiania (Lea, 1856)	7
Radix brevicauda (Sowerby, 1873)	5
Radix hookeri (Reeve, 1850)	8
Radix luteola (Lamarck, 1822)	4
Radix ovalis (Gray, 1822)	4
Radix persica (Issel, 1865)	4
Rhithrogena nepalensis (Heptagennidae)	10
Rhitrogena sp. (Heptageniidae)	8
Rhyacophilidae	6

Salifa (Herpobdelloidea) lateroculata (Kaburaki, 1921)	5
Salifa (Nematobdella) biharensis Nesemann et al., 2003	6
Salifidae	3
Sartoriana spinigera (Wood-Mason, 1871)	6
Scaphula celox Benson, 1836	8
Scaphula deltae Blanford, 1867	8
Scirtidae	10
Segmentina calatha (Benson, 1850)	4
Segmentina trochoidea (Benson, 1836)	5
Septaria tesselata (Lamarck, 1816)	8
Septariidae	8
Sericostomatidae	6
Sermyla riqueti (Grateloup, 1840)	4
Simuliidae	5
Siphlonuridae	10
Sisyridae	8
Solecurtidae	8
Sphaeriidae	5
Spongillidae	7
Stenopsychidae	7
Stenothyra deltae (Benson, 1836)	8
Stenothyra monilifera (Benson, 1856)	8
Stenothyra nana Prashad, 1921	8
Stenothyra ornata Prashad, 1921	8
Stenothyridae	8
Stratiomyidae	4
Stylaria fossularis Leidy, 1852	6
Succinea spec.	5
Succineidae	5
Tabanidae	4
Taeniopterygidae	10
Talitridae	8
Thiara granifera (Lamarck, 1822)	4
Thiara lineata Gray, 1828	4
Thiara scabra (O.F. Müller, 1774)	5
Thiaridae	4
Thremmatidae	8
Tipulidae	7
Torleya nepalica (Ephemerellidae)	6
Tricula godawariensis n. sp.	10
Tricula montana (Benson, 1843)	10
Tubifex tubifex (O. F. Müller, 1774)	N.C.

Tubificidae (*Limnodrilus hoffmeisteri, Branchiura sowerbyi*)	2
Tylenchida	N.C.
Uenoidae	9
Unionidae	6
Varuna literata (Fabricius, 1774) (Grapsidae)	4

Veliidae	8
Viviparidae	6
Whitmania laevis (Baird, 1869)	8

Appendix: XXV

Extended NEPBIOS (Nepalese Biotic Score) taxa list of benthic macroinvertebrates (Sharma *et al.*, 2007, to be published)

Taxa	Score
Capniidae, Ephemerellidae(*Drunella sp.*), Enchytraeidae(*Marionina spp.*), Epiophlebiidae, Helicopsychidae, Helodidae(Scirtidae), Heptageniidae(*Epeorus rhithralis*), Heptageniidae(*Rhithrogena nepalensis*), Hirudinidae(*Myxobdella nepalica, Dinobdella ferox*), Hydrobiidae, Leuctridae,Nipharyidae, Peltoperlidae, Perlidae(Acroneuria spp.), Perlidae(*Calicneuria sp.*), Pomatiopsidae, Siphlonuridae, Sphaeriidae(*Pisidium casertanum, Pisidium ellisi*), Taeniopterygidae, Uenoidae.	10
Athericidae, Chloroperlidae, Enchytraeidae (*Fridaericia perrperi*), Goeridae, Leptophlebiidae(*Habrophlebiodes sp.*), Limnocentropodidae,Naididae(*Nais alpina*), Neoephemeridae, Perlodidae, Polycentropodidae, Potamidae (*Himalayapotamon spp.*), Sphaeriidae (*Pisidium annadalei, Pisidium prasongi*), Tubificidae(*Aulodrilus limnobius*)	9
Arcidae, Baetidae (Centroptilum sp.), Brachycentridae, Chironomidae (Diamesinae), Elmidae, Euphaeidae, Gammaridae(Gammarus lacustris), Glossiphonidae (*Helobdella stagnalis, Paraclepsis praedatrix*), Glossosocolecidae (Glyphidrilus spp.), Glossosomatidae, Heptageniidae(*Epeorus bispinosus*), Heptageniidae((*Iron psi*), Heptageniidae (Rhithrogena spp.), Hydrobiosidae, Lepidostomatidae, Limnephilidae, Lumbricidae, Lumbriculidae, Lymnaeidae (*Galba simulans, Galba truncatula*), Nemouridae, Neritidae, Perlidae, Philopotamidae,Psephinidae, Rhyacophilidae, Sphaeriidae(Pisidium atkinsonianum), Stenopsychidae, Stenothyridae.	8
Aphelocheiridae, *Baetidae (Cloedodes sp.)*, Baetidae (*Baetiella spp.*), Baetidae (*Baetis spp.*), Baetidae (*Baetiella ausobskyi*), Baetidae (*Baetis sp1.*), Corydalidae, Ephemerellidae, Ephemerellidae (*Cincticostella sp.*), Ephemeridae, Erpobdellidae (Erpobdella *spp.*), Gammaridae, Gyrinidae, Heptageniidae, Heptageniidae(*Cinygmina sp.*), Heptageniidae (*Notacanthurus cristatus*), Hydraenidae, Leptophlebiidae, Limoniidae, Pleuroceridae, Psychomyiidae, Salifidae (*Barbronia sp.*) , Simuliidae, Tipulidae.	7
Aeshnidae, Assiminaeidae, Baetidae (*Baetis sp.5*), Baetidae (*Baetis sp.4*), Caenidae, Ceratopogonidae,Corbiculidae(*Corbicula bensoni, Corbicula assamensis*), Cymothoidae, Ecnomidae, Ellobiidae, Ephemerellidae(*Torleya nepalica*), Grapsidae (*Varuna literata*), Heptageniidae(*Electrogena* sp.), Hydrometridae, Hydropsychidae, Hydroptilidae, Hymenosomatidae, Naididae (*Ilyodrilus templetoni, Aulophorus furcatus*) , Nephthydae, Nereidae, Novaculidae, Onchidiidae, Scirtidae, Tubificidae (*Limnodrilus udekemianus*), Talitridae, Viviparidae.	6
Amblemidae, Atyidae, Baetidae (*Baetis sp.2*), Baetidae (*Baetis sp.3*), Bithyniidae, Chlorocyphidae, Coenagrionidae, Corduliidae, Dryopidae, Hirudinidea (*Asiaticobdella spp., Poecilobdella granulose*), Hydrophilidae, Leptophlebiidae (*Euthraulus spp.*), Naididae (*Dero limosa, Dero digitata*), Odontoceridae, Paratelphusidae (*Sartoriana spinigera*), Protoneuridae, Sphaeriidae (Pisidium nerillianum), Unionidae.	5
Calopterygidae, Chironomidae (*Microtendipes* sp.), Chironomidae (*Polypedilum* sp.), Corbiculidae (*Corbicula striatella*), Dytiscidae, Gerridae, Glossiphoniidae, Lymnaeidae, Micronectidae, Naucoridae, Nepidae, Palaemonidae, Planorbidae, Ranatridae, Salifidae (*Barbronia weberi*), Sphaeriidae (*Pisidium clarkeanum*), Thiaridae, Tubificidae (*Aulodrilus pluriseta, Limnodrilus claperecleanus*).	4
Atyidae (*Caridina* spp.), Corixidae, Libellulidae, Lumbricidae, Megascolecidae, Noteridae, Notonectidae, Salifidae.	3
Culicidae, Physidae, Tubificidae (*Brachiura sowerbyi, Limnodrilus hoffmeisterai*).	2
Chironomidae [*Chironomus* group *riparius (= thummi)* and group *plumosus*]	1

Appendix XXVI:

Calculation of Bach water quality Index (an example of October)

Month	Parameter	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6		Station 7	
		Value	$q_i^w i$	Value	$q_i^w i$	Value	$q_i^w i$	Value	$q_i^w i$	Value	$q_i^w i$	Value	$q_i^w i$	Value	$q_i^w i$
October	Temp(^{0}C)	17.2	1.438	20.5	1.388	16	1.443	16.5	1.441	19.67	1.404	18.33	1.427	23	1.318
	pH	7.13	1.585	7.03	1.583	6.67	1.56	6.83	1.574	7.13	1.585	7.03	1.583	6.2	1.518
	O_2 sat. %	84.81	2.447	78.65	2.394	63.95	2.204	65.54	2.234	64.42	2.204	48.06	1.935	52.03	2.006
	BOD_5 mg/L	1.84	2.466	2.98	2.377	9.12	1.69	15.2	1.304	37.04	1.304	75.99	1.304	78.35	1.304
	NO_3-N	0.08	1.583	0.21	1.581	0.33	1.578	0.39	1.576	0.52	1.574	1.37	1.553	3.23	1.5
	NH_4-N	0.05	1.995	0.12	1.995	0.16	1.96	0.31	1.862	0.42	1.815	0.83	1.697	1.31	1.654
	PO4	0.1	1.533	0.2	1.434	0.27	1.366	0.32	1.32	0.68	1.167	1.47	1.04	1.81	1.04
	Cond. uS/cm	33.33	1.368	44.1	1.371	57.4	1.375	62.43	1.375	71.93	1.376	122.03	1.38	276.4	1.372
	WQI		91.0893		77.5327		48.7086		35.19184		29.3397		21.559		18.5272
	WQ class		I		I-II		II-III		III		III		III-IV		III-IV

Appendix XXVII:

Calculation of Ministry of Public Transport and Public Works water quality Index (an example of October)

Month Oct.	Parameter	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6		Station 7	
		Value	Point awarded	Value	Point awarded	Value	Point awarded	Value	Point awarded	Value	Point awarded	Value	Point awarded	Value	Point awarded
	O_2 sat. %	84.81	2	78.65	2	63.95	3	65.54	3	64.42	3	48.06	4	52.03	3
	BOD_5 mg/L	1.84	1	2.98	1	9.12	4	15.2	5	37.04	5	75.99	5	78.35	5
	NH_4-N	0.05	1	0.12	1	0.16	1	0.31	1	0.42	1	0.83	2	1.31	3
	Sum of points		4		4		8		9		9		11		11
	WQ condition		Excellent		Excellent		Fair		Fair		Fair		Bad		Bad

Appendix XXVIII A:

Calculation of Saprobic water quality class using Original NEPBIOS, NEPBIOS-BRS, Extended NEPBIOS and GRS for stations 1 to 4 (an example of October)

Species	Station 1				Station 2				Station 3				Station 4			
	ON	BR	EN	GR	ON	BR	EN	GR	ON	BR	EN	GR	ON	BR	EN	GR
Perlidae	8	8	8	9	8	8	8	9								
Baetidae (*Baetis sp.*)	7	7	-	7	7	7	-	7	7	7	-	7	7	7	-	7
Caenidae	7	7	6	7	7	7	6	7	7	7	6	7	7	7	6	7
Heptageniidae	7	7	7	7	7	7	7	7								
Ephemerellidae	7	7	7	6	7	7	7	6	7	7	7	6	7	7	7	6
Leptophlebiidae	7	7	7	8	7	7	7	8								
Glossosomatidae	7	8	8	9	7	8	8	9	7	8	8	9				
Hydropsychidae	6	6	6	3	6	6	6	3	6	6	6	3	6	6	6	3
Dytiscidae					4	4	4	-	4	4	4	-	4	4	4	-
Elmidae	8	8	8	10	8	8	8	10								
Gyrinidae					6	7	7	7								
Hydrophilidae					6	5	5	-								
Limoniidae					8	7	7	8								
Simuliidae					7	7	7	5	7	7	7	5				
Chironomidae									1	1	1	1	1	1	1	1
Tabanidae					-	6	-	4	-	6	-	4	-	6	-	4
Stratiomyidae																
Muscidae																
Nepidae																
Aphelnocheiridae	7	7	7	7	7	7	7	7								
Gerridae									4	4	4	4				
Corixidae									4	3	3	2	4	3	3	
Vellidae	-	-	-	8												
Macromiidae																
Gomphidae	4	-	-	-	4	-	-	-	4	-	-	-	4	-	-	-
Corydalidae	6	7	7	7	6	7	7	7								
Salifidae																
Tubificidae																
Physidae																
Planaridae (*Dugesia sp.*)	-	- -	-	9	-	-	-	9								
Total score	81	79	71	97	112	115	101	113	58	60	46	48	40	41	27	28
ASPT	6.75	7.18	7.1	7.46	6.59	6.8	6.73	6.88	5.16	5.3	5	4.7	4.8	4.8	4.8	4
SWQC	II	I-II	I-II	I-II	II	II	I-II	I-II	II-III	II - III	II-III	II-III	II-III	II-III	II-III	III

Note: ON = Original NEPBIOS BR = NEPBIOS-BRS EN = Extended NEPBIOS GR = GRS
ASPT = Average Score Per Taxon SWQC = Saprobic Water Quality Class

Appendix XXVIII B:

Calculation of Saprobic water quality class using Original NEPBIOS, NEPBIOS-BRS, Extended NEPBIOS and GRS index for stations 5 to 7 (an example of October)

Species	Station 5				Station 6				Station 7			
	ON	BR	EN	GR	ON	BR	EN	GR	ON	BR	EN	GR
Perlidae												
Baetidae (*Baetis sp.*)	7	7	-	7	7	7	-	7				
Caenidae												
Heptageniidae												
Ephemerellidae												
Leptophlebiidae												
Glossosomatidae												
Hydropsychidae	6	6	6	3	6	6	6	3				
Dytiscidae	4	4	4	-								
Elmidae												
Gyrinidae												
Hydrophilidae												
Limoniidae												
Simuliidae												
Chironomidae	1	1	1	1	1	1	1	1	1	1	1	1
Tabanidae												
Stratiomyidae												
Muscidae												
Nepidae												
Aphelocheiridae												
Gerridae												
Corixidae												
Vellidae												
Macromiidae												
Gomphidae	4	-	-	-	4	-	-	-				
Corydalidae												
Salifidae					3	3	3	3				
Tubificidae	1	2	-	-	1	2	-	-				
Physidae					2	2	2	2				
Planaridae												
Total score	23	20	11	11	24	21	12	16	1	1	1	1
ASPT	3.83	4.0	3.67	3.67	3.43	3.5	3	3.2	1	1	1	1
SWQC	III	II-III	III	III-IV	III	III	III-IV	III-IV	IV	IV	IV	IV

Note: ON = Original NEPBIOS BR = NEPBIOS-BRS EN = Extended NEPBIOS GR = GRS
ASPT = Average Score Per Taxon SWQC = Saprobic Water Quality Class

Appendix: XXIX

One way ANOVA of test of significance of seasonal variation of physico-chemical and biological parameters of Manahara river

Parameters		Sum of squares	df	Mean Square	F	Sig.
Temperature	Between Groups	2184.150	9	242.683	30.526	.000
	Within Groups	477.008	60	7.950		
	Total	2661.158	69			
VELOCITY	Between Groups	1.582	9	.176	10.835	.000
	Within Groups	.974	60	1.623E-02		
	Total	2.556	69			
DEPTH	Between Groups	.759	9	8.428E-02	3.524	.001
	Within Groups	1.435	60	2.392E-02		
	Total	2.194	69			
Discharge	Between Groups	136.378	9	15.153	4.140	.000
	Within Groups	219.635	60	3.661		
	Total	356.012	69			
PH	Between Groups	2.242	9	.249	5.485	.000
	Within Groups	2.725	60	4.541E-02		
	Total	4.966	69			
DO	Between Groups	48.963	9	5.440	1.160	.337
	Within Groups	281.349	60	4.689		
	Total	330.312	69			
Oxygen sat %	Between Groups	1922.966	9	213.663	.431	.913
	Within Groups	29716.969	60	495.283		
	Total	31639.934	69			
BOD	Between Groups	6588.071	9	732.008	.336	.959
	Within Groups	130568.840	60	2176.147		
	Total	137156.910	69			
FREE_CO2	Between Groups	5589.780	9	621.087	1.508	.166
	Within Groups	24704.386	60	411.740		
	Total	30294.166	69			
Tot.alk/Bicarb.alk	Between Groups	63099.937	9	7011.104	1.110	.370
	Within Groups	379028.175	60	6317.136		
	Total	442128.112	69			
Bicarbonate	Between Groups	93916.549	9	10435.172	1.110	.370
	Within Groups	564137.799	60	9402.297		
	Total	658054.348	69			
TOT.HARD	Between Groups	6430.018	9	714.446	.459	.896
	Within Groups	93374.295	60	1556.238		
	Total	99804.313	69			
Ca(mg/L):	Between Groups	592.561	9	65.840	.542	.838
	Within Groups	7284.401	60	121.407		
	Total	7876.962	69			
Ca hardness:	Between Groups	3689.914	9	409.990	.543	.838
	Within Groups	45342.911	60	755.715		
	Total	49032.825	69			
Mg(mg/L):	Between Groups	60.967	9	6.774	.664	.738
	Within Groups	611.937	60	10.199		
	Total	672.904	69			
Chloride:	Between Groups	2345.811	9	260.646	.944	.495
	Within Groups	16571.499	60	276.192		
	Total	18917.310	69			
NO3	Between Groups	5.213	9	.579	.519	.855
	Within Groups	67.005	60	1.117		
	Total	72.218	69			

PO4	Between Groups	9.426	9	1.047	.848	.575
	Within Groups	74.074	60	1.235		
	Total	83.500	69			
AMMONIA	Between Groups	20.791	9	2.310	1.186	.320
	Within Groups	116.829	60	1.947		
	Total	137.619	69			
Conductivity:	Between Groups	416727.928	9	46303.103	1.119	.363
	Within Groups	2481638.994	60	41360.650		
	Total	2898366.922	69			
TDS:	Between Groups	172524.107	9	19169.345	1.102	.375
	Within Groups	1043482.887	60	17391.381		
	Total	1216006.994	69			
Tot. Coliforms	Between Groups	4299879904.667	9	477764433.852	.033	1.000
	Within Groups	157688657259.143	11	14335332478.104		
	Total	161988537163.810	20			
H	Between Groups	1.548	9	.172	.214	.991
	Within Groups	48.319	60	.805		
	Total	49.867	69			
C	Between Groups	8.353E-02	9	9.281E-03	.076	1.000
	Within Groups	7.290	60	.121		
	Total	7.373	69			
E	Between Groups	.254	9	2.828E-02	.534	.843
	Within Groups	2.755	52	5.297E-02		
	Total	3.009	61			
DENSITY	Between Groups	982657.533	9	109184.170	3.528	.001
	Within Groups	1856992.053	60	30949.868		
	Total	2839649.586	69			
BACH	Between Groups	2.432	9	.270	.225	.990
	Within Groups	71.929	60	1.199		
	Total	74.361	69			
MPTPW	Between Groups	6.514	9	.724	.400	.930
	Within Groups	108.571	60	1.810		
	Total	115.086	69			
GRS	Between Groups	1.643	9	.183	.168	.997
	Within Groups	65.143	60	1.086		
	Total	66.786	69			

Appendix: XXX

One way ANOVA of test of significance of spatiao variation of physico-chemical and biological parameters at different stations of Manahara river

Parameters		Sum of Squares	df	Mean Square	F	Sig.
Temperature	Between Groups	279.083	6	46.514	1.230	.303
	Within Groups	2382.074	63	37.811		
	Total	2661.158	69			
VELOCITY	Between Groups	.253	6	4.221E-02	1.155	.342
	Within Groups	2.303	63	3.655E-02		
	Total	2.556	69			
DEPTH	Between Groups	.616	6	.103	4.102	.002
	Within Groups	1.577	63	2.504E-02		
	Total	2.194	69			
Discharge	Between Groups	98.849	6	16.475	4.036	.002
	Within Groups	257.164	63	4.082		
	Total	356.012	69			
PH	Between Groups	.920	6	.153	2.388	.038
	Within Groups	4.046	63	6.423E-02		
	Total	4.966	69			
DO	Between Groups	224.374	6	37.396	22.239	.000
	Within Groups	105.938	63	1.682		
	Total	330.312	69			
Oxygen sat %	Between Groups	22833.984	6	3805.664	27.227	.000
	Within Groups	8805.950	63	139.777		
	Total	31639.934	69			
BOD	Between Groups	116533.763	6	19422.294	59.332	.000
	Within Groups	20623.147	63	327.352		
	Total	137156.910	69			
FREE_CO2	Between Groups	15179.533	6	2529.922	10.545	.000
	Within Groups	15114.633	63	239.915		
	Total	30294.166	69			
Tot.alk/Bicarb.alk	Between Groups	289419.257	6	48236.543	19.900	.000
	Within Groups	152708.855	63	2423.950		
	Total	442128.112	69			
Bicarbonate	Between Groups	430766.866	6	71794.478	19.900	.000
	Within Groups	227287.482	63	3607.738		
	Total	658054.348	69			
TOT.HARD	Between Groups	82957.514	6	13826.252	51.704	.000
	Within Groups	16846.798	63	267.409		
	Total	99804.313	69			
Ca(mg/L):	Between Groups	6497.401	6	1082.900	49.452	.000
	Within Groups	1379.561	63	21.898		
	Total	7876.962	69			
Ca hardness:	Between Groups	40443.326	6	6740.554	49.439	.000
	Within Groups	8589.499	63	136.341		
	Total	49032.825	69			
Mg(mg/L):	Between Groups	476.233	6	79.372	25.425	.000
	Within Groups	196.671	63	3.122		
	Total	672.904	69			
Chloride:	Between Groups	11869.284	6	1978.214	17.683	.000
	Within Groups	7048.026	63	111.873		
	Total	18917.310	69			
NO3	Between Groups	61.002	6	10.167	57.108	.000
	Within Groups	11.216	63	.178		
	Total	72.218	69			

PO4	Between Groups	55.659	6	9.276	20.991	.000
	Within Groups	27.841	63	.442		
	Total	83.500	69			
AMMONIA	Between Groups	69.168	6	11.528	10.610	.000
	Within Groups	68.451	63	1.087		
	Total	137.619	69			
Conductivity:	Between Groups	1861969.741	6	310328.290	18.864	.000
	Within Groups	1036397.181	63	16450.749		
	Total	2898366.922	69			
TDS:	Between Groups	783572.850	6	130595.475	19.026	.000
	Within Groups	432434.144	63	6864.034		
	Total	1216006.994	69			
Tot. Coliforms	Between Groups	144912516341.143	6	24152086056.857	19.801	.000
	Within Groups	17076020822.667	14	1219715773.048		
	Total	161988537163.810	20			
H	Between Groups	46.212	6	7.702	132.733	.000
	Within Groups	3.656	63	5.803E-02		
	Total	49.867	69			
C	Between Groups	6.846	6	1.141	136.302	.000
	Within Groups	.527	63	8.371E-03		
	Total	7.373	69			
E	Between Groups	2.184	6	.364	24.253	.000
	Within Groups	.825	55	1.501E-02		
	Total	3.009	61			
DENSITY	Between Groups	911188.085	6	151864.681	4.961	.000
	Within Groups	1928461.501	63	30610.500		
	Total	2839649.586	69			
BACH	Between Groups	68.136	6	11.356	114.928	.000
	Within Groups	6.225	63	9.881E-02		
	Total	74.361	69			
MPTPW	Between Groups	99.486	6	16.581	66.962	.000
	Within Groups	15.600	63	.248		
	Total	115.086	69			
GRS	Between Groups	61.236	6	10.206	115.851	.000
	Within Groups	5.550	63	8.810E-02		
	Total	66.786	69			

PHOTO DISPLAY

Plate 1: Sampling station 1, Salinadi river, Sakhu

Plate 2: Sampling station 2, Manahara river at Sakhu after confluence of Salinadi and Naldum Khola, Sakhu

Plate 3: Sampling station 3, Manahara river at Brahmakhel after its confluence with Mahadev Khola.

Plate 4: Sampling station 4, Manahara river at Bode.

Plate 5: Sampling station 5, Manahara river at Sinamangal.

Plate 6: Sampling station 6, Manahara river at Imadol after its confluence with Hanumante Khola.

Plate:7: Sampling station 7, Manahara river at Chyasal. (before confluence with Bagmati river)

Plate 8: Researcher determining dissolved oxygen content of water in the field.

Plate 9: Researcher at the sampling of macroinvertebrates with guidance of Prof. Dr. Uma Kant Ray Yadav (supervisor)

Plate 10: Researcher observing the samples of macroinvertebrates with Dr. Surya Ratna Gubhaju

Plate 11: Researcher identifying the macroinvertebrates at the laboratory of Central of Department of Environmental Science, Tribhuvan University.

Plate 12: On going religious activitiesn at Salinadi on "Swasthanani Purnima' below the sampling station 1.

Plate 13: Washing and bathing in the Manahara river at Bode.

Plate 14: Sewage outfall to Manahara river from Mulpani.

Plate 15: Solid waste dumping at the bank of Manahara river at Jadibuti above sampling station 6.

Plate 16: Foam generated by the partially treated wastewater from Kodku wastewater treatment plant before mixing to Manahara river, Balkumari.

Plate 17: Squatter settlements at both banks of Manahara river at Jadibuti above sampling station 6.

Plate 18: Government notice for not extracting sand from the Manahara river.

THE END