ICIMOD Working Paper 2019/6

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Freshwater ecosystems of the Koshi River basin, Nepal: A rapid assessment

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Freshwater ecosystems of the Koshi River basin, Nepal: A rapid assessment

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Abbreviations and acronyms

ASPT	Average Score per Taxon
DO	Dissolved Oxygen
EC	Electrical Conductivity
EPT	Ephemeroptera, Plecoptera, and Trichoptera
FGD	Focus Group Discussion
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Flood
HDP	High Density Polypropylene
HKH	Hindu Kush Himalaya
KRB	Koshi River Basin
masl	Meters above Sea Level
mg/l	Milligram per Litre
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NEPBIOS	Nepalese Biotic Score
NTU	Nephelometric Turbidity Unit
PO_4	Phosphate
RFB	Rapid Field Bio-assessment
RHA	Rapid Habitat Assessment
RQC	River Quality Class
SD	Standard Deviation
SOP	Standard Operating Procedure
TH	Total Hardness
WQC	Water Quality Class
μS/cm	microSiemens per cm
μm	micrometre

Executive summary

Freshwater ecosystems cover only 0.8% of the earth's surface, but they are amongst the most diverse systems in the world. They are vital for the life and well-being of billions of people as they provide different direct and indirect services. Our present focus of the study, the Koshi River basin (KRB), one of the largest tributaries to the Ganga River, is home to about 40 million people who depend on it for the ecosystem services. This basin is especially important to the people of Nepal, whose livelihoods and economic growth it supports. However, freshwater ecosystems in the KRB are changing because of various natural disturbances and human interventions. Moreover, limited knowledge is available on the status of its freshwater ecosystems. The assessment of the status of freshwater is crucial for managing, conserving, and restoring any freshwater ecosystem. Therefore, this study carried out a rapid assessment of the Koshi basin of Nepal to produce knowledge on the status of the river ecosystems in the basin.

This paper used multi-criteria analysis to identify the critical freshwater ecosystems in the KRB. Based on consultations with local communities, thematic experts, local/national-level stakeholders, and a secondary review of relevant literature, the most critical sites were selected for the physico-chemical analysis of water, rapid habitat assessment (RHA), bio-screening, and habitat sampling for evaluating the physical components and the quality of the freshwater. A total of 18 focus group discussions (FGDs) were conducted to get information on the pressures and dependency of the local people on these freshwater ecosystems.

This study found 86 critical freshwater ecosystems in 13 districts of the basin through the multi-criteria and geographic information system (GIS) analysis. By employing multiple criteria parameters – such as the many existing and proposed hydropower plants, changes in agricultural land, increase in built-up area, forest cover loss, change in the course of waterbodies, and increase in the degraded vegetation area – these freshwater ecosystems were found to be in the category of critical ecosystems.

For a further study, six of the most critical freshwater ecosystems, i.e. rivers, were selected based on the existing stress on them, which are in three geographical locations. Physico-chemical analysis – such as pH, temperature, dissolved oxygen (DO), total hardness (TH), electrical conductivity (EC), and turbidity of samples – and habitat assessment of the high and middle mountain regions showed acceptable ranges for supporting life with slightly polluted, but good habitat condition. Such readings in the Terai/Chure region showed the sites to be moderately polluted, but with fair habitat condition. Meanwhile, 32 families (9 orders and 2 classes) of macro-invertebrates were observed in the sampling stations, with the highest number of 19 families in the High Mountain and the least (12) in the Terai/Chure. The thin presence of macro-invertebrates in Terai/Chure indicates the predominance of polluted water in the downstream area compared to the upstream area.

The results showed that human interference (development activities such as dam construction for hydropower and irrigation, waste dumping, and unstainable agricultural practices) and sparse vegetative cover have affected the vitality of the ecosystems in the study sites. It was also found that freshwater ecosystems, the major sources for irrigation and household use in the study sites, have been decreasing over time, and limited activities have been conducted till now to conserve these freshwater sources.

Therefore, to control the further degradation of these freshwater ecosystems, and to conserve and sustainably manage the freshwater sources, this study recommends promoting community-based integrated watershed management. Similarly, endorsing incentives in the sphere of ecosystem services will help link upstream and downstream communities, whereby managing resources upstream secures benefits for downstream communities and incentives (monetary/non-monetary payment) for upstream communities. Furthermore, as proper information about the status of freshwater ecosystems is still lacking in the basin, it is imperative to conduct further studies and research to understand the complex hydrological dynamics and impact of climate change on the different components of the basin.

Key words: critical freshwater ecosystem, water quality, habitat condition, water pollution

Introduction

Freshwater ecosystem

Any aquatic system with an average salinity of less than 0.5 parts per thousand is defined as a freshwater ecosystem (Moss, 2009). Freshwater ecosystems, which include lakes, ponds, rivers, streams, springs, and wetlands, are vital for all living things. They are essential for the long-term sustainability of aquatic life and systems, for the well-being of local communities, and for the conservation of biological diversity (Whitten et al., 2002). They provide different direct and indirect services, such as provisioning, regulating, supporting and cultural services. There is a growing recognition of the services provided by freshwater ecosystems – such as supplying water for drinking, irrigation and industrial purposes; they also play a role in flood control, transportation, purification of toxins, sustaining the habitats of plants and animals, food supply, and even recreation (Baron et al., 2003). Though these freshwater systems occupy only 0.8% of the earth's surface and make up only 0.01% of the world's water, they support almost 6% of all the described species (Dudgeon et al., 2005).

However, as freshwater ecosystems are highly vulnerable, factors such as rapid socio-economic development, land-use change and increase in temperature lead to alteration of the structural and functional process of these ecosystems. Such factors have impaired the distribution and abundance of aquatic organisms, the water quality and the ecological integrity of freshwater ecosystems (Martin et al., 2014). Moreover, unsustainable agricultural practices, livestock and domestic discharges, deforestation, introduction of exotic species, and direct erosion have increased the quantity of organic matter and suspended solids in the water, resulting in strong alterations in the ecological functioning of aquatic systems (Kaufman, 1992).

Freshwater ecosystem services are also sensitive to climate and land-cover changes (Hoyer and Chang, 2014). With the advent of climate change, aspects such as water availability, monsoonal patterns, water tables and freshwater storage in glaciers are also undergoing change (Taylor et al., 2014). Besides, irrigation abstraction and hydropower development have altered the flow regimes of rivers/streams, which have resulted in ecological degradation and loss of biological diversity; this will ultimately lead to unhealthy ecosystems that are unable to provide important ecosystem services (Poff et al., 1997). The degradation of freshwater ecosystems and their services have highly affected the local communities, especially the poor and marginalized people. Thus, there is an increasing need to understand the status of freshwater ecosystems and identify the key drivers or pressures on these ecosystems so that effective measures to conserve, manage, and utilize freshwater can be taken without any further delay.

Importance of freshwater ecosystems in the Koshi basin

The KRB, one of the most important river systems of the Hindu Kush Himalayan (HKH) region, originates in the Himalaya. It is one of the major contributors to the Ganga River. It covers around 87,000 km^2 of catchment area, out of which 46% lies in Nepal. Here, the basin is about 160 km from north to south, and covers six geological and climatic belts. It contains within itself 8 major peaks of over 8000 masl, including Mt Everest; 13 rivers and streams, 36 glaciers, and 296 glacial lakes (Bajracharya et al., 2007). Its three largest tributaries, the Sunkoshi, Arun, and Tamor, join at Tribeni, where the Sapta Koshi turns south and flows through the Barahkshetra gorge for about 15 km before reaching Chatara in the Terai. Downstream of Chatara, the Trijuga River drains the southern Mahabharata range in Nepal, flowing from west to east into the Koshi River, which then flows for almost 10 km through a narrow gorge before entering the plains. The "Sapta Koshi", meaning "Koshi" swollen with the waters of the seven rivers, finally merges into the river Ganga in India (Dixit et al., 2009; Sharma et al., 2005).

The basin stretches from the Tibetan Plateau through Nepal to the Indo-Gangetic Plain in India. Thus, it functions as a vital biological corridor for various fauna. It is characterized by various types of ecosystems and habitats such as glaciers, snow lands, rock formations, wetlands, rangelands, forests, alpine meadows with grasses and sedges, and floodplains (Bhatta et al., 2016). There are seven protected areas in the basin, out of which six are in Nepal: Qomolangma National Park (Tibet Autonomous Region, China), Sagarmatha National Park, Langtang National Park, Shivapuri National Park, Makalu Barun National Park, Kanchenjunga Conservation Area, and Koshi Tappu Wildlife Reserve (a designated Ramsar site).

Agriculture, hydropower generation, and other major activities are dependent on the sustained quantity of water supply from the Koshi River and its tributaries. Apart from that, the freshwater ecosystems found in the basin are used for fishery, drinking water, and irrigation. Nearly 48 billion cubic metres of water is available annually in the Koshi basin of Nepal to generate 10,086 MW of economically feasible power; and it irrigates approximately 500,000 ha of agricultural land (WECS, 1999), with one of the largest irrigation facility, Morang-Sunsari, irrigating nearly 66,000 ha of agriculture land downstream (Fish et al., 1986). Meanwhile, the Koshi Tappu Wildlife Reserve provides ecosystem services (though selectively) worth USD 16 million per year, out of which 85% is generated from provisioning services (Sharma et al., 2015).

However, the freshwater ecosystems of the KRB are changing (Uddin et al., 2015) due to land-use and land-cover alterations (Uddin et al., 2016). This has resulted in loss of habitat for many aquatic and terrestrial species (Chettri et al., 2013). Besides, the trend of increasing precipitation and flows (Agarwal et al., 2014; Bharati et al., 2014; Nepal, 2016), variations in glacier dynamics (Wang and Zhang, 2014), heightened risk from glacial lake outburst flood (GLOF) (Khanal et al., 2015), and agricultural intensification (Dahal et al., 2007) have affected the health of the KRB's freshwater.

Despite the clear importance of freshwater in social and economic development, very little knowledge is available about its status and biodiversity. Because of the complex nature of freshwater systems, there is a lack of comprehensive and synthesized data on the distribution of freshwater biota (Abell et al., 2008). But assessment of the state of freshwater ecosystems is crucial for managing freshwater, as well as for conserving and restoring these ecosystems. Therefore, freshwater ecosystems should be assessed separately from terrestrial and other systems because of their importance to human well-being and their unique species composition, ecological dynamics, and functions (Herbert et al., 2010). Thus, this study provides researchers, aquatic resource managers, land planners, and policymakers information on the status of freshwater ecosystems in the KRB so that urgent development needs related to water resources can be addressed in a timely manner while balancing competing demands and accounting for critical and bundled freshwater ecosystem services. This paper, with the help of the rapid assessment tool, aims to understand the current status of the KRB's freshwater ecosystems; it also attempts to identify the dependency factors, the major drivers of change and the associated pressure on these ecosystems.

Methodology

Identification of critical freshwater ecosystems

According to Fleiner (2014), critical freshwater ecosystem areas are those that hold great importance to their environment, both natural and human; they are highly vulnerable to climatic and non-climatic changes; and are being degraded or at the risk of being degraded due to development activities and increased and/or competing demands for services. The following criteria, proposed by Fleiner (2014), were used to select the critical freshwater ecosystems:

- High biological diversity and/or corridor function (e.g. habitat/species diversity, indicator species)
- Livelihood and development dependence (e.g. water supply, fishery, other services) on freshwater ecosystem areas
- Rapidly increasing user and/or development pressures and/or overuse that threaten or disrupt ecosystem functions (e.g. encroachment, resource overuse, population increase, pollution, hydropower, expansion of irrigated farming land, land-use changes, industries)
- Actual or potential ecosystem change and/or degradation (in terms of water flow regime, water quality, habitat, land cover in riparian areas, biological diversity/species composition)

Topography survey maps, Landsat images (of 2010), geology/soil information, and population data were collected for the multi-criteria analysis to identify the critical freshwater ecosystem areas. These identified areas were ranked using the weighted overlay of various factors. The data sets used were the Euclidean distance of existing and proposed hydropower plants, road networks, built-up gain, agricultural area gain, forest-cover loss, and change in the value of the normalized difference vegetation index (NDVI) between 2000 and 2015 (Figure 1). Composites of 16 days of Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI values representing the 289th Julian day (middle of October) between 2000 and 2015 were used for this study.

A pair-wise ranking was performed to find out the relative weightage of the factors contributing to the vulnerability of the water resources. The relative weightage values were used for the weighted overlay of the factors concerned in raster formats. Before overlaying the factors, Z scores of all the factors were calculated. These Z scores were used for the spatial overlay analysis. The Z scores were calculated using the following formula:

Z = (Individual pixel value – mean value)/Standard Deviation of the dataset .... (1)

For further research, three different geographical areas were selected: High Mountains, Middle Mountains, and Terai/Chure (Table 1). Two districts were selected from each geographical area from where one freshwater ecosystem (i.e. a river) was selected purposively to collect water samples, conduct habitat assessment, and to hold FGDs.

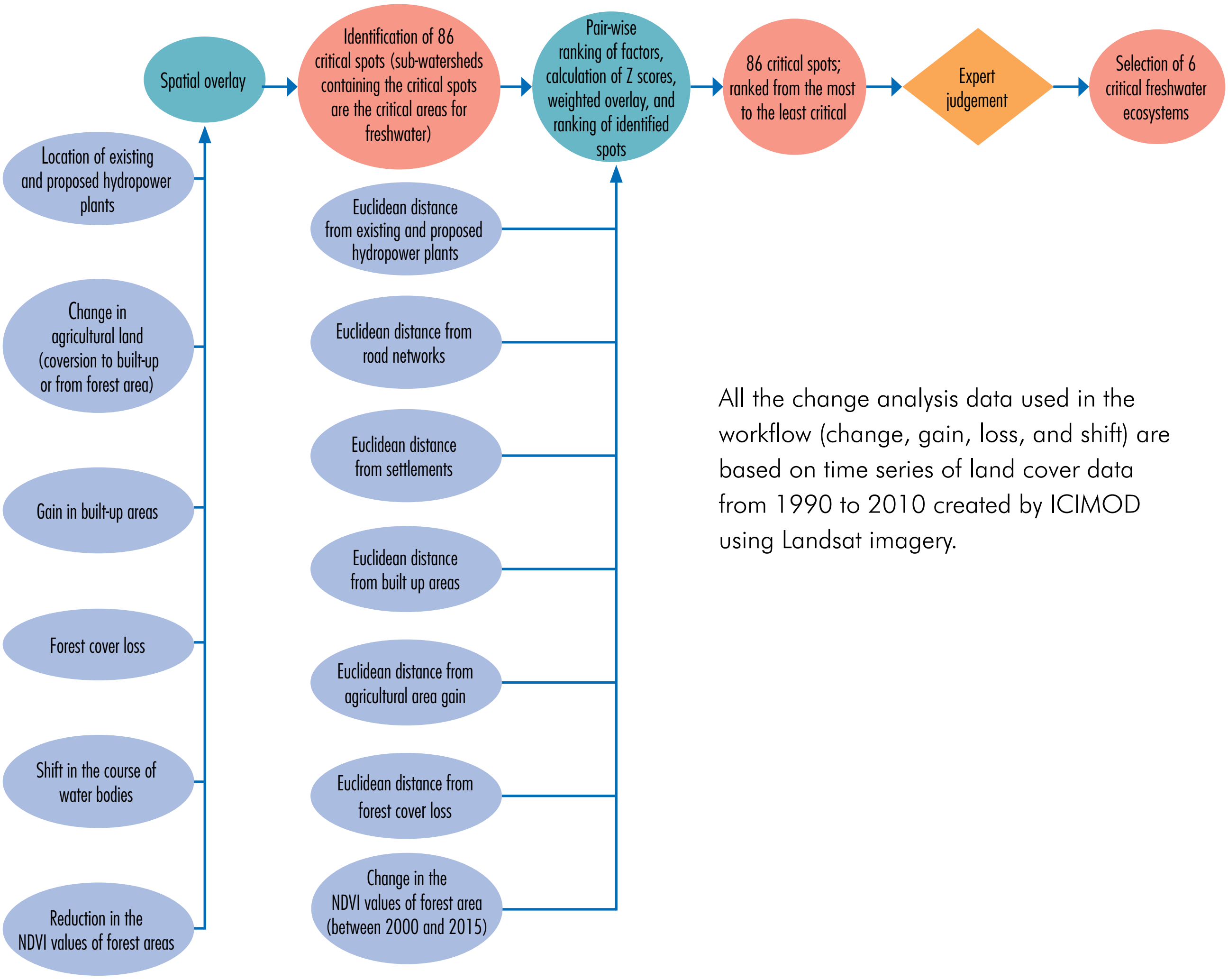
Table 1: **Study sites from three different geographical areas**

Geographical location	Rivers	Districts
High Mountains	Tingla and Melamchi	Solukhumbu and Sindhupalchok
Middle Mountains	Nibuwa and Sabha	Dhankuta and Sankhuwasabha
Terai/Chure	Triyuga and Koshi	Udayapur and Sunsari

Zone selection

Water samples were taken from three different zones of each river. These zones were selected locally based on the observed stressors influencing the rivers. The reference zone/upstream was supposed to be undisturbed and pristine, and in close adherence to the ideal natural state; the impact zone/midstream had visible impacts of human influence/development activities on the aquatic ecosystem; and the recovery zone/downstream was compared to the reference zone so that the restoration capacity of the natural body would be sufficient to restore the lost qualities as exhibited in the impact zone. The reference zone was always chosen at 3–5 km above the impact zone whereas the distance for the recovery zone varied across the study due to the differences in its restoration capacity to overcome the stress factor.

Figure 1: **Flowchart of GIS analysis**



All the change analysis data used in the workflow (change, gain, loss, and shift) are based on time series of land cover data from 1990 to 2010 created by ICIMOD using Landsat imagery.

Physico-chemical analysis of water

Standard operating procedures (SOPs) and the Guideline Specification of Standard Methods for Analysis of Water and Wastewater (APHA, 1998) were followed for the physico-chemical measurement. Elaborate water physico-chemical analysis was done for both physical (temperature, DO, turbidity, pH) and chemical parameters (nitrates, orthophosphates, TH) by collecting the water samples from three zones of each river.

Altogether 72 water samples were collected from 4 sampling points located within 500 m in each zone. These samples were collected in new, white high-density polypropylene (HDP) pre-cleaned bottles. These bottles were washed with distilled water prior to collecting the samples. The samples were collected from a depth of 5–10 cm below the surface water by allowing them to settle in a beaker in order to minimize the variations in the observed parameters, and then stored in an ice box maintained at a temperature of 4°C. The physical parameters were measured in the field, whereas the samples were transported to the laboratory in the Aquatic Ecology Centre, Kathmandu University, for analysing the chemical parameters.

The procedure of quality assurance was carried out by calibrating the probes used in the field as prescribed in SOP, which was further confirmed with the standard solution in the laboratory. Errors were minimized by reconfirming the test kits with standard solutions for each sampling site. The probes for pH, conductivity, temperature, and nitrate showed ± 0.1 to ± 0.2 errors to the standard reference solution, whereas the blank solution, i.e., distilled water, was used for TH and orthophosphate with the value of the blank solution subtracted from the readings of the analysed samples.

Habitat assessment and macro-invertebrate assemblage

Biological water quality assessment is one of the most reliable, affordable and field-based tools used to evaluate the health status of rivers/streams (Iliopoulou-Georgudaki et al., 2003). This assessment was done in five of the six sub-watersheds of the Koshi. However, due to the high-volume flow of water in the Koshi River, the sampling of micro-invertebrates could not be done. As for macro-invertebrate assessment, samples were collected from all the zones of each river.

The assessment followed a qualitative sampling procedure (Barbour et al., 1999), and was mostly carried out using a technique called "kick sampling". The macro-invertebrates were collected using a hand-net with a mesh size of 200 micrometre (μm) and the samples were collected from riffles (fast* and shallow* bed features), pools (slow* and deep* bed features), and runs (fast* and deep* bed features) (Table 2), as well from available substrates such as boulders, cobbles, and gravel. The hand-net was placed against the water current just before the habitat was disturbed with the anticipation that the organism would be swept with the water current into the net. In some cases, the habitats were disturbed by hands as well. After sorting the samples in a white tray, the unidentified biota were preserved in 70% ethanol for lab assessment.

Table 2: **Waterbody characteristics**

*Fast: >0.3 m/s (1 ft/s)	*Slow: <0.3 m (1 ft/s)
*Deep: >0.5 m (1.5 ft)	*Shallow: <0.5 m (1.5 ft)

Multi-habitat assessment protocol

Habitat assessment is an integral part in the evaluation of impairment and for documentation of each bio-survey site, and is done prior to sampling. The parameters used by the habitat assessment protocol are based on the key physical characteristics of the waterbody and its catchment (Barbour et al., 1999). The parameters listed in the RHA evaluate the physical components of a stream/river (channel bed, banks, and riparian vegetation) and how its physical condition affects aquatic life. There are 10 parameters employed here, with each scored on a scale of 0 (Poor) to 20 (Excellent). Different habitat assessment field data sheets exist for high-gradient and low-gradient streams/rivers, and so these were used accordingly during the study based on visual observation. The methodology was based on a study by Barbour et al. (1999). Then the parameter scores were totalled and compared to a reference condition score. The reference condition is most useful if it is specific to the stream/river type being evaluated. The references can be identified locally within the watershed or the area of study; regional references can be used too. However, not all reference sites selected for this study met the criteria for a typical reference site, so the RHA scored from a site was compared to RHA score ranges. Then the totalled score circled for 10 habitat parameters was divided by 200, which is the total possible score for RHA. The score ranges used to evaluate the habitat condition of the studied sites are in Table 3.

Table 3: **Rapid habitat assessment scores used to evaluate habitat conditions**

Reference condition	0.85–1.0
Good condition	0.65–0.84
Fair condition	0.35–0.64
Poor condition	0.00–0.34

Rapid field bio-assessment

This is a screening protocol used after the multi-habitat assessment protocol by Moog (2007). This includes the rapid screening of both biotic and abiotic components of the streams/rivers such as the turbidity of water, the presence of suspended solids, non-natural turbidity, foam, odour, waste dumping, ferro-sulphide reduction, algal vegetation, the presence of filamentous green algae, and the presence or absence of macro-invertebrate taxon. Based on visual observations and the relative abundance of the macro-invertebrate fauna, rapid field bio-assessment (RFB) pre-classifies the sampling sites into five classes (Table 4). RFB was used in each studied site except in the Koshi River because of the high volume of water in the river.

Table 4: **River quality classes**

River quality class (RQCs)	Description
I	None to very slight pollution
II	Moderate pollution
III	Critical pollution
IV	Heavy pollution
V	Very heavy to extreme pollution

Nepalese Biotic Score

Nepalese Biotic Score (NEPBIOS) is an assessment tool developed specifically for the rivers in Nepal in order to assess the water quality in them using macro-invertebrates as the bio-indicators. Method-wise, it is similar to average score per taxon (ASPT) (Sharma, 1999). Here, scores are assigned ranging from 1 to 10 for about 82 macro-invertebrate families based on the pollution tolerance shown by each family (Score 1 = most pollution-tolerant family, and Score 10 = most pollution-intolerant family). Each identified macro-invertebrate was given a score following NEPBIOS and the total score for the sample was calculated by adding the score given to each benthic invertebrate. The total score thus obtained for the sample was divided by the total number of families identified in the sample. This average score was then matched with the score given in the score transformation table to obtain the water quality class (WQC) (Table 5). WQC was estimated using NEPBIOS/ASPT (Sharma, 1996).

Table 5: **Water quality classes of the study sites**

NEPBIOS/ASPT Original scale	NEPBIOS/ASPT for midlands	NEPBIOS/ASPT for lowlands	WQC	Description
8.00–10.00	7.50–10.00	6.50–10.00	I	Unpolluted to very slightly polluted
7.00–7.99	6.51–7.49	6.00–6.49	I–II	Slightly polluted
5.50–6.99	5.51–6.50	5.00–5.99	II	Moderately polluted
4.00–5.49	4.51–5.50	4.00–4.99	II– III	Critically polluted
2.50–3.99	3.51–4.50	2.50–3.99	III	Heavily polluted
1.01–2.49	2.01–3.50	1.01–2.49	III– IV	Very heavily polluted
1	1.00–2.00	1	IV	Extensively polluted

The macro-invertebrate samples collected were sorted and identified in the laboratory following the methods of Birmingham et al. (2005), Clifford (1996), and Merritt and Cummins (1996). The samples were observed under a light microscope for proper identification; the identification was done up to the family level. The results obtained from this macro-invertebrate identification were used to estimate NEPBIOS.

Socio-economic stressor assessment

A total of 18 FGDs, 3 in each district, were conducted to acquire information on user and development pressure on the Koshi basin, and to find out the dependence of local livelihoods on the freshwater ecosystems of the basin. Similarly, information was also gathered on the activities that were being carried out to conserve water.

Results and discussion

Identification of critical freshwater ecosystems in the Koshi River basin

Climate change and human intervention have resulted in changes in the structural and functional process of the freshwater ecosystems in the KRB. This has decreased both the quantity and quality of the water. Ultimately, the entire watershed could be jeopardized. Under these circumstances, a rapid assessment of the freshwater ecosystems was performed by selecting the freshwater sources of critical watershed areas. A time series analysis with topographic maps and satellite imagery was carried out to analyse the status and temporal changes in the water surface delineations of the basin. Altogether, 86 critical freshwater ecosystems in 13 districts were identified and ranked during the analysis (Figure 2). Out of these, 38 critical freshwater ecosystems were located in the High Mountains, 33 in the Middle Mountains and 15 in the Terai/Chure regions (Annex I). Different factors such as existing and proposed hydropower plants, changes in agricultural land, increase in the built-up area, loss of forest cover, vegetation degradation, and changes in water bodies characterized these freshwater ecosystems as critical (Annex II).

After consultations with stakeholders and experts, six of the most critical freshwater ecosystems were chosen for performing detailed assessments of these ecosystems at the watershed level (Figure 3). These sites were selected based on the present stress on the rivers (Table 6). Furthermore, as the pressure factors differ depending on the location (Lira-noriega et al., 2015), sites from three geographical locations were selected. These sites show great diversity in terms of their topography, slope, aspect, climate, vegetation, demography, and sociocultural features.

Figure 2: **Location of potential critical freshwater ecosystems**

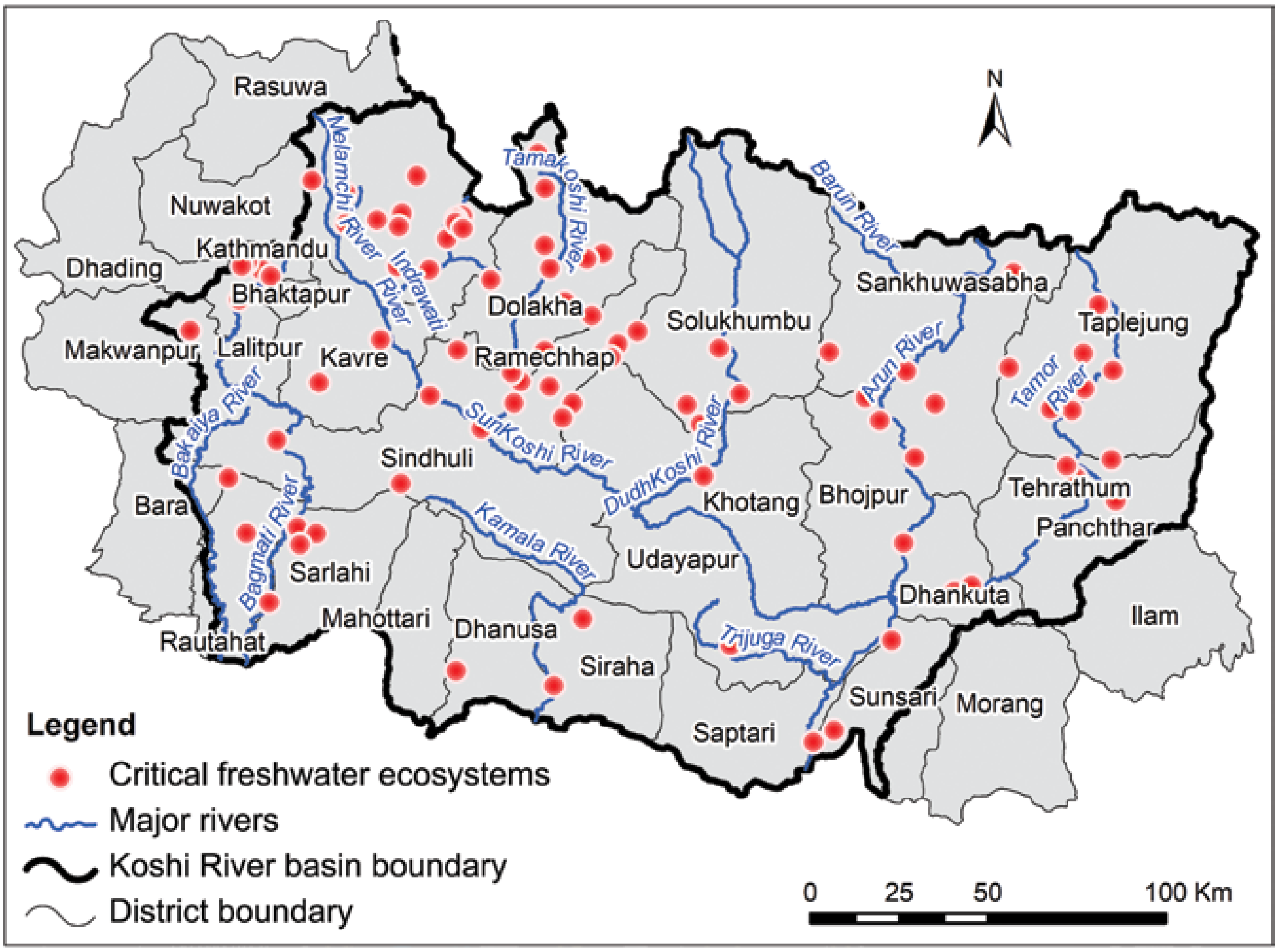


Figure 3: **Location of six of the most critical freshwater ecosystems at the watershed level**

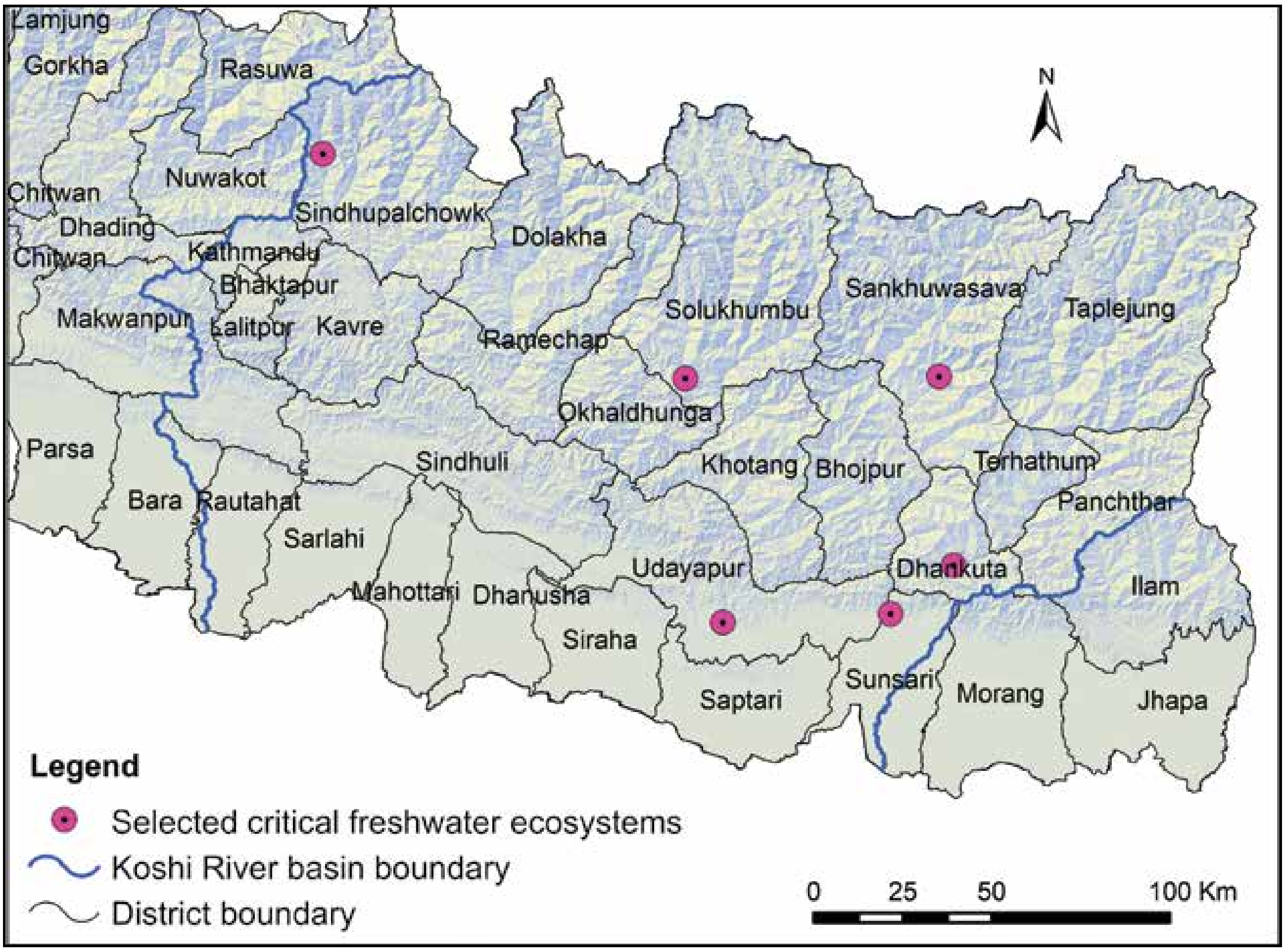


Table 6: **Selected critical sites for rapid assessment**

SN	District	VDC/ Municipality	Altitude (masl)	Geographic region	Present stress
1	Solukhumbu	Tingla	1,800	High Mountains	Ongoing hydropower plant construction
2	Sindhupalchok	Helambu	1,400	High Mountains	Ongoing construction of Melamchi–Kathmandu water supply pipelines
3	Dhankuta	Dhoku	712	Middle Mountains	Drinking water scheme
4	Sankhuwasabha	Dhupu	430	Middle Mountains	Ongoing hydropower plant construction
5	Udayapur	Triyuga	90	Terai/Chure	Nutrient loading/settlement
6	Sunsari	Barahachettra	80	Terai/Chure	Irrigation and hydropower

Physico-chemical analysis of water

Physical parameters

pH is an important physico-chemical parameter of freshwater ecosystems that influences the biotic composition (Singh et al., 2017). A wide variation in pH was recorded in the impact zone of the Koshi River (Table 7). This may be due to the effluent mix from the reservoir of the irrigation canal, sediment loads from the construction work on the canal, and due to the shallow water level at the impact zone where water is diverted and stored in a dam. In this study, the alkaline nature of all the river water may be attributed to human intervention – such as disposal of untreated sewage – and higher photosynthetic activities by the macrophytes (Cook, 1996).

The degree of hotness or coldness of water varies during the day; this change in temperature affects not only the growth, condition and survival of biota, but also the rates and occurrence of biological processes (Singh et al., 2017). The Triyuga River (at the recovery zone) had a mean maximum temperature of 24.83°C, whereas the Melamchi River (at the reference zone) had a mean minimum temperature of 6.65°C. The variation in temperature of the water at different sites may be due to the different timings of collection, the influence of atmospheric condition, and elevation (Merritt and Cummins, 1996; Singh et al., 2017). Besides, fluctuation in the water flow, and biotic and abiotic parameters may also lead to the change in the temperature of the rivers (Singh et al., 2017). Water samples from the Koshi River recorded a wide variation in temperature ranging from 14.60°C to 22.90°C (Table 7). A similar wide range of temperature variability was reported by Opute (1991) in the Narmada River in India. Water temperature can also vary in small sections only metres apart, depending on the local conditions (Selvanayagam and Abril, 2016).

The EC of a river can be attributed more to the observed pollution of the river system. The EC in streams and rivers are affected primarily by the geology of the area through which the water flows (Selvanayagam and Abril, 2016). In the present case, the measured EC values were within the range of 67.75–81.25µS/cm for the High Mountains of the KRB, 101.75–107.25µS/cm for the Middle Mountains, and 129.75–352.50µS/cm for the Terai/Chure region (Table 6). The high value of EC at Terai/Chure may be due to human interference in the form of drains being allowed to flow into the river system and also due to cremation at the river site. A similar observation was made by Singh et al. (2017) and Chandrashekar et al. (2003). The lowest EC value observed in the High Mountains can be attributed to less human disturbance because of low population density compared to the Middle Mountains and Terai/Chure (CBS, 2011). A low EC value can also be attributed to water levels rising in the rivers due to rainfall.

The DO measured from the three geographical regions is presented in Table 7. It is an important parameter that assesses the water quality because of its influence on organisms living in the waterbody. The actual amount of DO varies with temperature, pressure and salinity (Selvanayagam and Abril, 2016). The measured value of DO varied from 4 mg/l (in the Triyuga River located at 1,800 masl) to 7.75 mg/l (in the Tingla River located at 90 masl). Mostly, the high value of DO was measured in high-elevation rivers; this shows the relation between oxygen content, altitude, and temperature. The degree of pollution in a river was also a deciding factor for DO concentration.For example, the Triyuga River contains high nutrient loading as it flows through the nearby settlement areas (Table 6). In the case of the Tingal River, the high speed of flow gives a good mixing of atmospheric oxygen to the water, while in the case of the Triyuga River, the movement of water is slow.

Turbidity is a measure of the extent to which light is either absorbed or scattered by suspended materials in water. These suspended solids can be in the form of silt, clay, sand, industrial waste, sewage, organic matter, and phytoplankton and other microscopic organisms. The turbidity of all the six rivers was recorded at various locations. The recorded turbidity values ranged from 5 NTU to 500 NTU (Table 7). The samples were taken during the winter season when the turbulence in the rivers was less. The low turbidity of a river facilitates water purification processes such as flocculation and filtration. Low turbidity reflects lower erosion from cultivated lands (Collins and Jenkins, 1996). However, mixing of high sediment-loaded flushed water from the irrigation canal was the major reason behind the increased turbidity in the Koshi River.

Chemical parameters

The hardness of water is an important parameter in determining the suitability of water for household and industrial uses (Venkatesharaju et al., 2010). The maximum average TH recorded was 292 mg/l as $CaCO_3$ at the recovery zone of the Triyuga River, whereas the minimum average TH recorded was 110.5 mg/l as $CaCO_3$ at the reference zone of the Nibuwa River (Table 7). The water quality of the Triyuga River was substantially poor with very high TH due to the effluents from the nearby settlement of Gaighat Bazaar.

Nitrogen, which might affect the productivity of freshwater, is one of the essential nutrients of plants (Singh et al., 2017). The average value of nitrate concentration recorded in the study sites was found to be as low as 0 mg/l (in the Tingla and Nibuwa rivers) and as high as 4.13 mg/l (in the Koshi River) (Table 7). Exceptionally, the samples collected at the recovery zone of the Koshi River showed remarkably high value (15.5 mg/l) of nitrates. This can be attributed to the release of the reservoir water used for irrigation purposes into the main river system. Besides, the decomposition of organic matter and free cattle grazing could have increased the nitrate concentration at that site. High use of mineral nitrogen and organic fertilizers for crops can also lead to a high concentration of nitrates in the river water (Dahal et al., 2007).

Table 7: **Descriptive statistics of the physico-chemical analysis of water in the three geographical locations of the KRB**

Water sources	Parameters	Recovery zone				Impact zone				Reference zone			
		Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
High Mountains													
Tingla	pH	8.37	8.77	8.49	0.19	8.24	8.36	8.29	8.24	8.24	8.32	8.27	8.24
	Temperature	6.6	6.7	6.65	0.06	7	7.4	7.20	7	6.3	6.9	6.63	6.3
	EC	79	82	81.25	1.50	75	81	78.25	75	79	83	80.00	79
	DO	7	8	7.50	0.50	7	8	7.75	7	7	7	7.00	7
	Turbidity									5	5	5.00	5
	Nitrate	0.3	0.4	0.35	0.06	0.3	0.4	0.33	0.3	0	0	0.00	0
	Orthophosphate	0.047	0.095	0.07	0.02	0.02	0.029	0.02	0.02	0.031	0.033	0.03	0.031
	TH	114	120	117.00	2.58	114	118	116.00	114	112	124	118.00	112
Melamchi	pH	8.19	8.22	8.21	0.01	8.19	8.22	8.21	0.01	8.16	8.3	8.25	0.06
	Temperature	10.2	11.2	10.60	0.43	9.4	9.7	9.55	0.13	9.1	9.8	9.35	0.31
	EC	67	69	67.75	0.96	69	73	70.50	1.91	68	72	70.25	2.06
	DO	7	7	7.00	0.00	6	6	6.00	0.00	7	7	7.00	0.00
	Turbidity	5	5	5.00	0.00	5	5	5.00	0.00	5	5	5.00	0.00
	Nitrate	1.2	2.4	1.90	0.60	1	1.4	1.25	0.17	1	2	1.60	0.43
	Orthophosphate	0.06	0.89	0.27	0.41	0.016	0.075	0.04	0.03	0.042	0.044	0.04	0.00
	TH	112	118	114.50	2.52	118	128	123.50	5.26	126	126	126.00	0.00

Water sources	Parameters	Recovery zone				Impact zone				Reference zone			
		Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Middle Mountains													
Sabha	pH	8.57	8.69	8.63	0.06	8.59	8.83	8.66	0.12	8.39	8.52	8.44	0.06
	Temperature	15.1	18	17.03	1.35	17.7	20.4	18.98	1.37	19.1	19.8	19.50	0.32
	EC	102	112	105.75	4.50	99	105	101.75	2.50	100	104	101.75	1.71
	DO	5	6	5.25	0.50	4	5	4.50	0.57	5	5	5.00	0.00
	Turbidity	5	5	5.00	0.00	5	5	5.00	0.00	5	5	5.00	0.00
	Nitrate	0.5	0.8	0.60	0.14	0.6	0.7	0.68	0.05	0.4	0.6	0.50	0.08
	Orthophosphate	0.067	0.093	0.08	0.01	0.053	0.149	0.08	0.04	0.064	0.086	0.07	0.01
	TH	132	138	135.00	2.58	130	136	133.00	2.58	128	136	133.50	3.79
Nibuwa	pH	8.16	8.34	8.23	0.08	8	8.13	8.08	0.06	8.09	8.19	8.15	0.04
	Temperature	17.8	18.3	17.98	0.22	16.4	17.3	16.95	0.39	17.5	18.5	17.98	0.41
	EC	105	110	107.25	2.22	96	107	103.25	4.92	104	105	104.50	0.58
	DO	4	6	5.00	0.81	6	6	6.00	0.00	5	5	5.00	0.00
	Turbidity												
	Nitrate	0	0.1	0.08	0.05	0.3	0.4	0.33	0.05	0	0	0.00	0.00
	Orthophosphate	0.004	0.018	0.01	0.01	0.004	0.009	0.01	0.00	0.002	0.007	0.01	0.00
	TH	108	116	112.00	3.27	110	120	116.50	4.73	106	114	110.50	3.42

Water sources	Parameters	Recovery zone				Impact zone				Reference zone			
		Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Terai/Chure													
Koshi	pH	8.1	8.21	8.18	0.05	7.96	9.64	8.48	0.78	8.21	8.38	8.29	0.07
	Temperature	16.7	17.2	17.03	0.22	20.7	22.9	21.83	0.92	14.6	15	14.80	0.16
	EC	143	145	144.00	0.82	133	192	149.25	28.55	129	130	129.75	0.50
	DO	6	6	6.00	0.00	5	5	5.00	0.00	5	5	5.00	0.00
	Turbidity					500	500	500.00	0.00				
	Nitrate	0.4	0.5	0.45	0.06	0.3	15.5	4.13	7.58	0.7	0.7	0.70	0.00
	Orthophosphate	0.1	0.12	0.11	0.01	0.12	0.146	0.13	0.01	0.14	0.175	0.15	0.01
	TH	148	158	154.50	4.43	144	150	147.50	2.52	128	142	137.00	6.22
Triyuga	pH	8.44	8.52	8.47	0.04	8.39	8.43	8.42	0.02	8.57	8.58	8.58	0.01
	Temperature	23.8	25.4	24.83	0.71	21.9	22.7	22.15	0.37	21.6	24	22.48	1.05
	EC	344	366	352.50	9.43	315	323	319.25	3.30	324	330	326.75	2.75
	DO	4	5	4.25	0.50	4	4	4.00	0.00	4	4	4.00	0.00
	Turbidity	5	5	5.00	0.00	5	5	5.00	0.00	5	5	5.00	0.00
	Nitrate	0.7	0.8	0.75	0.06	1.6	2.1	1.80	0.22	0.5	0.6	0.55	0.06
	Orthophosphate	0.016	0.164	0.12	0.07	0.142	0.164	0.15	0.01	0.137	0.217	0.17	0.03
	TH	274	302	292.00	12.33	262	288	275.50	13.40	274	286	280.00	5.16

The maximum average phosphate concentration was recorded at 0.17 mg/l in the Triyuga River, whereas the minimum average phosphate concentration was recorded at 0.01 mg/l in the Nibuwa River. The average phosphate concentration was found less in these study sites compared to that recorded by Dahal et al. (2007) in Ansikhola and Chakhola. Usually, phosphate (PO_4) is absorbed by the soil or used by biota, and little is detected in the waterbodies (Collins & Jenkins, 1996; Dahal et al., 2007). The phosphate value was found to be below the permissible limit of 1.5 mg/l (WHO, 1996) at all the sites of all the rivers.

Habitat assessment

The study found that all the sites of the High Mountains and Middle Mountains (i.e. Tingla, Melamchi, Nibuwa, and Sabha rivers), except for the impact sites of the Tingla River, were in a good condition, with an RHA score of above 0.65, while the Terai/Chure site (i.e. the Triyuga River) was in a fair habitat condition, with an RHA score between 0.35–0.64 (Table 8). Similarly, according to RFB, rivers in the high and middle mountain zones were slightly to moderately polluted compared to those in the Terai/Chure zone, which are critically polluted (Table 8). This might be due to high human intervention at these rivers. According to Shrestha et al. (2008), waste dumping on the banks, domestic sewage, agricultural run-off, and industrial discharge result in river pollution.

Table 8: **Findings from RHA and macro-invertebrate assemblage**

	Rivers	Site description	Sample codes	RHA score	Condition	RQC	NEPBIOS/ ASPT	WQC
Solukhumbu	Tingla	Reference	S1	0.91	Reference	I	6.29	II
		Impact	S2	0.64	Fair	II	7	I–II
		Recovery	S3	0.76	Good	I/II	7	I–II
Sindhupalchowk	Melamchi	Reference	S4	0.84	Good	I	7.23	I–II
		Impact	S5	0.825	Good	II	6.18	II
		Recovery	S6	0.845	Good	I	7.4	I–II
Dhankuta	Nibuwa	Reference	S7	0.76	Good	I	7.11	I–II
		Impact	S8	0.66	Good	I/II	7.57	I
		Recovery	S9	0.735	Good	II	6.5	II
Sankhuwasabha	Sabha	Reference	S10	0.695	Good	I/II	6	II
		Impact	S11	0.735	Good	I	7.55	I
		Recovery	S12	0.77	Good	I	6.85	I–II
Udayapur	Triyuga	Reference	S13	0.545	Fair	III	5.62	II
		Impact	S14	0.525	Fair	II	6.37	I–II
		Recovery	S15	0.6	Fair	III	5.14	II
Sunsari	Koshi	Reference	*					
		Impact	*					
		Recovery	*					

* Macro-invertebrate sampling could not be performed due to the high volume of water

Macro-invertebrate assemblage

A total of 32 families representing 9 orders (Ephemeroptera, Plecoptera, Trichoptera, Odonata, Diptera, Coleoptera, Lepidoptera, Megaloptera and Hydrophila) and 2 classes (Insecta and Gastropoda) were observed in the study sites (Figure 4). The number of benthic macro-invertebrates varies considerably with the elevation of the freshwater ecosystem (Shrestha et al., 2008) and the pollution level of the water (Selvanayagam and Abril, 2016). That is why the highest number of families was observed in the Tingla River while the least number of families was found in the Triyuga River (Figure 5).

In terms of EPT (Ephemeroptera, Plecoptera, and Trichoptera) richness, the Tingla River's reference zone registered the highest number of EPT families (10) followed by the recovery zone (7) and the impact zone (5) (Annex III). The reference zone of the Melamchi River also registered the highest number of EPT families (10) followed by the impact zone (7) and the recovery zone (6). In contrast, the Nibuwa River's recovery zone registered the highest number of EPT families (5) followed by the impact zone (4 families) and the reference zone (3). As for the Sabha River, its recovery zone registered 9 EPT families, and the reference and impact zones 6 each. In the case of the Triyuga River, the reference and impact zones had 5 EPT families each, and the recovery zone 3. It has to be noted here that in most of the impact zones, the EPT count was low and the order Plecoptera was absent.

Figure 4: **Macro-invertebrate diversity in the KRB**

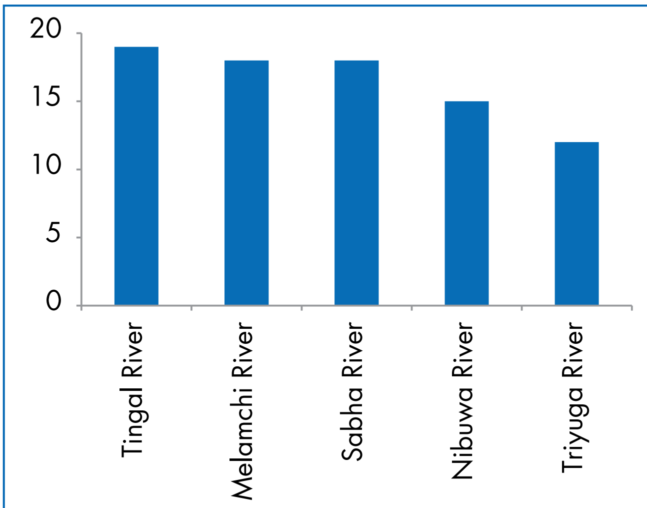
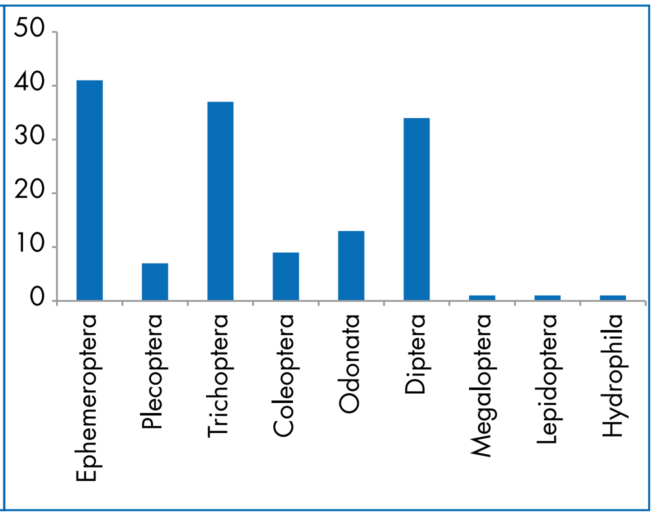


Figure 5: **Number of families of macro-invertebrates in different rivers of the KRB**



Stressors in freshwater ecosystem and its surroundings

Most of the stream banks and riparian zones were impaired with vegetation resulting in mild to severe erosion, like in the Tingla, Melamchi, and Sabha rivers. Waste dumping (Triyuga River), very less vegetative cover (Tingla, Melamchi, Sabha, and Koshi rivers), and unsustainable agricultural practice (Nibuwa River) were observed in these riparian zones. The rapid habitat assessment and exotic index identified both point sources – such as dam construction, sediment deposition, water abstraction, and waste dumping – and non-point sources such as unsustainable agricultural practices, erosion, toilet discharge, road construction, and run-off as stressors. These stressors will have an impact on the biotic and abiotic conditions of the rivers and could induce more degradation in the future. In 2007, Dahal et al. had noted that agricultural disturbances have resulted in a higher turnover of water chemistry and benthic macro-invertebrates in Ansikhola of the KRB. Earlier, in 2001, Brewin et al. had found a similar high turnover of benthic composition in agricultural land compared to other land use in Likhu Khola.

There is also the risk of major hazards in the form of flash floods, monsoon-related floods, and landslides in the high and middle mountains, especially in Solukhumbu and Sindhupalchok districts. In these districts, road construction leads to landslides, especially in the rainy season. In the case of the Terai/Chure, massive floods during the monsoon and river-bank cuttings are the major hazards. Then there is the problem of droughts during the dry season, mainly in Sunsari and Udayapur.

Dependency of local communities on freshwater ecosystems in the Koshi River basin

Farming is the main form of livelihood of the communities in this region. Agricultural land is irrigated by seasonal streams and rainfall in the high and middle mountains whereas in the Terai/Chure region, it's the private irrigation schemes, deep boring and state-owned canals (e.g. the Sunsari–Morang irrigation canal in the Koshi River) that provide the water. Paddy, mustard, maize, millet, wheat, potato, and lentils are the major crops grown in the study area, depending on elevation and site conditions. Both cattle manure and chemical fertilizers are equally being used for fertilizing the fields. Besides agriculture, the local communities earn their living from fishing as well, especially in the midstream/impact zones of the study area.

From the FGDs, it was learnt that each household in the region utilizes about 150–300 litres of water every day. Natural springs, wells, ditches, and falls are the major water sources in the high and middle mountains whereas deep boring and wells are the major sources of water in Terai/Chure. The local communities reported that the availability of water has been decreasing in recent years, especially in winter in the high and middle mountain zones. This has led to social/communal conflicts in these areas. In the case of people living in the high and middle mountains, they have to walk an average distance of 500 m–1.5 km from their villages to fetch water; but that's not the case with the villagers of Terai/Chure, except in the recovery zone of Udayapur where they have to walk for around half an hour to get water as the iron content in their well water is rather high. However, no concrete actions, except for some plantations, have been carried out to conserve the water sources in these areas, especially in the high and middle mountains.

Conclusion and recommendations

This rapid assessment provides a broad overview of the status of the freshwater ecosystems in the KRB. This study shows that almost 86 critical freshwater ecosystems exist in the basin – 38 in the High Mountains, 33 in the Middle Mountains, and 15 in the Terai/Chure region. It reveals that parts of the Koshi River in the High Mountains are only slightly to moderately polluted and are in a good habitat condition compared to the segments in the low altitude of the Terai/Chure region. There are a number of drivers degrading the quality of the river system, which include but are not limited to, direct sewage disposal in the rivers and the excess use of pesticides and fertilizers in agriculture. The EPT values in our analysis confirmed such degradation in water quality.

Both RHA and the exotic index have identified the point sources – such as dam construction work, sediment deposition, water abstraction, and waste dumping – and the non-point sources – such as unsustainable agricultural practices, erosion, toilet discharge, road construction, and run-off – as major stressors in the KRB. RHA values indicate that the habitats in the upper part of the Koshi are in a better state than the lower parts where there is high human interference and excessive dependence on river resources.

This study suggests the need for integrated river basin management in order to sustain the freshwater ecosystems in the KRB. Since there are significant data gaps regarding the freshwater ecology of the Koshi River, more detailed investigations have to be undertaken in this area, especially in terms of development projects and their impacts. We draw below four major recommendations for the sustainable management and conservation of the freshwater ecosystems in the KRB:

- Community-oriented integrated watershed management based on the principles of integrated river basin management is a strategic option for conserving the freshwater ecosystems of the area. This approach suggests the integration of technologies within the natural boundaries of a drainage area and involves flood control, reducing soil erosion and sediment accumulation, land and water conservation practices such as water harvesting, recharging groundwater, crop diversification, and integrated nutrient and pest management.
- Initiate incentives for ecosystem service concepts and schemes. Our study reveals that upstream land-use activities are directly correlated with water quality downstream. Large-scale development projects such as hydro dams and irrigation canals need to consider upstream–downstream linkages, and at the conceptual stage itself, they have to be inventive and eco-friendly.
- The relationship between aquatic fauna and flora diversity with the quality of water needs to be assessed empirically. Particularly, the impact of water flow downstream on aquatic life needs a systematic analysis while ensuring the minimum required environmental flows when large-scale development projects such as hydropower plants at the upstream reaches are designed.
- Hydrological dynamics and habitat interrelationships have to be understood better. The decisions on freshwater ecosystem management have to be based on the possible impacts of hydrological phenomena on freshwater life.

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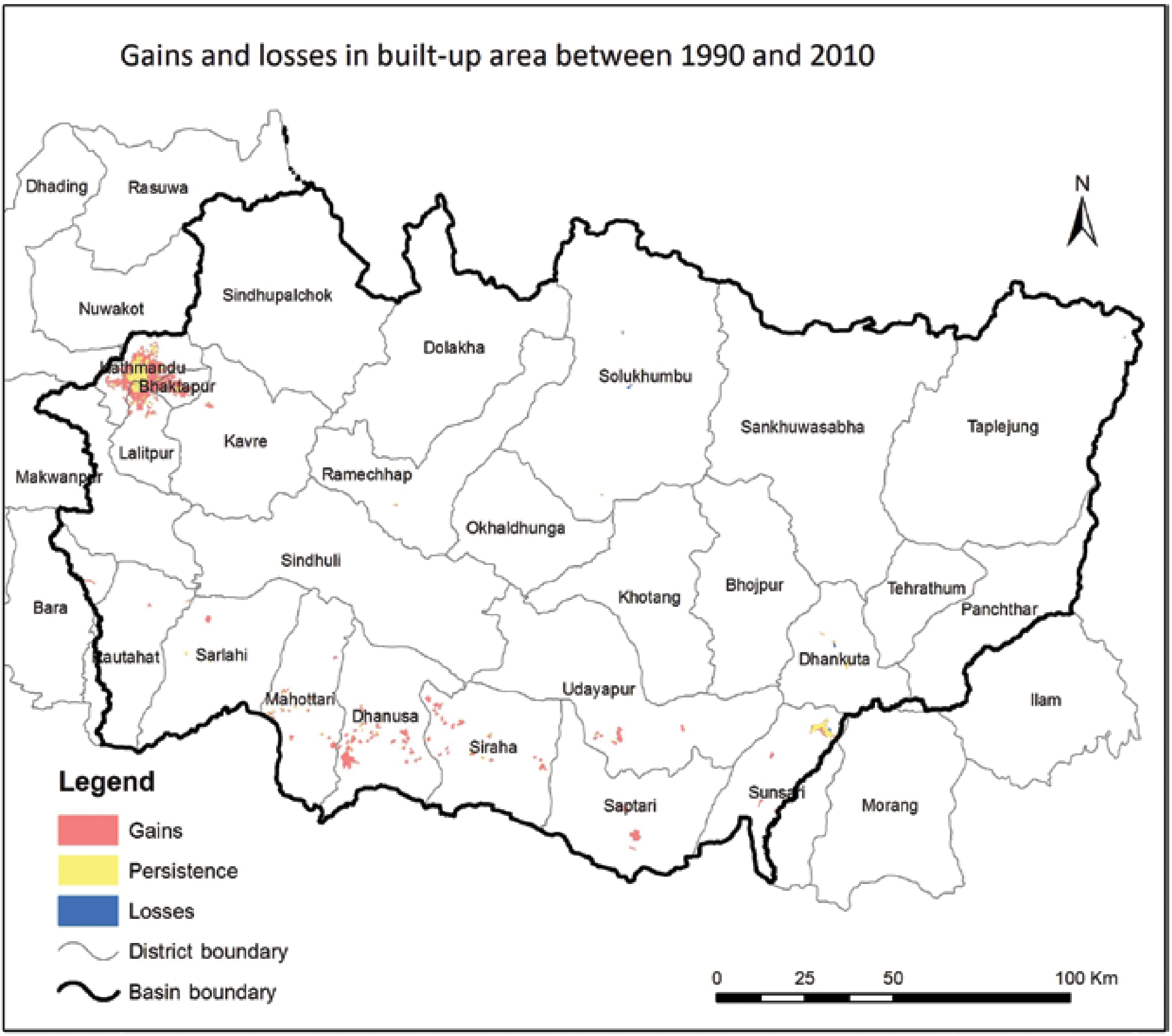
Annexes

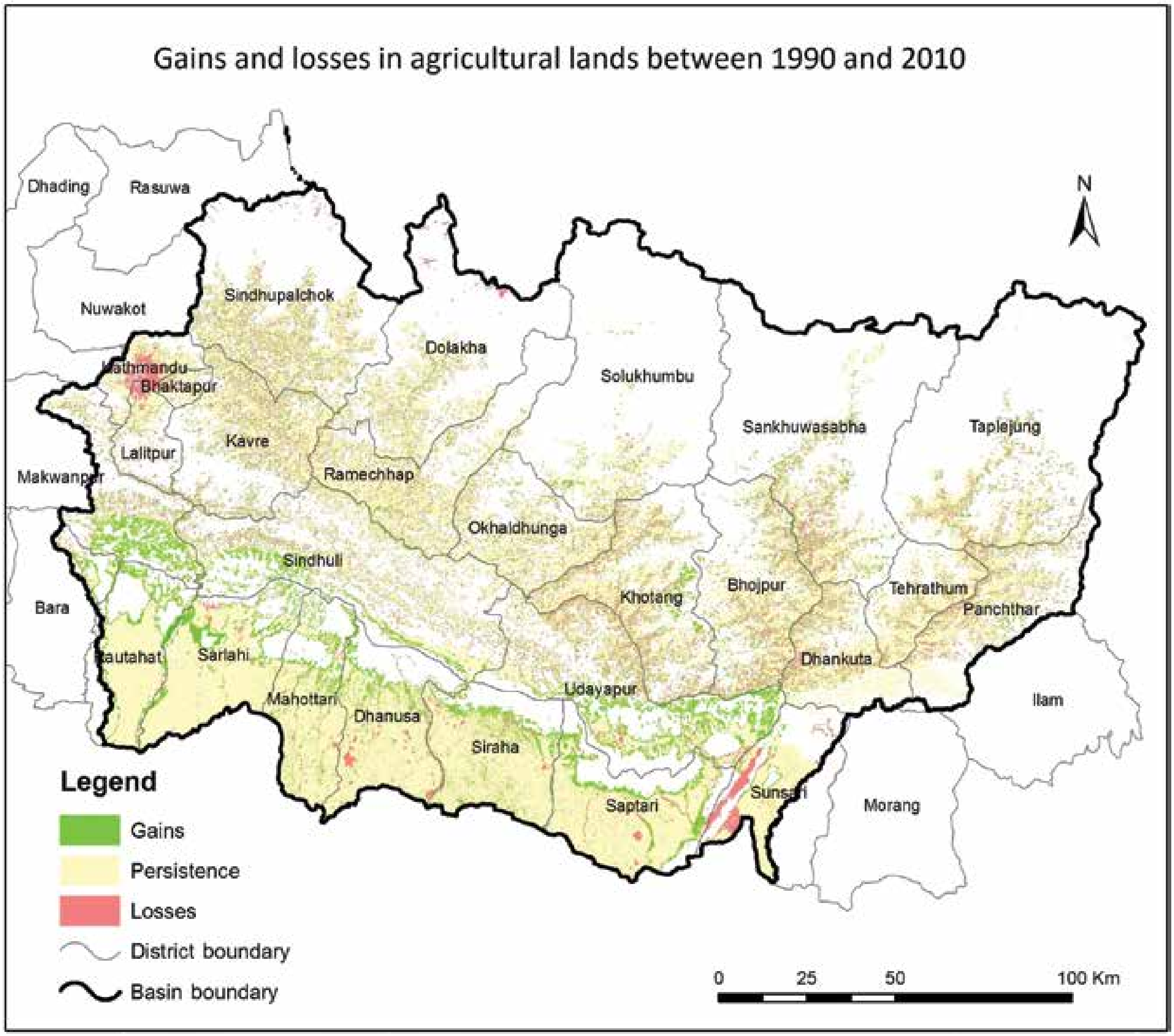
Annex I: List of critical freshwater ecosystems in the Koshi River basin

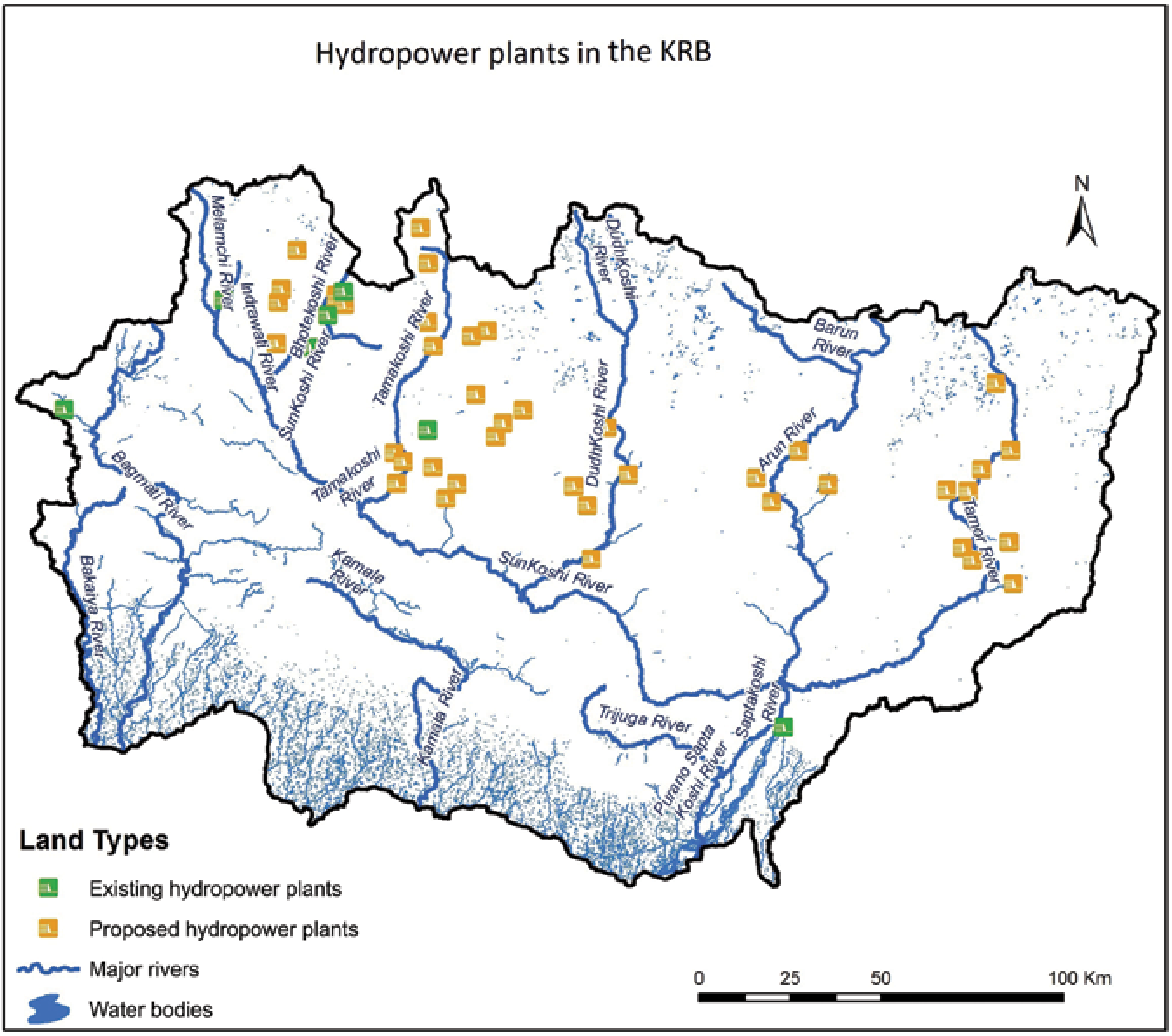
DISTRICT	VDC/Municipality	Province No.	Physiographic Zone	X_ UTM45	Y_UTM45	Weighted Z Score (Overall)	Rank
SINDHUPALCHOK	Kiul	3	High Mountains	361,980	3,091,946	-1.164249539	1
SINDHUPALCHOK	Bhote Namlang	3	High Mountains	370,711	3,084,339	-1.106173515	2
RAMECHHAP	Thokarpur	3	Middle Mountains	393,538	3,047,789	-1.043576717	3
LALITPUR	Lalitpur Sub- Metropolis	3	Middle Mountains	331,835	3,061,969	-0.934962988	4
MAKWANPUR	Kulekhani	3	Middle Mountains	318,143	3,053,218	-0.876133442	5
RAMECHHAP	Bhaluwajor	3	Middle Mountains	400,062	3,025,608	-0.872294009	6
KATHMANDU	Kapan	3	Middle Mountains	338,311	3,070,278	-0.801100016	7
RAMECHHAP	Gelu	3	Middle Mountains	409,385	3,032,924	-0.79050231	8
DOLAKHA	Bhimeswor Municipality	3	High Mountains	402,687	3,067,526	-0.769981682	9
SINDHUPALCHOK	Helambu	3	High Mountains	356,169	3,095,381	-0.749126613	10
KATHMANDU	Manmaiju	3	Middle Mountains	332,687	3,071,425	-0.736208797	11
KATHMANDU	Jorpati	3	Middle Mountains	340,816	3,068,506	-0.647871792	12
RAMECHHAP	Phulasi	3	Middle Mountains	408,736	3,041,357	-0.639520168	13
RAMECHHAP	Rakathum	3	Middle Mountains	385,690	3,035,017	-0.635766745	14
SINDHUPALCHOK	Marming	3	High Mountains	392,897	3,084,751	-0.62466222	15
SOLUKHUMBU	Wasa	1	High Mountains	467,096	3,048,319	-0.623596966	16
SOLUKHUMBU	Necha Batase	1	High Mountains	461,817	3,026,889	-0.600576043	17
RAMECHHAP	Gelu	3	Middle Mountains	411,217	3,038,904	-0.594858348	18
SARLAHI	Shankarpur	2	Terai	348,999	2,993,109	-0.585310638	19
KATHMANDU	Tokha Chandeshwari	3	Middle Mountains	334,243	3,072,408	-0.571954608	20
DHANKUTA	Dhankuta Municipality	1	Middle Mountains	533,171	2,988,721	-0.555604219	21
PANCHTHAR	Nagin	1	Middle Mountains	578,759	3,005,425	-0.537384868	22
DHANKUTA	Tankhuwa	1	Middle Mountains	538,205	2,981,474	-0.533239484	23
SOLUKHUMBU	Tingla	1	High Mountains	458,018	3,032,318	-0.528449774	24
SUNSARI	Baraha Chhetra	1	Terai	515,620	2,966,059	-0.52202332	25
RAMECHHAP	Gothgaun	3	Middle Mountains	423,011	3,028,732	-0.521064639	26
OKHALDHUNGA	Tarkerabari	2	Middle Mountains	425,864	3,032,813	-0.502015829	27
TAPLEJUNG	Khokling	1	High Mountains	566,407	3,030,831	-0.485799581	28
DHANKUTA	Phalate	1	Middle Mountains	519,035	2,993,474	-0.484528363	29
RAUTAHAT	Santapur (Matiaun)	2	Terai	334,027	2,996,236	-0.478187829	30
TERHATHUM	Ewa	1	Middle Mountains	567,519	3,011,884	-0.47757405	31
KHOTANG	Salle	1	Middle Mountains	462,733	3,012,332	-0.473702669	32
SARLAHI	Hariban	2	Terai	353,616	2,996,112	-0.466040105	33
SOLUKHUMBU	Lokhim	1	High Mountains	472,991	3,035,389	-0.458820403	34
TAPLEJUNG	Ikhabu	1	High Mountains	569,613	3,046,871	-0.454190314	35
RAUTAHAT	Rangapur	2	Churia	328,868	3,011,714	-0.447534084	36
SINDHUPALCHOK	Pangretar	3	Middle Mountains	385,481	3,070,434	-0.446298838	37
SINDHUPALCHOK	Irkhu	3	Middle Mountains	376,407	3,071,336	-0.443173647	38
PANCHTHAR	Nagi	1	Middle Mountains	577,528	3,016,927	-0.429871202	39

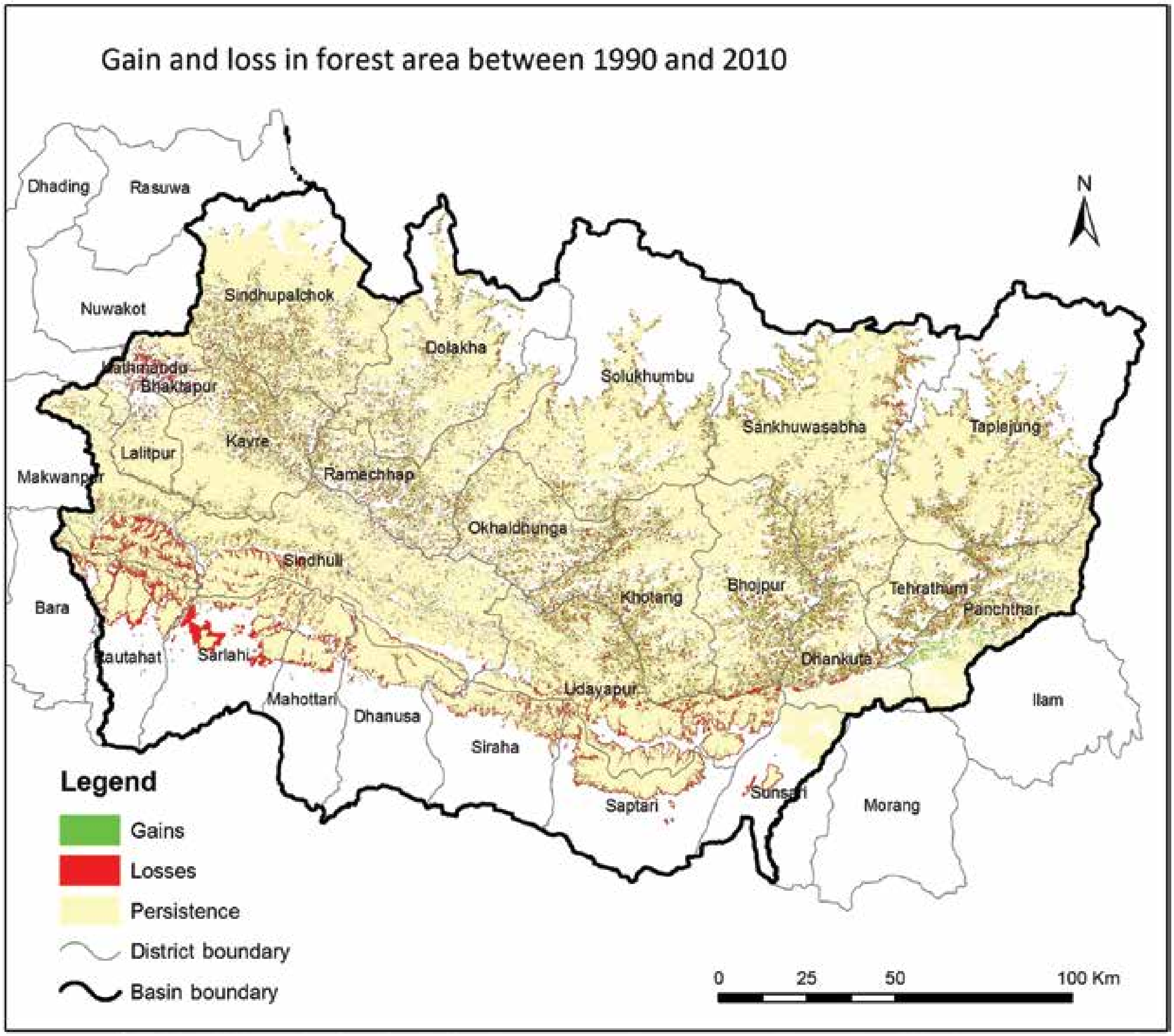
DISTRICT	VDC/Municipality	Province No.	Physiographic Zone	X_ UTM45	Y_UTM45	Weighted Z Score (Overall)	Rank
RAMECHHAP	Namadi	3	Middle Mountains	419,300	3,037,463	-0.413832456	40
SINDHUPALCHOK	Phulpingkatti	3	High Mountains	394,770	3,085,540	-0.383588314	41
TERHATHUM	Hwaku	1	Middle Mountains	564,897	3,015,215	-0.37878859	42
SANGKHUWASABHA	Kharang	1	Middle Mountains	522,275	3,017,444	-0.36399737	43
TAPLEJUNG	Lingtep	1	High Mountains	560,414	3,031,132	-0.343661159	44
SINDHUPALCHOK	Dubachaur	3	Middle Mountains	361,958	3,083,288	-0.343634248	45
KABHREPALANCHOK	Sarasyunkharka	3	Middle Mountains	371,808	3,051,417	-0.342781961	46
BHOJPUR	Mulpani	1	Middle Mountains	512,361	3,027,977	-0.338643521	47
SARLAHI	Karmaiya	2	Terai	348,395	2,997,854	-0.33741951	48
SINDHUPALCHOK	Selang	3	High Mountains	376,935	3,082,510	-0.33591786	49
SINDHUPALCHOK	Gati	3	High Mountains	390,416	3,079,100	-0.334842235	50
UDAYAPUR	Triyuga Municipality	1	Churia	468,566	2,963,677	-0.319907457	51
SINDHUPALCHOK	Marming	3	High Mountains	39,2887	3,0836,21	-0.316051036	52
SANGKHUWASABHA	Diding	1	High Mountains	519,755	3,041,833	-0.293467283	53
SOLUKHUMBU	Goli	1	High Mountains	436,636	3,045,736	-0.283571303	54
SOLUKHUMBU	Chaulakharka	1	High Mountains	438,659	3,049,448	-0.283275634	55
SIRAHA	Phulwariya	2	Churia	428,735	2,972,174	-0.28093493	56
RAMECHHAP	Betali	3	Middle Mountains	417,955	3,047,630	-0.26516664	57
DOLAKHA	Marbu	3	High Mountains	429,942	3,073,378	-0.264052093	58
SOLUKHUMBU	Bhakanje	1	High Mountains	444,076	3,053,022	-0.256062508	59
SINDHUPALCHOK	Golche	3	High Mountains	377,790	3,086,279	-0.255717069	60
SINDHUPALCHOK	Gumba	3	High Mountains	381,999	3,096,863	-0.252693921	61
BHOJPUR	Kulung	1	Middle Mountains	508,233	3,034,310	-0.24098447	62
SANGKHUWASABHA	Dhupu	1	Middle Mountains	529,248	3,032,788	-0.238875255	63
TAPLEJUNG	Limkhim	1	High Mountains	569,991	3,036,821	-0.227613419	64
TAPLEJUNG	Limkhim	1	High Mountains	569,991	3,036,821	-0.227613419	65
SINDHULI	Kalpabrikshya	3	Churia	377,435	3,010,214	-0.198802397	66
DOLAKHA	Syama	3	High Mountains	431,221	3,057,397	-0.198728874	67
SINDHUPALCHOK	Marming	3	High Mountains	394,979	3,081,996	-0.172099113	68
DOLAKHA	Laduk	3	High Mountains	419,520	3,070,696	-0.168534756	69
TAPLEJUNG	Tapethok	1	High Mountains	578,002	3,042,065	-0.138376534	70
KABHREPALANCHOK	Phalametar	3	Middle Mountains	354,444	3,038,571	-0.12227989	71
DOLAKHA	Jungu	3	High Mountains	423,693	3,061,351	-0.116109379	72
MAKWANPUR	Phaparbari	3	Churia	342,575	3,022,454	-0.087480761	73
SAPTARI	Bhardaha	2	Terai	493,608	2,937,493	-0.076532438	74
SANGKHUWASABHA	Bala	1	High Mountains	498,116	3,047,209	-0.069214977	75
DOLAKHA	Bulung	3	High Mountains	417,928	3,077,176	-0.06872645	76
DOLAKHA	Marbu	3	High Mountains	434,325	3,074,860	0.050925761	77
TAPLEJUNG	Olangchunggola	1	High Himalayas	573,969	3,060,507	0.095539778	78
TAPLEJUNG	Nalbu	1	High Himalayas	548758	3,042,740	0.211230338	79
SUNSARI	K T Wildlife Reserve	2	Terai	499,445	2,940,764	0.25084582	80
SARLAHI	Harkthawa	2	Terai	340,408	2,976,762	0.316941291	81
DHANUSHA	Janakpur Municipality	2	Terai	393,029	2,957,515	0.402644753	82
DOLAKHA	Lamabagar	3	High Himalaya	418,037	3,093,261	0.48277238	83
SANGKHUWASABHA	Cheapuwa	1	High Mountains	549,965	3,069,464	0.597609818	84
SIRAHA	Belaha	2	Terai	420,562	2,953,373	0.768146276	85
DOLAKHA	Lamabagar	3	High Himalaya	416,030	3,103,036	0.881535411	86

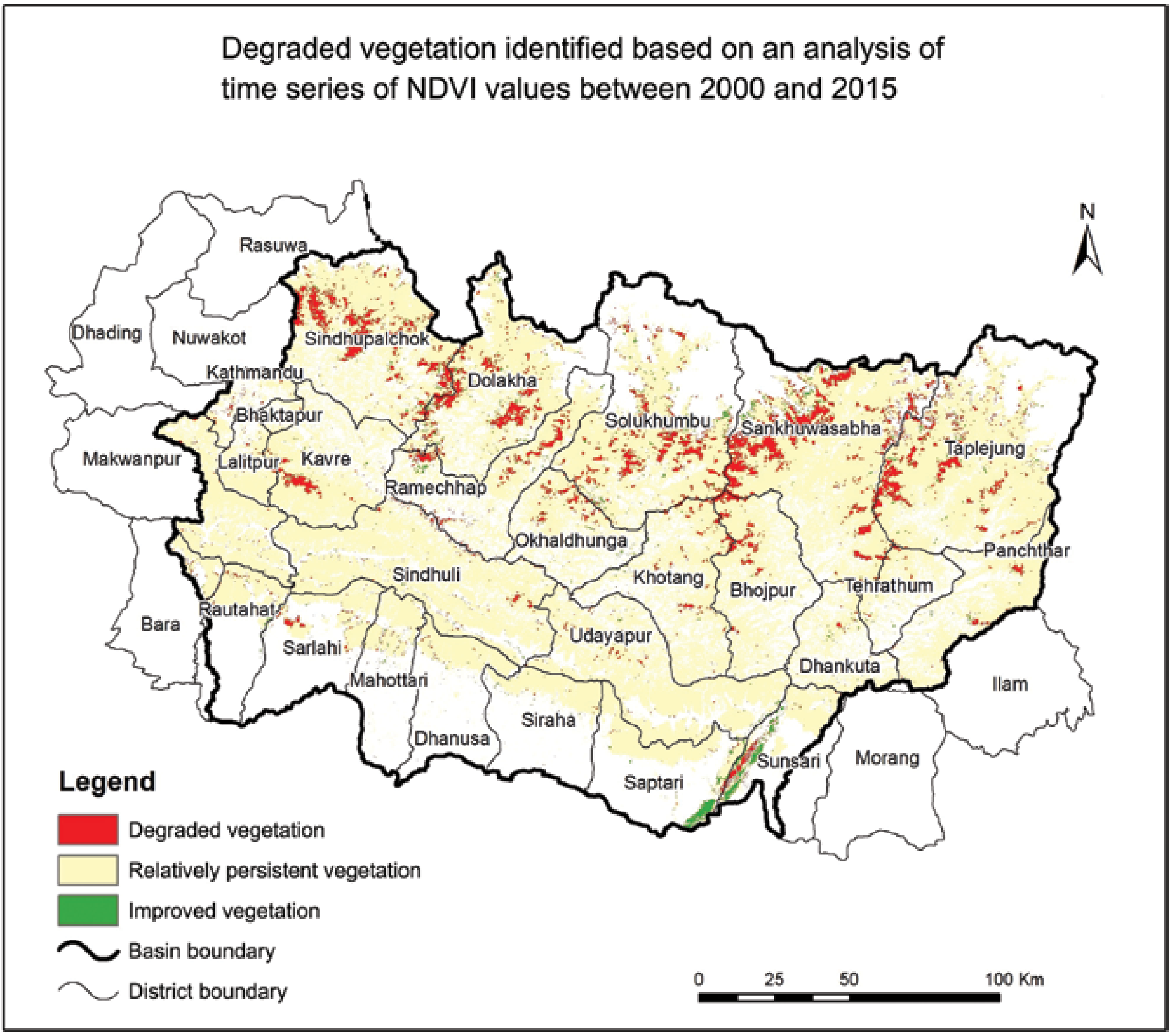
Annex II: Multiple criteria evaluation parameters

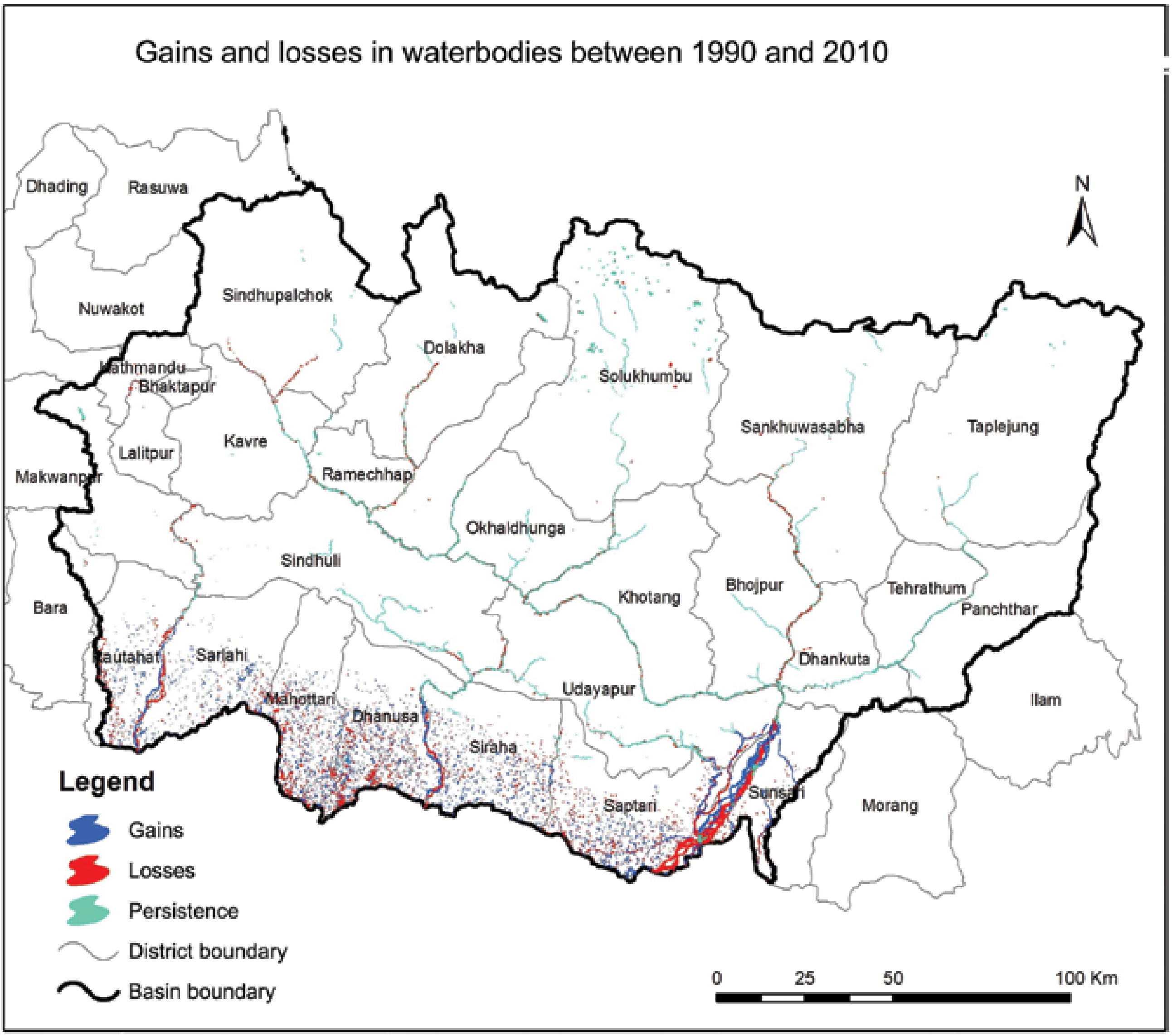



Gains and losses in agricultural lands between 1990 and 2010
Dhading
Rasuwa
Nuwakot
Sindhupalchok
Dolakha
Solukhumbu
Bhaktapur
Lalitpur
Kavre
Makwanpur
Ramechhap
Sankhuwasabha
Taplejung
Okhaldhunga
Sindhuli
Khotang
Bhojpur
Tehrathum
Panchthar
Bara
Sarlahi
Dhankuta
Udayapur
Ilam
Mahottari
Dhanusa
Siraha
Saptari
Morang
N
Legend
Gains
Persistence
Losses
District boundary
Basin boundary
0 25 50 100 Km


Hydropower plants in the KRB
N
Melamchi River
Indrawati River
Bhotekoshi River
SunKoshi River
Tamakoshi River
DudhKoshi River
Barun River
Bagmati River
Tamakoshi River
Arun River
Tamor River
Kamala River
SunKoshi River
Bakaiya River
Kamala River
Trijuga River
Saptakoshi River
Purano Sapta Koshi River
Land Types
Existing hydropower plants
Proposed hydropower plants
Major rivers
Water bodies
0
25
50
100 Km


Gain and loss in forest area between 1990 and 2010
Dhading
Rasuwa
Nuwakot
Sindhupalchok
Dolakha
Bhaktapur
Solukhumbu
Lalitpur
Kavre
Sankhuwasabha
Taplejung
Makwanpur
Ramechhap
Okhaldhunga
Sindhuli
Bara
Khotang
Bhojpur
Tehrathum
Panchthar
Sarlahi
Dhankuta
Udayapur
Mahottari
Dhanusa
Ilam
Siraha
Saptari
Sunsari
Morang
N
Legend
Gains
Losses
Persistence
District boundary
Basin boundary
0
25
50
100 Km


Degraded vegetation identified based on an analysis of
time series of NDVI values between 2000 and 2015
N
Rasuwa
Dhading
Nuwakot
Sindhupalchok
Kathmandu
Dolakha
Bhaktapur
Solukhumbu
Sankhuwasabha
Taplejung
Makwanpur
Lalitpur
Kavre
Ramechhap
Okhaldhunga
Panchthar
Sindhuli
Khotang
Bhojpur
Tehrathum
Bara
Rautahat
Sarlahi
Udayapur
Dhankuta
Mahottari
Ilam
Siraha
Dhanusa
Sunsari
Morang
Saptari
Legend
Degraded vegetation
Relatively persistent vegetation
Improved vegetation
Basin boundary
District boundary
0 25 50 100 Km


Gains and losses in waterbodies between 1990 and 2010
Dhading
Rasuwa
Nuwakot
Sindhupalchok
Dolakha
Solukhumbu
Kathmandu
Bhaktapur
Lalitpur
Kavre
Makwanpur
Ramechhap
Okhaldhunga
Sankhuwasabha
Taplejung
Sindhuli
Khotang
Bhojpur
Tehrathum
Panchthar
Bara
Rautahat
Sarlahi
Mahottari
Dhanusa
Siraha
Udayapur
Dhankuta
Ilam
Saptari
Sunsari
Morang
N
Legend
Gains
Losses
Persistence
District boundary
Basin boundary
0
25
50
100 Km

Annex III: List of macro-invertebrates found in the study sites

Class	Order	Family	NEPBIOS Score
Tingla River reference (S1)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Heptageniidae	10
		Baetidae	7
Insecta	Plecoptera	Perlidae	8
		Chloroperlidae	5
Insecta	Trichoptera	Hydropsychidae	6
		Stenopsychidae	6
		Polycentropodidae	7
		Rhyacophilidae	8
		Brachycentridae	7
Insecta	Diptera	Tipulidae	8
		Athericidae	10
		Tabanidae	2
		Chironomidae	1
		Simuliidae	7
Insecta	Coleoptera	Psephenidae	7
Insecta	Megaloptera	Corydalidae	2
		ASPT	6.29
Tingla River impact (S2)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Leptophlebiidae	10
		Baetidae	7
Insecta	Trichoptera	Brachycentridae	7
		Polycentropodidae	7
Insecta	Diptera	Simuliidae	7
		Chironomidae	1
		Tipulidae	8
		Athericidae	10
		Sum	63
		ASPT	7
Tingla River recovery (S3)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Heptageniidae	10
		Leptophlebiidae	10
		Baetidae	7
Insecta	Plecoptera	Perlidae	8
Insecta	Trichoptera	Hydropsychidae	6
		Polycentropodidae	7
Insecta	Diptera	Tipulidae	8
		Chironomidae	1
Insecta	Coleoptera	Pesphenidae	7
		Elmidae	7
		ASPT	7

Class	Order	Family	NEPBIOS Score
Melamchi River reference (S4)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Heptageniidae	10
		Baetidae	7
Insecta	Plecoptera	Perlidae	8
Insecta	Trichoptera	Hydropsychidae	6
		Stenopsychidae	6
		Philopotamidae	7
		Polycentropodidae	7
		Rhyacophilidae	8
		Lepidostomatidae	5
Insecta	Odonata	Gomphidae	6
Insecta	Diptera	Tipulidae	8
		Athericidae	10
		ASPT	7.23
Melamchi River impact (S5)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Heptageniidae	10
		Baetidae	7
Insecta	Trichoptera	Hydropsychidae	6
		Stenopsychidae	6
		Philopotamidae	7
		Glossosomatidae	9
Insecta	Odonata	Gomphidae	6
Insecta	Diptera	Tabanidae	2
		Chironomidae	1
		Tipulidae	8
		ASPT	6.18
Melamchi River Recovery (S6)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Heptageniidae	10
		Leptophlebiidae	10
		Baetidae	7
Insecta	Trichoptera	Hydropsychidae	6
		Glossosomatidae	9
Insecta	Diptera	Tipulidae	8
		Athericidae	10
		Simuliidae	7
		Chironomidae	1
		ASPT	7.4
Nibuwa River reference (S7)			
Insecta	Ephemeroptera	Heptageniidae	10
		Baetidae	7
Insecta	Trichoptera	Hydropsychidae	6
Insecta	Odonata	Gomphidae	6

Class	Order	Family	NEPBIOS Score
		Coenagrionidae	4
Insecta	Diptera	Athericidae	10
		Simuliidae	7
Insecta	Coleoptera	Psephenidae	7
		Elmidae	7
		ASPT	7.11
Nibuwa River impact (S8)			
Insecta	Ephemeroptera	Heptageniidae	10
		Baetidae	7
		Ephemerellidae	6
Insecta	Trichoptera	Hydropsychidae	6
Insecta	Diptera	Simuliidae	7
Insecta	Coleoptera	Psephenidae	7
		Gyrinidae	10
Insecta	Lepidoptera	Crambidae	
		ASPT	7.57
Nibuwa River Recovery (S9)			
Insecta	Ephemeroptera	Baetidae	7
		Heptageniidae	10
Insecta	Trichoptera	Hydropsychidae	6
		Polycentropodidae	7
		Brachycentridae	7
Insecta	Diptera	Chironomidae	1
		Simuliidae	7
Insecta	Coleoptera	Psephenidae	7
		ASPT	6.5
Sabha River reference (S10)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Baetidae	7
Insecta	Plecoptera	Perlidae	8
Insecta	Trichoptera	Hydropsychidae	6
		Stenopsychidae	6
		Rhyacophilidae	6
Insecta	Odonata	Gomphidae	6
Insecta	Diptera	Tipulidae	8
		Chironomidae	1
		ASPT	6
Sabha River impact (S11)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Heptageniidae	10
		Leptophlebiidae	10
		Baetidae	7
Insecta	Plecoptera	Perlidae	8
Insecta	Trichoptera	Stenopsychidae	6
Insecta	Odonata	Gomphidae	6
Insecta	Diptera	Tipulidae	8
Insecta	Coleoptera	Psephenidae	7

Class	Order	Family	NEPBIOS Score
		ASPT	7.55
Sabha River recovery (S12)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Heptageniidae	10
		Leptophlebiidae	10
		Baetidae	7
		Arthropleidae	
Insecta	Plecoptera	Perlidae	8
Insecta	Trichoptera	Hydropsychidae	6
		Stenopsychidae	6
		Philopotamidae	7
Insecta	Odonata	Gomphidae	6
		Libellulidae	6
		Coenagrionidae	4
Insecta	Diptera	Tipulidae	8
		Athericidae	10
		Tabanidae	2
		ASPT	6.85
Triyuga River reference (S13)			
Insecta	Ephemeroptera	Ephemerellidae	6
		Leptophlebiidae	10
		Baetidae	7
Insecta	Trichoptera	Hydropsychidae	6
		Polycentropodidae	7
Insecta	Odonata	Gomphidae	6
Insecta	Diptera	Chironomidae	1
		Tabanidae	2
		ASPT	5.62
Triyuga River impact (S14)			
Insecta	Ephemeroptera	Baetidae	7
		Leptophlebiidae	10
		Caenidae	6
Insecta	Trichoptera	Hydropsychidae	6
		Polycentropodidae	7
Insecta	Odonata	Gomphidae	6
Insecta	Diptera	Tipulidae	8
		Chironomidae	1
		ASPT	6.37
Triyuga River recovery (S15)			
Insecta	Ephemeroptera	Caenidae	6
Insecta	Trichoptera	Hydropsychidae	6
		Polycentropodidae	7
Insecta	Odonata	Gomphidae	6
		Aeshnidae	6
Insecta	Diptera	Chironomidae	1
Gastropoda	Hydrophila	Planorbidae	4
		ASPT	5.14

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