DECLARATION

I, Upama K.C., 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. Any literature, data or works done by others and cited within this dissertation has been given due acknowledgement and listed in the reference section.

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Upama K. C.

Date: ________

CERTIFICATION

This dissertation entitled "Macroinvertebrates as biological indicators of climate induced change in Nepal Himalaya", by "*Upama KC*" under the supervision of "Prof. Dr. Subodh Sharma, Department of, Environmental Sciences and Engineering", Kathmandu University, Dhulikhel, Nepal, is hereby submitted in partial fulfillment of the requirements for Master of Science (M.Sc.) Degree in "Environment and Natural Resource". This work has not been submitted in any other university or institution previously for the award of a degree.

APPROVED BY:

Signed Date	Signed Date
Dr. Subodh Sharma Supervisor Professor and Head Department of Environmental Science and Engineering Kathmandu University Dhulikhel, Nepal	External Examiner

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ABSTRACT

The rivers and streams of Himalayan region are most vulnerable to climate change and are likely to affect all freshwater ecosystems and their fauna. Benthic macroinvertebrates are sensitive to changes in temperature, precipitation, and the associated flow regimes, which make them particularly responsive to the effects of climate change.

There are three objectives of the study- 1) to assess the water quality of fifteen streams at different altitude (700 m – 3700 m) from Manaslu Conservation Areas (MCA) and Annapurna Conservation Areas (ACA) using benthic macroinvertebrates (BMI) as biological indicators with the help of biotic indices such as NEPBIOS, BMWP/ASPT, and HBI scores; 2) assess the change in precipitation and temperature in the study area for the past 30 years; and 3) to document baseline data for the climate change study using bioindicators. Multi habitat sampling (MHS) method was used for the collection of BMI.

In the last 30 years, there was an increment in the temperature and precipitation. Due to alter in the climate drivers there were changes in the ecosystem. Benthic macroinvertebrates responded well to the change. There was a strong positive correlation between altitude and EPT taxa richness. However, there was strong negative correlation between temperature and EPT taxa richness. The EPT and diptera composition of lower altitude resembles the higher sites; this similarity in taxa composition of macroinvertebrate indicates the taxa shifting to higher altitude. The EPT taxa abundance and diversity was higher in all the sites; and OCH abundance and diversity was gradually decreasing with the increase in altitude. Benthic Macroinvertebrates (BMI) such as Leptophlebiidae, Perlodidae, Limoniidae, Planariidae Empididae, Capniidae, Rhyacophilidae, and Brachycentridae were observed as temperature sensitive taxa and BMI such as Baetidae, Simuliidae, Chironmidae, and Tipulidae were observed as the temperature tolerant.

Key words: Climate change, biological indicators, temperature tolerance and intolerance, bioassessment, EPT taxa, macroinvertebrates.

ABBREVIATIONS

^{o}C	Degree Centigrade
μS	Micro Siemens
ACA	Annapurna Conservation Area
AEC	Aquatic Ecology Centre
ASSESS-HKH	Assessment Systems to Evaluate the Ecological Status of River in the Hindu Kush-Himalaya Region
ASPT	Average Score Per taxon
BMI	Benthic Macroinvertebrate
BMWP	Biological Monitoring Work Party
CO2	Carbon dioxide
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, Trichoptera
FPOM	Fine Particulate Organic Matter
GRSBIOS	Ganga River System Biotic Score
GPS	Global Positioning System
HAS	Habitat Assessment Field data Sheet
HBI	Hilsenhoff Biotic Index
IPCC	Intergovernmental Panel on Climate Change
ICIMOD	International Centre for Integrated Mountain Development
MCA	Manaslu Conservation Area
NAST	Nepal Academy of Science and Technology
NEPBIOS	Nepalese Biotic Score
NLBI	Nepal Lake Biotic Index
OCH	Odonata, Coleoptera, Heteroptera
PA vial	Presence/Absence Vial
USEPA	United States Environmental Protection Agency
VDC	Village Development Committee
WECS, 2004	Water and Energy Commission Secretariat
WHO	World Health Organization
WQC	Water Quality Class

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CHAPTER 1: INTRODUCTION

1.1 Background

Nepal is rich in freshwater resources with 6000 rivers and rivulets. Most of the big and perennial rivers in Nepal have originated from melting of snow (Sharma et al. 2008). They flow from high-mountains with greater velocity and have enormous energy to clean the shores with mechanical process (Sharma et al. 2008) and others are spring-fed which flow through the mid hills of Nepal. River water fulfills the major demands (drinking, cleaning, irrigation, and hydropower) of people in both the rural and urban localities. The water quality for drinking purpose is concerned widespread among the public in Nepal. However, very little attention is given to quality of water in river. But mostly the poor and migrated laborer communities are directly dependent on rivers as a source for their livelihood. Despite various benefits of river and stream water, the continuous and improper use is degrading their integrity of water quality. There are a number of anthropogenic stressors which affect the rivers/streams globally such as eutrophication (Telesh 1999), agricultural intensification (Dahal et al. 2007), thermal effluent discharge (Badruzzaman et al. 2008), water abstraction (Matthaei et al. o2010), organic pollution (Deckere et al. 2011), and river bed extraction (Kondolf 1997, Brown et al. 1998, Dahal et al. 2012) have profound impacts on river morphology and its biodiversity.

Furthermore, anthropogenic activities increase the concentration of greenhouse gases directly affect air temperature and precipitation which are considered as primary climate drivers. Global air temperatures have increased about 0.6 ^{0} C over the last 30 years and 0.8^0 C over the last century (Hansen et al. 2006). Global climate change will result in a more variable hydrological cycle expressed as substantial increase in precipitation and a greater evaporation rate (IPCC 2001). There is always a higher probability of flood conditions during the months of June through September because 75% of annual rainfall (1,700mm) occurs during monsoon season. However, in rest of months there is a noticeable decrement in the volume of river water (Sharma et al. 2008).Change in these primary climate drivers will affect stream/river water and aquatic-life resources mainly through direct and indirect alternation in hydrologic and thermal regimes.

Benthic macroinvertebrates have been successfully used as indicators of a variety of stressors in rivers and streams widely (Sharma 1996, Sharma et al. 2005, Dahal et al. 2007, Chaube et al. 2008, Emere and Nasiru 2009, Barbour et al. 2010). Several countries have developed family level biotic indices for macroinvertebrates (e.g. Armitage *et al.* 1983 in Great Britain, Stark 1985 in New Zealand, Camargo 1993 in Spain, Chessman 1995 in Australia) such as Hilsenhoff (1977) biotic index (HBI) which is based on an organism's relatively sensitivity to stream quality conditions (Reif 1977). In the 1990s a first region-specific score based method for Nepalese rivers (NEPBIOS) was developed by Sharma and modified for the Bagmati River System by Pradhan (1998) as NEPBIOS/BRS, and followed by the development of the GRSBIOS/ASPT (Ganga River System Biotic Score by Nesemann 2007.

1.2 Statement of Problem

Climate change is a global issue and every nation is equally accountable to work to minimize the impact of it. Unfortunately, Nepal lacks climate change related studies. Emission of greenhouse gases is significantly low in Nepal; however, due to topographical feature and the location, the impact is more pronounced in the Himalaya. Earlier reports show that the temperature in the Himalaya is increasing and that has alarmed the local people. It is obvious that the glacier in the mountains melt on increasing temperature and this can be an indication of drought in the near future because many of the rivers and lakes are glacier-fed. Moreover, sudden melting of glacier can trigger natural disaster events such as landslides, flash floods, soil erosion and drought; and ultimately disturb the drinking water sources and its quality (WWF 2005). The rivers and streams of Himalayan region are most vulnerable to climate change and are likely to affect all freshwater ecosystems eventually.

1.3 Rationale

Impacts of stressors can be assessed by monitoring routine physico-chemical parameters. Monitoring practices that involve physical, chemical and biological measurements are considered the best (Metcalfe 1989, Reynoldson et al. 1989) as such practices provide comprehensive information on the effect of water quality on aquatic ecosystems. The traditional physico-chemical water quality monitoring methods alone fail to provide consistent information regarding ecological status of the rivers and streams (Schofield and Davies, 1996). Decades passed still there is lack of sufficient and reliable data relating to biotic parameters. Rivers and streams are most important sources for the livelihood of local peoples in many VDCs of rural area in Nepal. There is no any baseline data for the future studies from the region such as, Manaslu Conservation Area (MCA), and Annapurna Conservation Area (ACA) using macroinvertebrates as biological indicator. In both the region, very limited study has been performed in the river water quality by means of biological parameters.

Aquatic ecosystems along with their fauna are vulnerable to a variety of climate-related changes. As there is change in the global temperature, there is also alter in water temperatures, stream flow patterns, and flow regimes. As a consequence, sensitive aquatic invertebrates are negatively impacted due to their relatively narrow range of habitat requirements and high degree of specialization in high elevation habitats (Muhlfeld et al. 2012).

Therefore climate change is likely to affect all freshwater ecosystems. The study of climate change impacts on any ecosystem requires long term data; unfortunately, Nepal Himalaya lacks these data. For this reason, this study aimed to have baseline data for climate change study using macroinvertebrates as an indicator.

1.4 Objectives

The general objective of this study is to assess the impact of climate induced change on river ecosystem and assess the water quality of streams at altitudinal variation. In order to achieve general objective, following specific objectives were formulated.

1. Analysing Physico-chemical and biological (macroinvertebrates) parameters of selected river sites with varying elevation.

2. Assessing the water quality with the application of selected biotic scores and biotic indices for validation of the methods in use.

3. Assessing the impact of climate induced change on river ecosystem and indicator taxa diversity and abundance.

1.5 Hypothesis

H_{01}: There is no correlation between temperature and EPT richness

$H_{a1:}$ There is correlation between temperatures and EPT richness

H_{02}: There is no correlation between altitudinal variation and taxa diversity.

H_{a2}: There is a correlation between altitudinal variation and taxa diversity.

1.6 Limitations of the study

Limitations of the study are:

i. Macroinvertebrates were identified up to family level.

ii. The result is based on one time data.

CHAPTER 2: LITERATURE REVIEW

In river ecosystem, there is a unidirectional flow of water, nutrients, inorganic, and organic materials from headwater mountain streams to lowland rivers river (Suren 1994). Benthic macroinvertebrates (BMI) that are depending on these substances are highly sensitive to temperature, precipitation, and the flow regime of the streams (Bunn and Arthington 2002, Lytly and Poff 2004). Therefore whenever there are longitudinal changes in the macroinvertebrate communities, either there is a change in the trophic level (Vannote et al. 1980) or change in hydraulic stress (Statzner and Higler 1986), or perhaps there is change in land-use (Ward 1989). Increase in air and water temperaturesalso bring changes in growth and timing of the development of macroinvertebrates (Bayoh and Lindsey 2003). Fluctuation in the environmental conditions may also cause difference in the abundance and composition of benthic invertebrates. In short macroinvertebrates can be a good indicator of Climate change effect in river ecosystem.

The complex mountain system in the Himalayan region is extremely vulnerable to global warming (Bandyopadhyay and Gyawali 1994, Eriksson et al. 2009). In global context, the average temperature has increased 0.60° Celsius in the last 30 years and 0.80° Celsius over the last century (Hansen et al. 2006, Jain and Golam 2007). Glaciers are melting in an abnormal way and this aberrant alter has resulted in the unseen floods and extreme droughts putting millions of life on vulnerable state (Marahatta 2005, 2006, Phillips 2012,). Ten Major rivers in Asia (Table 2-1) were born from the Himalayas; billions of people are living on the basin of these rivers and they are depending on the natural resources available on these river basins (Nicholls 1995, Sanlaville and Prieur 2005, Macintosh 2005, Penland and Kulp 2005, Woodroffe et al. 2006, Eriksson et al. 2009). These rivers have supported agricultural sectors in the Indian subcontinent and in China (Stern 2006, Eriksson et al. 2009). Unfortunately, the continuous change on the climate may produce disorder on these rivers resulting in the exacerbation of the socioeconomic condition of the people in these areas (Stern 2006).

Table 2-1 Principal rivers of the Himalayan Region

River	Annual Mean Discharge m^3/Sec	% of glacier melt in river flow+	Basin Area (km^2)	Population Density	Population x1000	Water availability (m^3/person/year)
Amu Darya	1376	not available	534739	39	20855	2081
Brahmaputra	21261	-12	651335	182	118543	5656
Ganges	12037	-9	1016124	401	407466	932
Indus	5533	up to 50	1081718	165	178483	978
Irrawaddy	8024	Unknown	413710	79	32683	7742
Mekong	9001	-7	805604	71	57198	4963
Salween	1494	-9	271914	22	5982	7876
Tarim	1262	up to 50	1152448	7	8067	4933
Yangtze	28811	-18	1722193	214	368549	2465
Yellow	1438	-2	944970	156	147415	308
Total					**1345241**	

Source: ICIMOD 2012

Earth's normal climate plays a vital role in the stability of social and natural system (USGRP 2002). Unfortunately, earlier reports have already shown a significant change in the standard average period of weather, climate, due to natural variability or as a result of human activities (IPCC 2001, 2007, WHO 2010). Despite few localized benefits brought about by global warming (WHO 2010), there are numerous negative impacts. It worsens the status of clean air, safe drinking water, and change in the availability of drinking water supplies. Moreover, water boundary movement and displacement, insufficient food, insecure shelter, and change in the habitat of macroinvertebrate in the long run are also caused due to climate change (IPCC 2007, USEPA 2008, WHO 2010).

2.1 Bioassessment

Aquatic organisms have potential to reflect all sources of disturbances to which they are exposed over time such as environmental change, climate change, and anthropogenic change (EPA 2008). They are capable of revealing more information than by measuring concentrations of chemical pollutants or toxicity tests (Resh and Rosenberg 1984, Rosenberg and Resh 1993, USEPA 1999). Therefore bioassessments provide means of assessing overall integrity of river systems (EPA 2008). However, available information on the bioassessment of river and stream is not enough. Assessment programs require better understanding of climate-associated changes in aquatic macroinvertebrates. Especially in the developing world, bioassessment programs using macroinvertebrates are still in the infant stage. There is continuous emission and disposal of pollutants in the environment. Aquatic organisms are continuously exposed to different magnitude, frequency, and duration to synergistic of these stressors (EPA 2008).

In the context of Nepal, few studies are involved in the investigation of macroinvertebrates in relation to climate change. Majority of the past studies on water bodies were based on the analysis of physical and chemical parameters (Reynolds et al. 1998, Lacoul and Freedman 2005, Sharma et al. 2009). Despite the fact that we have less expertise on macroinvertebrates, we are real behind on the resources to carry on the research activities on climate change. Although studies on macroinvertebrates were started earlier in 1950s, majority of the studies were carried out by foreign investigators (Shah and Shah 2011) and only after 1990s macroinvertebrate study was carried out more seriously.

Prior to 1954, there was not much published information on the macroinvertebrates in Nepal. However after mid-fifties, morphology, habitat, and behavior of benthic macroinvertebrates were described; and collection and taxonomic identification of MIB was carried out (Kimmins 1964, Mall 1978, Ito 1986). Nevertheless, identification was never adequate. Still there were many benthic invertebrates needed to be identified and described.

After 1990s, bioassessment studies were carried out using different parameters. Suren (1994) reported the influence of altitude and the land use changes on macroinvertebrate assemblages from riffles in the streams of Western Nepal. Sharma (1996) investigated river systems of Nepal; and introduced the Nepalese biotic score (NEPBIOS). Moreover, water quality assessment of different rivers in Nepal was carried out (Sharma & Moog 1996, Pradhan 1998, Khanal 2001). These studies reported the information on the effects of natural and anthropogenic effects on the benthic invertebrate fauna from Nepal.

Recently the ecological assessment work in Nepal was accelerated. More efficient and reliable tools were developed for the ecological assessment of streams and river system. And of course it paved a path to better understand the biological community in the rivers in Nepal (ASSESS-HKH 2008).

2.2 Climate change effects on streams and rivers

Air temperature and precipitation are considered primary climate drivers. Change in the greenhouse gases has direct impact on these climate drivers (IPCC 2007). It is no wonder that climate change may influence the global average air temperature to be 1.1–2.9°C (lowest emissions) to 2.4–6.4°C (highest emissions) (IPCC 2007). Moreover, it is likely that the trend of precipitation may shift and may become more violent; it may be more in winter and less in summer (Hayhoe et al. 2007, IPCC 2007). This change may cause more winter precipitation as rain instead of snow; earlier snow-melt; earlier ice-off in rivers and lakes; and longer periods of low flow and more frequent droughts in summer; and these conditions will cause serious problems in the aquatic ecosystem (Fisher et al. 1997, Barnett et al. 2005, Hayhoe et al. 2007, IPCC 2007). There will be alterations in hydrologic and thermal regimes (IPCC 2007) causing greater variability and flashiness of stream flows (Moore et al. 1997, Hayhoe et al. 2007). These changes in the stream will have negative impact on aquatic ecosystems through influence on sediment supply and transport, habitat stability, channel formation and maintenance, and water volume, which, in part, controls habitat availability and water quality (Poff and Allan 1995, Richter et al. 1996, Poff et al. 1996, Poff et al. 2002).

2.3 Climate Change effects on Aquatic Organism and Ecosystems

The sensitivity of common biological indicators especially the macroinvertebrate is not well known. However, there is enough evidence from previous studies that climate change has direct effect on the aquatic ecosystems (Walther et al. 2002, Root et al. 2003, Parmesan 2006). Water temperature plays an important role in maintaining the biological functions in aquatic macroinvertebrates such as growth, feeding, metabolic rates, reproduction, and survival (EPA 2008). Majority of these organisms have tolerance for smaller temperature range; and this temperature regime determines the distribution of organisms based on their tolerance to temperature, food supply, and other adaptive features (Vannote and Sweeney 1980, Matthews, 1998). Therefore when there is thermal change in the environment then these biological indicators are expected to migrate to the favorable elevation or they will die (EPA 2008). In the case of macroinvertebrates, they cannot migrate or shift to longer distance so thermal raise above their tolerance level will keep them in higher stress level.

2.3.1 Macroinvertebrates as Indicators

Macroinvertebrates are the wide range of backboneless animal species that are visible to our naked eyes. They have a life span of up to a year or greater; they are mostly inactive and are less capable of migrating from the impact zone. These organisms are retained on a 0.25 mm mesh net. Freshwater rivers, streams, wetlands, and lakes are the areas where macroinvertebrates are found the most. These aquatic organisms include annelids, arachnids, crustaceans, insects, and mollusca. These organisms spend their life in water for the most part, so their survival is directly related to the quality of water. Furthermore, these species are highly vulnerable to the degradation of water sediment due to physical or chemical conditions (Water facts 2001, Alam et al. 2008).

Macroinvertebrates, in stream water monitors the environmental quality (Loeb and Spacie 1994, Alam et al. 2008). Any changes (biological, chemical, or physical) that occur in the aquatic ecosystem have direct impact on the resident organisms (Loeb and Spacie 1994). So, these resident organisms are an important component of freshwater ecosystems and are capable of detecting the effects of sporadic and cumulative pollution of their habitat (Pauw and Vanhooren 1983, Furse et al. 2006).These are also sensitive to changes in conditions such as, precipitation, temperature, and the associated flow regimes; hence they provide good indication of environmental change (Bunn and Arthington 2002, Lytle and Poff 2004).

These numerous different macroinvertebrate species have varying sensitivities to change in water quality and offers a wide spectrum of responses in their habitat (Hauer and Lamberti 1996). They are easy to collect and identify. The taxonomy of many of these macroinvertebrates is well known and keys of identification are also available (Hauer and Lamberti 1996). The responses of many of these species to different types of pollution have already been studied (Hauer and Lamberti 1996). Therefore, water quality assessment using macroinvertebrates is reliable affordable tools to assess the health status of river/steams system (Hynes 1970, Moog 1995).

The reference conditions may drift as temperature changes; so the issue of temporal variability is important especially when we are looking at the issue of climate change (Easterling et al. 2000, Palmer and Raisanen 2002, Diffenbaugh et al. 2005).

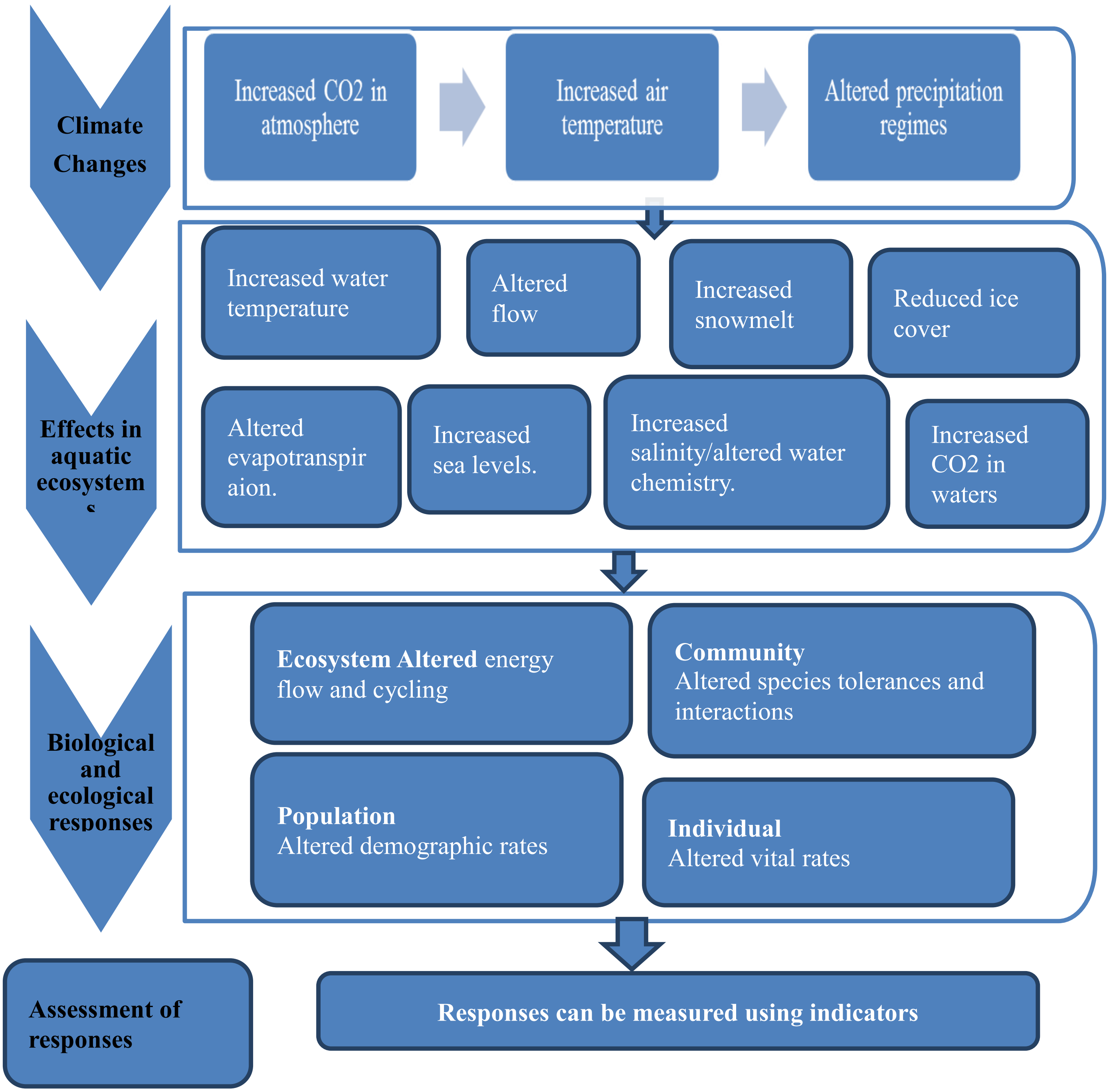

Figure 2-1 Conceptual diagram of how climate change affects aquatic Ecosystems and the possible ecosystem responses that can be measured using biological indicators

Source: United States Environmental Protection Agency EPA/600/R-07/085/ March 2008.

2.3.1.1 Change in Ranges, Distribution of species, and community composition

Based on Daufresne et al. (2003) study, spring macroinvertebrates are decreased with the increase in the temperature. Based on the study, done in the streams of Wales, over a 25 years period, temperature increased by 1°C and there is approximately 21% reduction in the abundance of macroinvertebrates (Daufresne et al. 2003, Durance and Ormerod, 2007). Golladay et al. (2004) from South East United States reported increased mortalities and local extinction in the freshwater mussels due to drought, along with depressed dissolved oxygen (DO) levels, and low water flows. The study found several low flow-sensitive species such as *Lampsilis straminea claibornensis, Villosa villosa,* and *Lampsilis subangulata.* Other species such as *Pleurobema pyriforme, Mediunidus penicillatus* were found and implied they were intolerance to drought due to decreased DO concentrations during low flows (Golladay et al. 2004). Furthermore, mussel species such as *Elliptio complanata/icterina, Villosa vibex,* and *Villosa lineosa* were tolerant to drought induced low flow and low oxygen Golladay et al. 2004).

2.3.1.2 Change in Phenology

Poff et al. (2002) reported that the growth rate and earlier maturation of aquatic invertebrates are enhanced by warmer water condition. This idea was also overlapped with the study done by Watanbe et al. (1999) in Japanese species of mayfly (*Ephoron shigae*). Earlier maturation of mayflies may result in the imbalance of trophic level because the predators of mayflies may not get enough food if the larvae of mayflies mature earlier and fly away.

2.3.1.3 Ecosystem effects

Earlier report shows that when CO_2 level increases, there is a negative impact on the nutritional quality of leaf litter to macroinvertebrate detritivores (EPA 2008). Moreover, the lower quality litter slows down the assimilation and results in the slower growth of macroinvertebrates (Tuchman et al. 2002). Eventually negative impact is seen in the overall aquatic food web. In general, nutrient enrichment leads to changes in the algal and diatom community composition of a stream, and sometimes, in some streams, to increased production and chlorophyll concentrations, leading to changes in primary invertebrate consumers (Gafner and Robinson 2007) which could cascade through the community (Power 1990, Rosemond et al. 1993).

2.4 Altitudinal Effect on Macroinvertebrates

Nepal Himalaya has the greatest altitudinal gradients on earth (Suren 1994). Benthic macroinvertebrate communities at different altitude respond differently. With the increase in altitude, the taxonomic richness decreases (Brewin 1995). Suren (1994) reported ten insect families were significantly less in higher altitude than in lowland Ss. In the higher altitude there is less oxygen availability compared to the lower altitude. The availability of oxygen depends on oxygen partial pressure, diffusion velocity, and diffusion sub layer thickness; all three factors decreases with the increase in temperature.

2.5 Dissolved Oxygen and Macro invertebrates

Availability of dissolved oxygen (DO) is an important factor that determines the composition and distribution of freshwater communities (Hynes 1960, Giller and Malmqvist 1998, Dobbs 2002). The concentration of DO depends on multiple factors such as photosynthesis carried by aquatic plants, respiration by aquatic organisms, changes in atmospheric temperature and pressure etc (Allan 1995, Dobbs 2002). Eriksen et al. (1984) reported that different taxa differ in their oxygen requirements and tolerance to hypoxia. Connolly et al. (2004) reported that macroinvertebrates from both upland and lowland responded in a similar manner to DO content. Mayflies turned out to be highly sensitive to low oxygen conditions; mortality was observed in Chironomidae when oxygen concentration was below 8% saturation (Connolly et al. 2004).

CHAPTER 3: METHODS AND MATERIALS

3.1 Study Area

Study was done in the tributaries of Budi Gandaki River and Modi River which lies in Manasalu Conservation Area (MCA) and Annapurna Conservation Area (ACA) in Nepal.

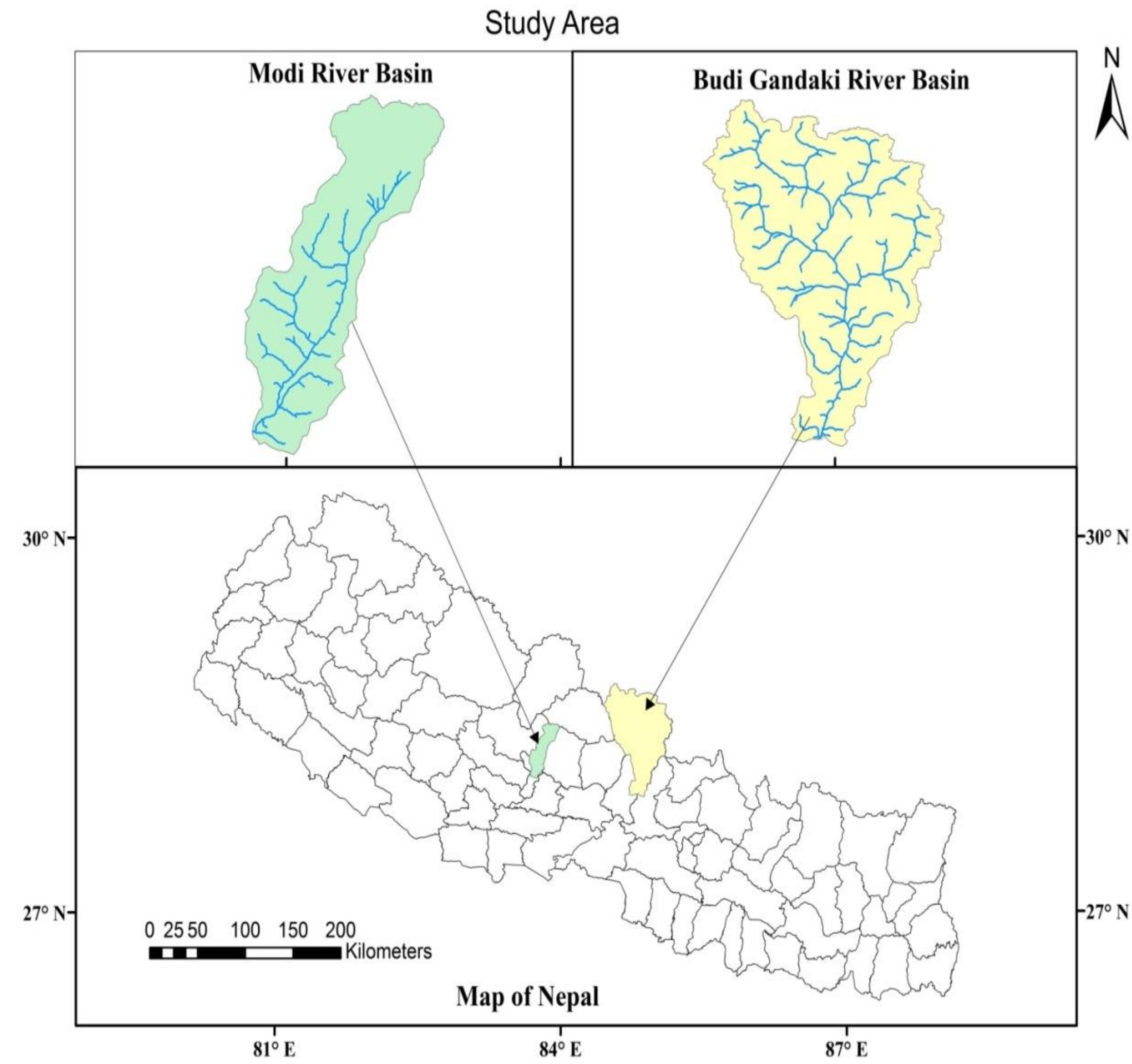

Figure 3-1 Map of Nepal

3.1.1 Manaslu Conservation Area (Region 1)

Manaslu conservation area (MCA) lies in western Nepal that has a total area of 1,663 km^2 and covers seven Village Development Committees (VDCs) (Samagaun, Lho, Prok, Bihi, Chumchet, Chhekampar and Sirdibas) with about 9,000 local residents (Swissa 2012). The area of MCA starts at an altitude of 600 m and the average rainfall is approximately 1900 mm per annum (National Trust for Nature Conservation 2012). Local people in this area are neglected in terms of basic infrastructures. They do not have good earning sources; they are solely dependent on the marginal agriculture and animal husbandry. Due to food deficit, they have to exploit natural resources for survival. Therefore, ecosystem is declining gradually in MCA. The Manaslu region has six climatic zones such as tropical, subtropical, temperate, subalpine, alpine, and arctic.

It is famous for an ideal place for village tourism experience. The region harbors a mosaic of habitats for 33 species of mammals, 110 species of birds, 11 species of butterflies and 3 species of reptiles. There are approximately 2000 species of plants, 11 types of forests and over 50 species of useful plants (National Trust for Nature Conservation 2012, Swissa 2012).

Sampling site in region 1

The research was focused on the tributaries of Budi Gandaki River. Five streams were sampled depending on accessibility, while trekking from Jagat to Kal Tal of Prok VDC covering an altitudinal range from 1300-3700m (Figure 3-2).

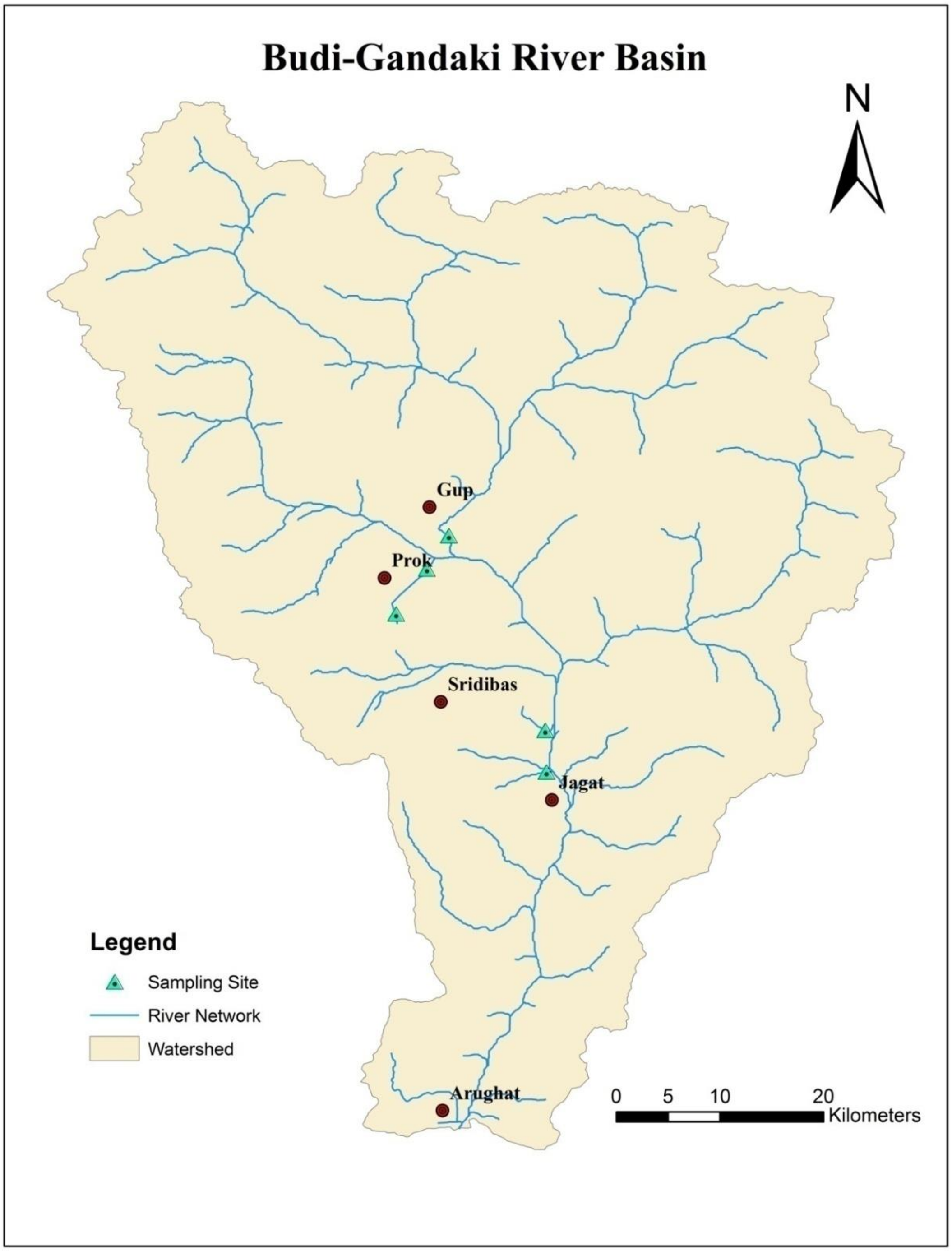

Figure 3-2 Budi Gandaki River Bain (Region 1)

3.1.2 Annapurna Conservation Area (Region 2)

Annapurna conservation area (ACA) lies to the Western part of the Capital city, Kathmandu. It is the largest conservation area (7,629 km^2) and covers fifty-seven Village Development Committees (VDCs) from five districts with over 100,000 local residents (National Trust for Nature Conservation, 2012). It covers an altitudinal range between 1,000 m – 8,000 m with an average annual rainfall range of 400 mm to 5,600 mm (Swissa 2012). It is the most popular protected area in Nepal with over 50,000 annual visitors (Swissa 2012, National Trust for Nature Conservation 2012). Compared to MCA, ACA is well protected and people have initiated various conservation programs including integrated conservation and development program from late 80s.

ACA is rich in biodiversity and is a treasure house for 1,226 species of flowering plants, 102 mammals, 474 birds, 39 reptiles and 22 amphibians. There are several features that make the Annapurna region a unique place in the world. The region contains world's largest rhododendron forest in Ghorepani. Tilicho lake, located in Manang – north of Annapurna massif, is the world's highest altitude fresh water lake.

Sampling Site region 2

The research was focused on the tributaries of Modi River. Ten Streams were sampled depending on accessibility, while trekking from Kusuma to Ghadruk VDC covering an altitudinal range from 700m to 1300m (Figure 3-3).

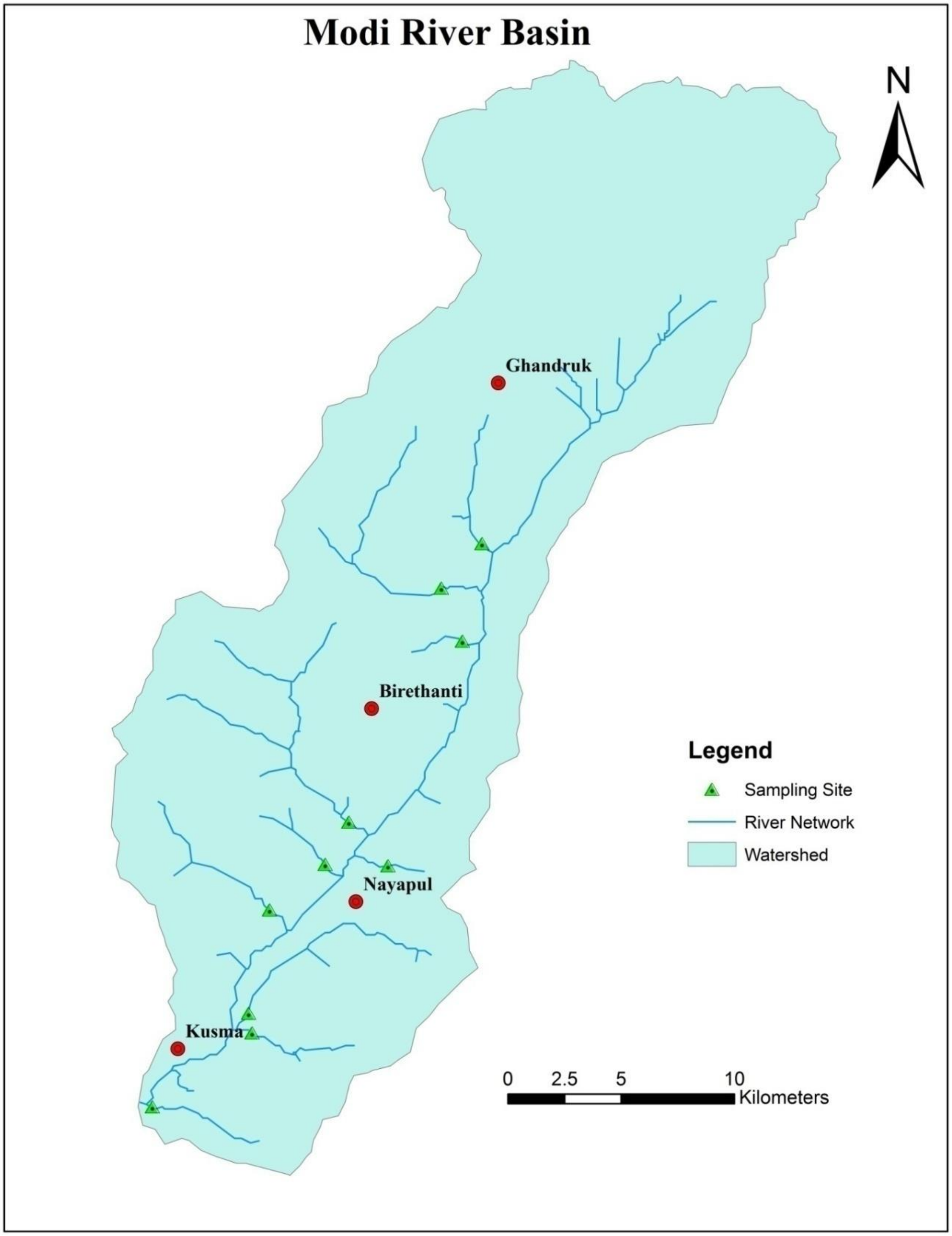

Figure 3-3 Modi River Basin (Region 2)

Site 1: Chinne Khola (S1)

It was the lower most stretch of the stream considered in this research. It was located near to Kusuma village of Parbat district at an altitude of 740m.Substrate available in this stream was 70% favorable for epifaunal colonization and fish cover. Gravel, cobble, and boulder particles are 50% surrounded by fine sediment. Out of four velocity/depth regime, fast-deep regime was absent. Slight deposition of sand was observed in pools. Water fills > 75% of the available channel. There was no channelization with infrequent riffles. Both side of bank was stable and around 90% of it was covered by local trees, and understory shrubs. No human activities upto the >18m width of riparian zone was noticeable.

Site 2: Rati Khola (S2)

Most of the substrate available in stream were disturbed or removed from the channel. Gravel, cobble, and boulder particles were 10% surrounded by fine sediment. All four velocity/depth regimes were present (slow-deep, slow-shallow, fast-deep and fast-shallow). No enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition was noticed. Water fills around 30% of the available channel and riffle substrate were mostly exposed. No channelization with relatively frequent riffles was observed. Bank was moderately stable, small area of erosion mostly healed over. More that 90% of stream bank surfaces and immediate riparian zone was covered by native vegetation which include, trees, understory shrubs etc.

Site 3: Jare Khola (S3)

Only 70% of substrate favorable for epifaunal colonization was observed. Gravel, cobble and boulder particles were 10 % surrounded by fine sediment. All four velocity/depth regimes were present. Non enlargement of islands or point bars with >75% of the available channel. Channelization was absent with relatively frequent riffles. Bank was stable but little potential for future. More than 90% of the stream bank surfaces and immediate riparian zone was covered by native trees, and shrubs. Width of riparian zone was not impacted by human activities up to >18 m.

Site 4: Ambot Khola (S4)

Gravel, cobble and boulder particles were 40% surrounded by fine sediment. Only around 70% of mix stable habitats were favorable for epifaunal colonization. All four velocity/depth regimes were present. Some new increase in bar formation, mostly from gravel and sand was documented. Water fills >75 % of the available channel with no channelization. Riffle was relatively frequent. Bank was stable with more than 90% covered by native vegetation and shrubs. Width of riparian zone was around 16 meters and minimally impacted by human activity.

Site 5: Bhadra Khola (S5)

Greater than 70 % of substrate was favorable for epifaunal colonization and fish cover. Out of four velocity/depth regime, deep-fast was missing and the gravel, cobble, and boulder particle were 25% surrounded by fine sediment. Moderate deposition of gravel was observed on old bars. Water fills 40% of the available channel with some channelization was observed. Occurrence of riffles was frequent. Right bank was stable whereas left bank was moderately stable around 30% of bank was affected by slight landslide and soil erosion. More than 90% of bank surface was covered by native vegetation.

Site 6: Bhurundi Khola (S6)

Mixture of stable habitat was observed which, was around 70% favorable for epifaunal colonization and fish cover. Only 5 % of gravel, cobble, and boulder particle were surrounded by fine sediments. All four velocity/depth regime were present with no island or point bars in stream. Water reaches base of both lower banks and minimal amount of channel substrate was exposed. The flow was in normal pattern with the occurrence of frequent riffles. Right bank was more stable then left bank. And vegetation coverage was around > 90% in right bank whereas in case of left bank only 70% of banks surface was covered. Right bank was not affected by any human activities but minimal human impact was noticed along left bank.

Site 7: Chimrun Khola (S7)

Approximately 70% of substrate was suitable for the epifaunal colonization. Gravel, cobble, and boulder were surrounded by fine sediment around 25%. Only two out of four habitat regimes were present in stream. Little or no enlargement of islands was formed. Water fills around 75% of available channel along with some channelization. Generally all flat water or shallow riffles was observed. Left bank was stable with native vegetation cover whereas right bank was slightly disturbed. Compared with right bank, left bank was not affected by human activities.

Site 8: Dhoti Khola (S8)

Around 40-70% of habitat was suitable for epifaunal colonization. Gravel, cobble and boulder particle were around 25 % covered by fine sediment. All four velocity/depth was observed with no enlargement of islands. Water reaches base of both lower bank, and minimal amount of channel substrate was exposed. Riffles were relatively frequent with no channelization. Right bank was stable whereas left bank was moderately stable. More than 90% of right bank was covered by native shrubs and trees whereas along left bank surfaces were less covered by vegetation native vegetation. Width of riparian zone was >18 meters and have not impacted by human but in left bank width of riparian zone was around 15 meters and human activities have impacted minimally.

Site 9: Sadi Khola (S9)

Mixed of stable habitat around 70% of substrate was favorable for epifaunal colonization and fish cover. About 15% of gravel, cobble, and boulder were surrounded by fine particles. Only three out of four of velocity/depth regimes were present. Some increase in bar formation by newly deposit sediment was observed. Water fills >75% of the available channel and no channelization were occurred with frequent riffles. Right bank was stable whereas left bank was moderately unstable. More than 90% of bank surfaces and immediate riparian zone was covered by native vegetation. Riparian zone was not affected by human activities.

Site 10: Thado Khola (S10)

Most of the substrate was disturbed or removed and only 40% of habitat was suitable for epifaunal colonization. Gravel, cobble, and boulder particles were surrounded by 5% of fine sediments. All four velocity/depth regimes were present. Some newly deposited bar was formed. Water fills >75% of available channel with no channelization. Right bank was stable with native vegetation cover whereas left bank was moderately unstable with native vegetation cover. Riparian zone was not impacted by human activities.

Site 11: Bhalu Khola (S11)

Greater than 80% of substrate was favorable for epifaunal colonization and fish cover, mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential. Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space. All four velocity/depth regimes was present (slow deep, slow-shallow, fast-deep, fast-shallow). Less than 5% of stream bottom was affected by sediment deposition. Water reaches base of both lower banks, and minimal amount of channel substrate is exposed. Water reaches base of both lower banks and minimal amount of channel substrate is exposed.

Site12: Ghatte Khola (S12)

About 40-70% of stable habitat was suitable for epifaunal colonization. Gravel, cobble, and boulder particles were around 20% surrounded by fine sediment. Out of four only 3 of the velocity\depth was present. Some newly formed bars were present. Water fills >75% of available channel. Some channelization was present. Riffle was relatively frequent. Right bank was stable but left bank was moderately stable with some erosion. Left bank was covered by native vegetation and right bank was less covered by native vegetation. Riparian zone was less impacted by human activities.

Site13: Pungmong Khola (S13)

Greater than 80% of substrate was favorable for epifaunal colonization and fish cover, mix of snags, submerged logs, cobble or other stable habitat and at stage to allow full colonization potential. Gravel, cobble, and boulder particles were 50-75% surrounded by fine sediment. Only three of the four regimes were present. Some new increase in bar formation, mostly from grave, sand or fine sediment, 5-30% of bottom affected, and slight depositions in pools. Water fills 25-75% of the available channel, and or riffle substrates were mostly exposed.

Site14: Tarang Khola (S14)

It lies in the Prok VDC of Manaslu Conservation Area at an altitude of 2400m. It was Greater than 70% of substrate favourable of epifaunal colonization and fish cover. Gravel, cobble, and boulder particles were 30% surrounded by fine sediment. All four velocity /depth regimes was available. Some new increase in bar formation, mostly form gravel. Water fills 75% of the available channel and riffle substrates were mostly exposed. Channelization was done. Riffles occurred frequently.

Right bank was stable and whereas left bank was less stable as compared with right one. Around 90% of stream banks surface was covered by native vegetation. Right bank was not impacted by human activities, hence left bank was somewhat impacted.

Site15: Melanchu Khola (S15)

It was the inlet of Kal tal at an altitude of 3700m. It lies in the Prok VDC of Manaslu Conservation Area. Grave, cobble, and boulder was not surrounded by fine sediment. All four velocity/depth regimes were present. Little or no enlargement of islands or point bars was observed with minimal amount of exposed channel substrate. Channel flow was in normal pattern and riffle occurs frequently. Left bank was moderately stable where as right bank was thermokarst (very irregular surfaces of marshy hollows and small hummocks formed as ice-rich permafrost thaws) has occurred. Both banks surfaces and immediate riparian zone was covered by native vegetation including sub alpine bushy trees. Riparian vegetation was not impacted by human activities.

3.2 Methods

Sampling was conducted in the months of May and June. Tributaries of Budhi Gandaki and Modi Rivers were sampled from Manaslu Conservation Area (MCA) and Annapurna Conservation area. Altogether 3000 m altitudinal difference was incorporated in the survey range from 700 m to 3700 m.

3.2.1 Hydro-meteorological Assessment

3.2.1.1 Climate data

The monthly mean temperature and precipitation data of last 30 years were collected from Department of Hydrology and Meteorology. In order to have representative data, data were collected from the nearest lower and upper station of study area (i.e. Kususm and Ghandruk; Jagat and Samdo)

3.2.2 Biological Assessment

3.2.2.1 Sampling

The sampling procedure followed the multi-habitat sampling approach (Moog 2007) that means the distributions of sampling units followed the distribution of habitats. The distribution of habitats in the stretch was estimated and used it as a basis for selection of sampling units. Ten sampling units were taken in order to cover all possible habitats. Sampling starts from the most down point of the investigated section to avoid a self made turbidity by using sampling net of 200 micrometer mesh size. Each sample units were emptied into a white tray and preserved in 70% ethanol.

3.2.2.2 Sample Sorting and Identification

The successive preserved samples were taken to laboratory for identification. In laboratory, samples were put in Petri dish rinsed thoroughly with clear water to remove preservative. Samples were then sorted and identified up to family level following key by Janecek (2006), Graf *et al*. (2006) and Huber et al. (2006). After identification, indices such as Nepalese Biotic Score (NEPBIOS) (Sharma 1996), Biological Monitoring Work Party (BMWP) (Hellawell 1978), Average Score Per Taxon (ASPT) (Tfrcedor 1988), and Hilsehoff Biotic Index (HBI) (Hilsenhoff 1988) were applied for the assessment of water quality. The description of water quality class is illustrated in table 3-1.

Table 3-1 Description of Water Quality Classes

Water Quality Class	**Degree of Pollution**	**Mapping color**
Class I	Non polluted to very slightly polluted	Blue
Class I –II	Slightly polluted	Blue/Green
Class II	Moderately polluted	Green
Class II-III	Critically Polluted	Green/Yellow
Class III	Heavily polluted	Yellow
Class III-IV	Very heavily polluted	Yellow/ Red
Class V	Extremely polluted	Red

3.2.3 Water Quality Assessment

For the assessment of Stream water quality, physico-chemical and biological parameters were considered.

3.2.3.1 Physico-Chemical parameter

Selected parameters such as temperature, pH, conductivity, and dissolved oxygen were analyzed in situ. Dissolved oxygen was measured only in sites of regain 2. For water nutrient analysis, samples were taken to AEC laboratory facility and the analyses were carried out. Summary of the parameters analyzed and equipment used are listed in table 3-2.

Table 3-2 Summary of the parameters analyzed and the equipment used for the sampling and analysis of stream waters

Analyzed Parameters	**Analyzing machine and methods**	**Remarks**
Temperature	Temperature meter	In situ
Dissolved Oxygen	DO probe (AZ 8402 S/N 1053451)	In situ (was done in region 2 only)
pH	pH probe (Oakton Waterproof pH Tester 10 Pocket pH Tester EW-35634-10)	In situ
Conductivity	Conductivity meter (Cole-Parmer Traceable Portable Conductivity Meter EW-19601-03)	In situ
Total Nitrogen	Spectrometetric Kjeldahl Nitrogen Nitrogen-Nitrate+Nitrogen-Nitrite.	2ml Sulphuric Acid as preservative
Total Phosphorus	Spectrophotometer Colorimetric, ascorbic acid method	

3.2.3.3 Detection of Coliform

PA vial was used to test the presence or absence of Coliform in all sites.

3.2.4 Habitat Assessment

Habitat assessment field data sheet (HAS) of selected river stretch been done by performing corridor survey. Geographic latitude, longitude and elevation were observed by using Geographic Positing System (GPS). Geographic features were observed from direct observation and secondary information (Annex A). The information collected from habitat assessment was mention in study area.

3.2.4.1 Corridor survey

For the selected river stretch, the sketch of the river section was drawn. The features of the rivers such as bank stability and vegetation, channel alteration, flow status like pool, riffles, runs, rapids, embeddedness, transverse structures like bridge, weirs, dams, sediment bar and stressors like sewage discharge, substrates abstraction, water abstraction, solid waste disposal, washing, bathing were surveyed carefully. This corridor survey reflects the present riverine environment including the current stressors to the riverine ecosystem and their impacts.

3.2.5 Watershed Assessment

Watershed assessment of each stream was done with the help of topographical map and Google earth. Watershed map was mapped by tracing method of each individual streams. With the help of map various watershed characteristics were identified such as dominant land use, stream morphology etc.

3.3 Data Analysis

3.3.1 Metric Calculation

Various types of metrics which were very sensitive to the water temperature and hydrology were calculated. The summary of the calculated metrics were depicted by table 3-3.

Table 3-3 A summary of type of macroinvertebrate metrics calculated for the analysis

Category	**Metric type**
Richness measures	Total number of taxa
	Number of EPT taxa
	Number of Ephemeroptera taxa
	Number of Plecoptera taxa
	Number of Trichoptera
Composition measures	% EPT
	% Ephemeroptera
Tolerance / intolerance measures	Number of intolerant taxa
	Identification of tolerant and intolerant taxa
Feeding measures	%Filters
	%Grazers and scrapers

3.3.2 Statistical Analysis

Macroinvertebrate abundance (N), taxon richness(S), Shannon-Wiener's diversity index (H, natural log), Simple correlation, were calculated as descriptive measures of the benthic community for each site (Legendre and Legendre 1976).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Hydro-meteorological Assessment

4.1.1 Climate data

The average annual temperature of Manaslu Conservation Area (MCA), region 1, was increased by 1.97 ^{o}C in the last 30 years (Figure 4-1). The year 2004 was recorded as the coldest year (18.14 ^{o} C); and 1998 was recorded as the warmest year (23.24 ^{o}C).

In lower region1, average annual precipitation trend was highly fluctuating. The year 1995 had the highest precipitation of 187.06mm of average annual rainfall. Conversely, the year 1998 was the driest year with least annual rainfall of 60.67 mm (Figure 4-1). Similarly, in upper region 1, average annual precipitation trend for the last 30 years was fluctuating every year. However, overall trend was gradually declining. The year 1981 had the highest precipitation of 256 mm of average annual rainfall; and the year 1995 was the driest year with an annual average rainfall of 11 mm (Figure 4-2).

The average annual temperature of Annapurna Conservation Area (ACA), region 2, was increased by 0.86 ^{o} C (Figure 4-3). The year 1997 was recorded as the coldest year (15.01 ^{o} C); and the year 2010 was recorded as the hottest year (17.09^{o}C) in the last 30 years.

Precipitation for the last 30 years was fluctuating and more or less linear until 2007; nevertheless, the year 2008 faced the drought with very little rainfall (135.51 mm) and the year 1990 and 2000 had the highest precipitation of 255.5 mm and 263.49 mm in lower region 2 (Figure 4-3). Moreover, the precipitation in upper region was slightly greater than the lower region. It was maintained between 141 mm to 411 mm per annum with some exceptions. In the last 30 years, the precipitation was dramatically high in 2001, 1998, and 2009 which reached up to 1005.63 mm, 2275.2 mm, and 3358.25 mm respectively (Figure 4-4).

In the current study, majority of the studied sites were spring fed. Based on Poff et al. (1996) study, increased variability in precipitation has impact on the runoff in the spring fed rivers. Stream\river water temperature regimes will be altered by increase in air temperature, variation in flow (Hawkins et al. 1997, Mohseni et al. 2003, Daufresen et al. 2003, Cassie et al 2006) which influences distribution, abundance, composition and functioning of aquatic macroinvertebrate (Poff and Allam 1995, Richarter et al. 1996, Matthews 1998). The temperature showed increasing trend and the precipitation was fluctuating in both the studied regions. The fluctuation will ultimately affect the existing aquatic fauna of these regions by creating competitive interactions, effecting on food supply, and also driving the time of life cycle events (phenology) (Sweeney and Vannote 1978, 1980, Hawkins et al. 1997, Matthews 1998).

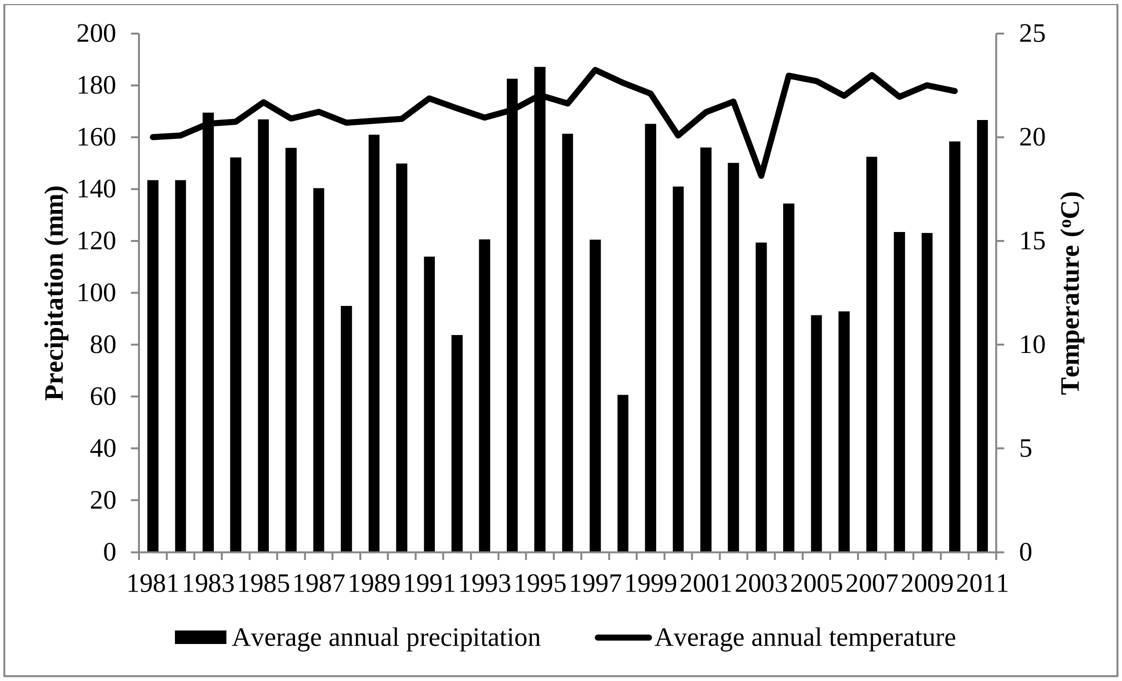

Figure 4-1 Average annual temperature and precipitation pattern of lower region 1

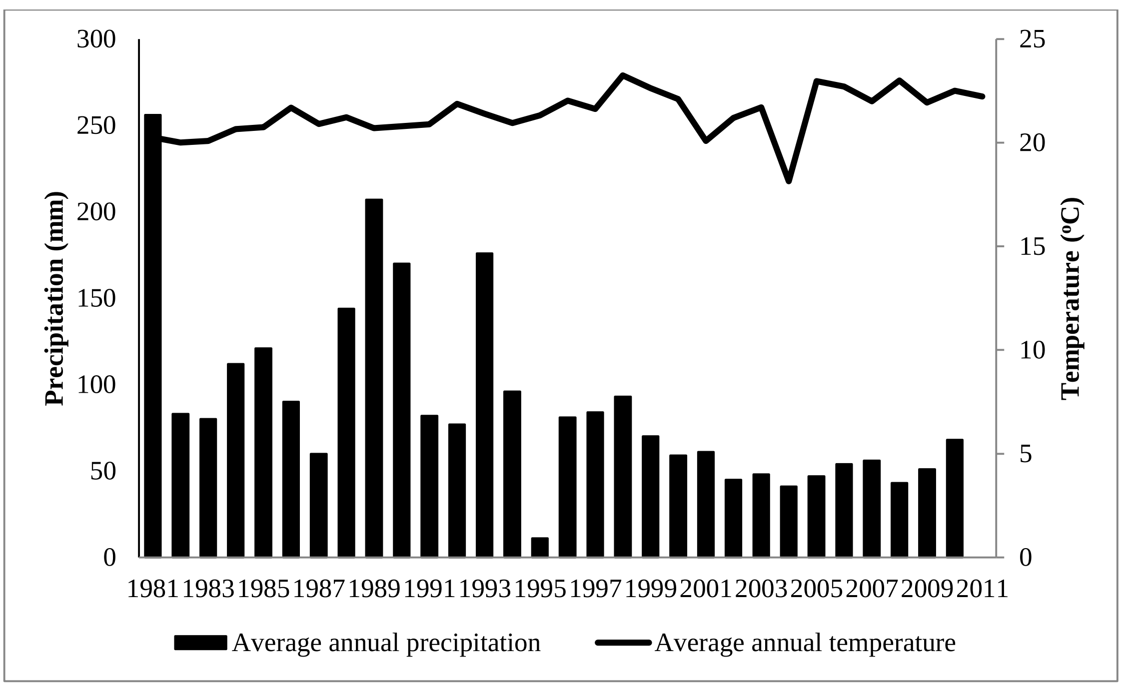

Figure 4-2 Average annual temperature and precipitation pattern of upper region 1

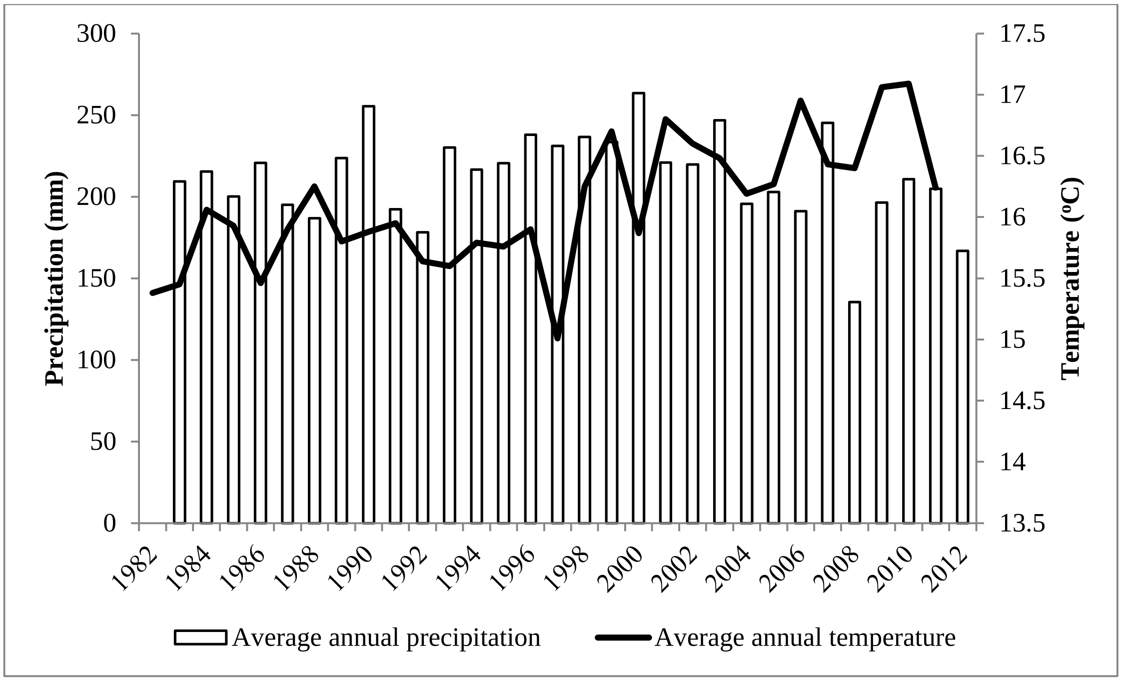

Figure 4-3 Average annual temperature and precipitation pattern of lower region 2

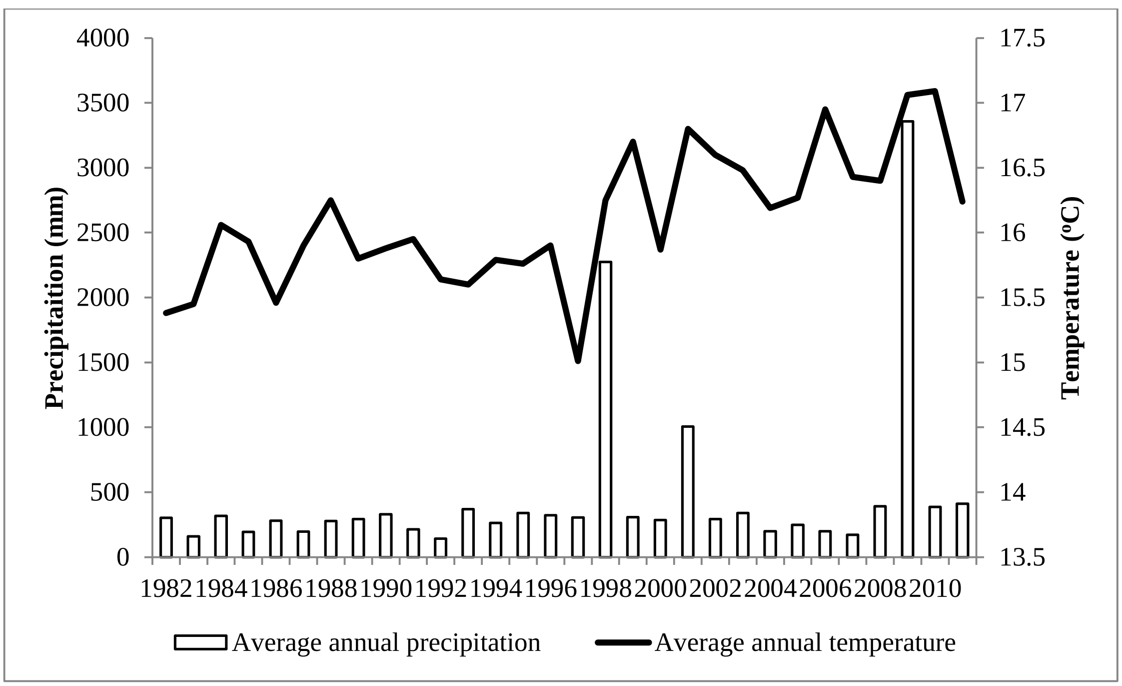

Figure 4-4 Average annual temperature and precipitation pattern of upper region 2

4.2 Biological Assessment

A total of 62 families and 10 orders of aquatic macroinvertebrates were identified from 53 composite samples collected in fifteen sites of Manaslu Conservation Area, region 1 and Annapurna Conservation Area, region 2. There were 40 families belonging to 10 orders and 48 families belonging to 9 orders from region1 and region 2 respectively.

In region 1, cumulative taxa richness was greater than 7 orders and 20 families in S11, whereas in the other sites these values were respectively fewer than 7, and around 20. Similarly, in region 2 cumulative taxon richness was greater than 7 orders, and 20 families in S4, whereas in the other sites these values were 7 and 20 respectively.

Planariidae and Dugesiidae were the only two families recorded belonging to the least diverse phylum Platyhelminthes. Similarly, 12 families from Diptera and 2 families from Odonata were the highest and least families identified from region 1 (Table 4-1). Moreover, 11 families from Trichoptera and three families of Hemiptera were the highest and least families identified from region 2 respectively. The number of family included in each insect order ranged from 0 to 12 and only around five families were responsible for most of the total abundance of an insect order. Insect taxon richness found on each site of both regions is listed in Table 4-1.

Table 4-1 Taxon richness found on each sites of region1 and region 2.

Insect Order	**Number of family in Region 1**	**Number of family in Region 2**
Diptera	12	6
Plecoptera	10	4
Coleoptera	4	8
Ephemeroptera	4	8
Trichoptera	5	11
Heteroptera	0	4
Odonata	2	3
Others	3	4
Total	40	48

Source: Field survey & laboratory analysis, 2013

4.3 Water Quality Assessment

4.3.1 Physico-Chemical parameter

4.3.1.1 Water Temperature

The temperature range was recorded in between 27.8 to 5.2 ^{o}C. The maximum temperature (27.8 ^{0}C) was recorded in S1 and the lowest temperature (5.2 ^{0}C) was recorded in S15. Bhattrai et al. (2008) mentioned change in water temperature is due to corresponding changes in atmospheric temperature. S15, inlet of *Kal Tal* had lowest temperature because it lies at 3700 m altitudeS4 and S5 showed high temperature compared to the other lower sites due to their southern aspect and low canopy coverage (Figure 4-5).

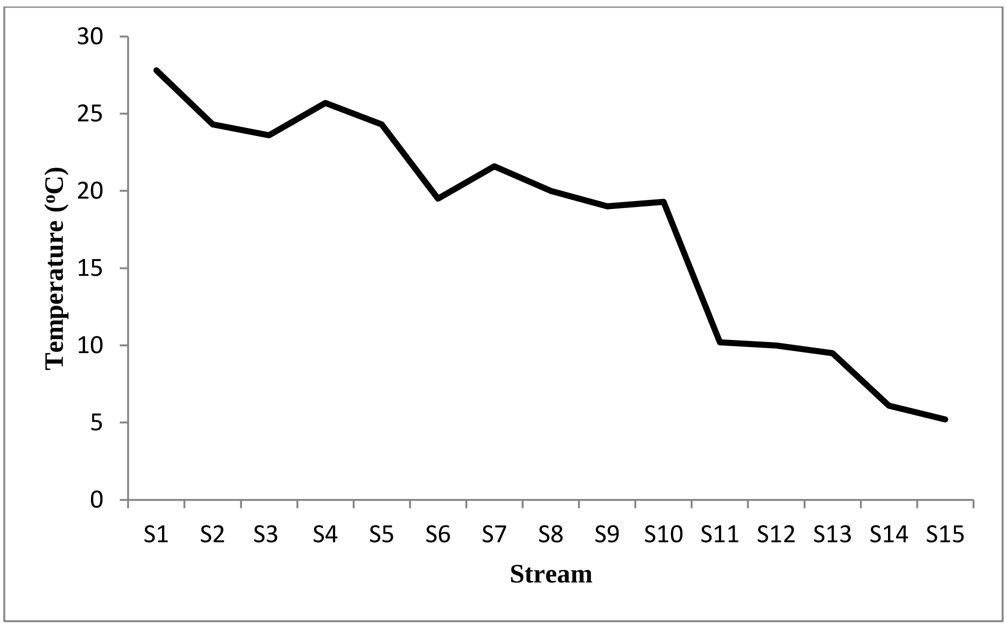

Figure 4-5 Temperature trend of each site with the increase in elevation

4.3.1.2 pH

The pH was recorded in between 7.36- 8.9 which means that all the sites had alkaline pH ranging from a medium value of 7.36 – 8.9 (Figure 4-6). Natural pH levels of streams typically fall between 6.5 and 9.0 depending on the surrounding soil and vegetation (Mesner and Geiger 2010). The lowest pH was recorded on site S7 attributed to inputs of allochthonous organic compound including organic acid from terrestrial sources in the catchment. The highest pH 8.9 was recorded on site S15.

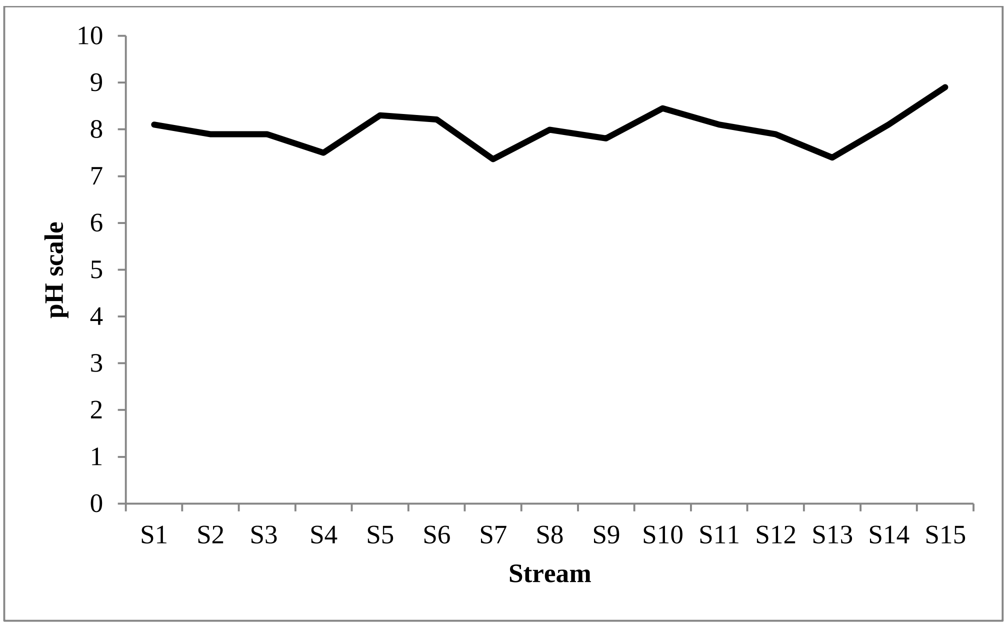

Figure 4-6 pH trend of each site with the increase in elevation

4.3.1.3 Dissolved Oxygen

The lowest dissolved oxygen was observed at site S7. Photosynthetic activities of algae and macrophytes can increase oxygen concentrations on a diurnal basis, particularly in relatively sluggish streams and rivers (Wetzel 2006, Livingstone 1991, Muller and Weise 1987). While moving from lower to higher altitude DO was observed in increasing trend that indicated higher the temperature lowers DO presence in water. Site S7 was relatively sluggish than other remaining sites but still low DO was recorded because as an impact caused by cattle watering.

4.3.1.4 Water Conductivity

Conductivity in streams and rivers are affected primarily by the geology of the area through which the water flows (USEPA, 2010). The conductivity (39 µS cm^{-1}) was recorded lowest in site S15 and highest in S1 and S10 (140 µS cm^{-1}). The highest conductivity (140 µS cm^{-1}) was recorded in sites S1 and S10 (Figure 4-7). Conductivity was low in S15 because of presence of granite in stream bed and low temperature. Granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water (USEPA 2010). Conductivity was also affected by temperature, the warmer the water, higher the conductivity.

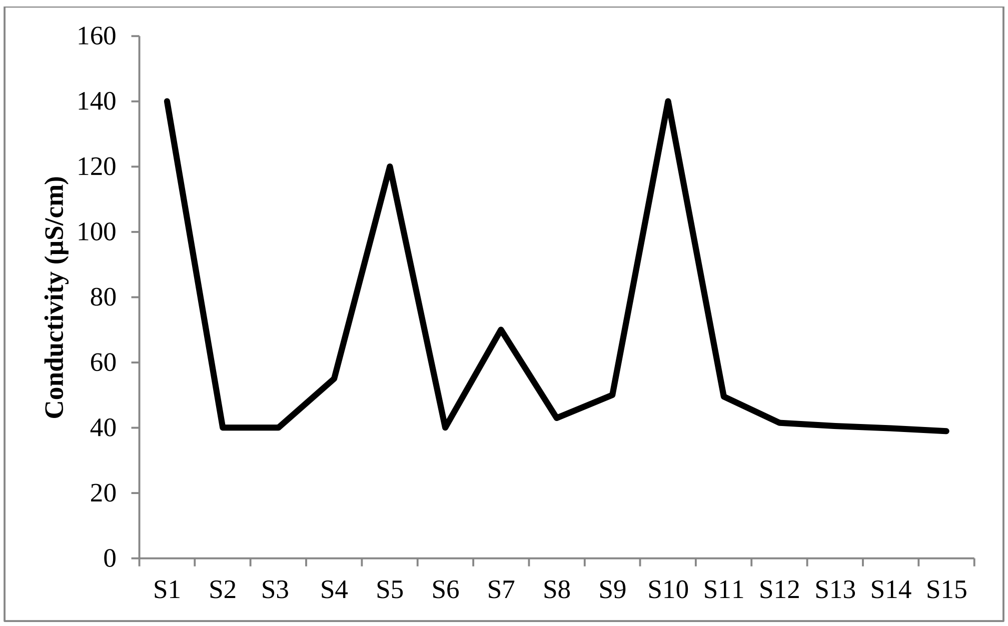

Figure 4-7 Conductivity trend of studied site with the increasing in elevation

4.3.1.5 Nutrients

Total phosphorus was almost at non detectable level i.e. < 0.05 mg/L in all sites except in S2 and S4. Measuring phosphorus in stream water is challenging, it involves very low concentration down to 0.01 milligram per liter (mg/L) or even low. Algal bloom, low dissolved oxygen, and death of certain fish, invertebrates, and other aquatic animals can make dramatic impact in streams even in lower concentration. In most fresh water it is very short supply (USEPA 2010). Phosphorus was detected as 0.08 and 0.06 mg/L in sites S2 and S4 respectively. It is due to the influence of agriculture runoff from cultivated land in the catchment

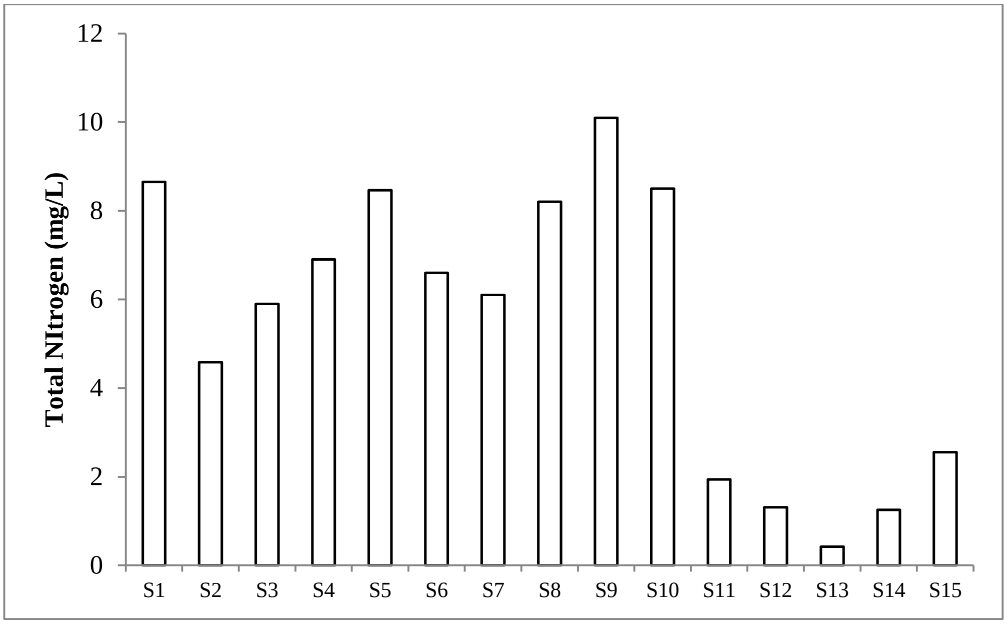

Figure 4-8 Total nitrogen at different sites with the increase in elevation

Total nitrogen (10.1mg/L) was detected highest in site S9 and lowest (0.42mg/L) in S13. Bedrock of the stream could be possible source of nitrogen concentrations of total nitrogen were highest in Phyllite followed by slate (Holloway et al. 1998). In S9 there was presence of slate rocks mixed with phyllite rocks. Nitrogen occurs in both organic and inorganic forms in the slate, where it is dominantly in inorganic forms in phyllite (Holloway et al. 1998). Generally, algal and diatom community will change with nutrient enrichment, and sometime, in some streams, to increased production and chlorophyll concentrations, leading to changes in primary invertebrate consumers (Gafner and Robinson 2007) which could cascade through the community (Power 1990, Rosemond et al. 1993). As compared with region 2, region1 was very least rich in nitrogen nutrient (Figure 4-8). It might be due to less atmospheric input because there were less human settlement and development activities within the conservation area. Similar result was documented by Gupta and Michael (1992) and Suren (1994) where the nutrient load increases in low land streams/rivers.

4.3.2 Biological parameter

According to NEPBIOS, S14 belonged to water quality class I indicating that the site was very slightly polluted; S2, S12, and S13 falls to Class II indicating that the sites were moderately polluted. Remaining all other sites, S3, S4, S5, S6, S7, S8, S9, S10, S11, and S15 except site S1 belonged to class I-II indicating that the sites were slightly polluted. Site S1 fall to class II-III which indicate that the site was critically polluted (Table 4-2).

Assessment of water quality using BMWP/ASPT method resulted that the sites such as S8 and S15 belonged to water quality class I indicating that they were slightly to no organic pollution. Similarly, S3, S5, S6, S9, and S12 belonged to water quality class II indicating that they were moderately polluted. Moreover, sites such as S1, S2, S10, and S13 belonged to water quality class II-III indicating that they were critically polluted. Other four sites such as S4, S7, S11, and S14 belonged to water quality class I indicating that they were slightly polluted (Table 4-2).

Assessment of water quality using Hilsenhoff (1997) method resulted that the sites such as S8, S11, S14, and S15 belonged to water quality class I indicating that the sites were very slightly polluted or no polluted. The site S1 belonged to Class III indicating that the site was heavily polluted. Sites such as S5, S9, and S10 belonged to Class II indicating that the sites were moderately polluted.

Based on water quality class, BMWP/ASPT and NEPBIOS have five overlapping sites; Hilsenhoff and NEPBIOS have four overlapping sites; BMWP/ASPT and Hilsenhoff have six overlapping sites (Table 4-2). Although these three standard indices have few overlapping sites, they didn't produce similar results in the broad spectrum. There are few possible reasons, Hilsenhoff method provides low scores compared to that of NEPBIOS and BMWP/ASPT. According to Hilsenhoff method, 0 score is given to RQC I and 10 score is given to RQC IV (Sharma, 1999). Moreover, in method BMWP, score 10 is given to RQC I and lowest score 1 is given to RQC IV (Sharma. 1999).

Also the families such as Euphaeidae, Belphariceridae, Neoephmeridae, Psephenidae, Limonocentropodidae, Elminthidae, Epiophlebiidae, Sciritidae Noteridae, Heptageniidae, Rhithro, Tabanidae, Limoniidae, Thaumaleidae, and Hydraenidae were not included in Hilsenhoff and BMWP methods; however, all these families were included in NEPBIOS method. Therefore, BMWP/ASPT, NEPBIOS, and Hilsenhoff didn't have overlapping results. Also the effectiveness of the different indices and scores in water quality assessment may varies depending on the nature of substrate (Sharma, 1999). Thus NEPBIOS is the standard method for finding out the water quality for Nepalese rivers and Streams.

Table 4-2 Summarized results of water quality class (WQC) with the application of NEPBIOS, BMWP/ASPT, and Hilsenhoff

S No.	Site Code	NEPBIOS	BMWP/ASPT	Hilsenhoff
1	S 1	II-III	II-III	III
2	S 2	II	II-III	I-II
3	S 3	I-II	II	I-II
4	S 4	I-II	I-II	I
5	S 5	I-II	II	II
6	S 6	I-II	II	I-II
7	S 7	I-II	I-II	I-II
8	S 8	I-II	I	I
9	S 9	I-II	II	II
10	S 10	I-II	II-III	II
11	S 11	I-II	I-II	I
12	S 12	II	II	I-II
13	S 13	II	II-III	II-III
14	S 14	I	I-II	I
15	S 15	I-II	I	I

Source: Field and Laboratory work, 2013

Family Baetidae was the most dominant taxa in majority of the sites taken at different altitudes (Table 4-3).). Site S11 (reference site), had the greatest heterogeneity in substrate composition. Simuliidae was dominant at sites S14 (2400m) and S6 (1060m). Heptageniidae was recorded as dominant taxa at sites S5 (960m) and S7 (1125m) and Uenoidae was dominant at site 9 (1260 m) (Table 4-3).

Table 4-3 Dominant taxa with the substrate composition of each site

Sites	RQC(NEPBIOS)	Dominant taxa	Substrate composition	Altitude
S 14	I	Simuliidae	MA-ME-MG-MI	2400
S 13	II	Baetidae	MG-MI-MA-ME	2100
S 12	II	Baetidae	MG-MA-ME-MI	1572
S 2	II	Baetidae	MG-ME-AK	760
S 15	I-II	Chloroperlidae	MA-ME-MI-MG	3700
S 3	I-II	Baetidae	ME-MA-MI	780
S 4	I-II	Baetidae	MG-MA-ME-MI	940
S 5	I-II	Heptageniidae	MG-MI-AK-MA	960
S 6	I-II	Simuliidae	MG-MA-MI-ME	1060
S 7	I-II	Heptageniidae	MI-AK	1125
S 8	I-II	Baetidae	MG-MI	1255
S 9	I-II	Uenoidae	MG-MI-MA-ME	1260
S 10	I-II	Baetidae	MI-MG-MA	1280
S 11	I-II	Baetidae	MG-MA-ME-MI-AK	1300
S 1	II-III	Coleptera	MG-MA-MI	740

Note-MG-Megalithal, MA-Macrolithal, ME-Mesolithal, MI-Microlithal, AK-Akal.

Source: Field and Laboratory work, 2013

4.3.3 Analysis of Coliform Presence/Absence

Coliform was present in all twelve sites; only three sites didn't have it (Annex D). In Melanchu (S15), Tarang (S14), and Bhalu (S11) stream coliform was absent. Site 15 (3700 m) is the inlet of Kal tal that was less influenced by anthropogenic activities. Tarang at an altitude of 2400 m, flow through the mixed forest dominated by pine trees. There was no human settlement but only steep grassland and forest in Bhalu khola at an altitude of 1300 m.

4.4 Habitat Assessment

4.4.1 Stream corridor survey

Presence of natural stressors such as landslide followed by some local erosion, and unusual high flow was observed in some sites. Occasional human disturbance such as, fishing, bathing/ washing, cultivated land, water diversion for mini hydropower and road construction were also observed. Each site was observed and documented by conducting visual based habitat assessment of each site. The information collected from visual based data has already been described in study site under Chapter 3. According to the habitat assessment field data sheet S11 with highest score of 184 out of 200 was considered as reference site in region 1. Similarly, S6 and S4 with equal highest score (171) were considered as reference sites in region 2.

4.5 Watershed Assessment

All the streams were spring fed and were perennial in nature. Only stream 15 was glacial fed (origin from direct snow melt). Dominant land use of watersheds of S1, S2, and S5 was cultivation. Fairly dense mixed forest dominated the land use in the catchment of S3, S6, S8, S9, S10, and S14. Watershed of S11 and S12 was dominated by grassland. Heavy landslide followed by erosion was observed in the watershed of S5, S9, and S10. There were altogether four types of land uses, cultivated land, forest land, grassland, and rocky Mountain land. However, there was very slight local watershed erosion along with rock fall in all five streams from Manaslu Conservation Area (MCA), region 1. All the streams were found to be sinuous; except for stream 7, which was slightly straight in pattern. Stream bank shape was observed to either steeply or gradually sloping (Table 4-4).

Four discrete land use types were incorporated in the studied region. At lower altitude, extensive agriculture was common, with crops such as rice, wheat, maize, potato etc, growing heavily on terraced land using animal wastes (cow dung). Forestation was the second major land-use type. Dense mixed forest with less intense agricultural land. The low temperate vegetation zones in between the altitude of 2000 m - 3000 m support the species such as *Pinus, Rhodendron* etc. Higher forestation areas in the sub-himalayan humid temperate zones in between the altitude of 3000 m – 4000 m support the vegetation species such as *Juniperous*, *Pinus*, *Rhododendron*, *Larix* etc. Rocky Mountain and steep grassland were the other two land use types.

Table 4-4 Watershed Assessment of each site

Watershed no. 1	Watershed features		Stream characterization		Stream Morphology	
	Dominant Land use	**Local Watershed erosion**	**Stream Subsystem**	**Stream Origin**	**Stream Pattern**	**Bank Shape**
WS1	Cultivation	Moderate				Steeply sloping
WS2	Cultivation	Moderate				Steeply sloping
WS3	Mixed forest	Moderate				Gradually sloping
WS4	Forest& Grassland	Moderate	Perennial	Spring fed	Sinuous	Gradually sloping
WS5	Cultivation	Heavy				Gradually sloping
WS6	Mixed forest	Moderate				Gradually sloping
WS7	Forest	Moderate			Straight	Steeply sloping
WS8	Mixed forest	Moderate				Steeply sloping
WS9	Mixed forest	Heavy		Spring fed		Steeply sloping
WS10	Mixed forest	Heavy			Sinuous	Steeply sloping
WS11	Grassland	Rock fall				Gradually sloping
WS12	Grassland	Rock fall				Gradually sloping
WS13	Rocky mountain	None				Undercut sloping
WS14	Mixed forest	None		Mixture of origin		Steeply sloping
WS15	Sub-alpine forest	None		Glacier (snow melt)		Gradually sloping

Source: Field and Laboratory work, 2013

4.6 Metric Calculation

4.6.1 Richness measures

Due to exposure to stressors, certain common metrics changes in features or attributes of the structure and /or function of the assemblage of macro invertebrate were measured. Richness of macroinvertebrate was measured into three different metric types.

4.6.1.1 Total number of taxa measure

The measure of overall variety of macroinvertebrate assemblage shows that, S11 in the top most position followed by S4. The Site, S2, was least rich in total number of taxa as compared to others sites (Figure 4-9). The total number of taxa richness was in fluctuating trend while moving from lower to higher elevation. Based on previous study, taxa richnes was in a decreasing trend while moving from lower altitude to higher altitude (Rundle et al. 1993, Ormerod et al. 1994, Suren 1994). Nevertheless, the current study revealed that the total number of taxa richness was in fluctuating trend while moving from lower to higher elevation. There are few potential reasons- 1) there was a rainfall few days prior the sampling in the region 1. Perhaps due to change in the flow regime, macroinvertebrate hide beneath the stone in order to protect against the high flow and shortage of food availability.

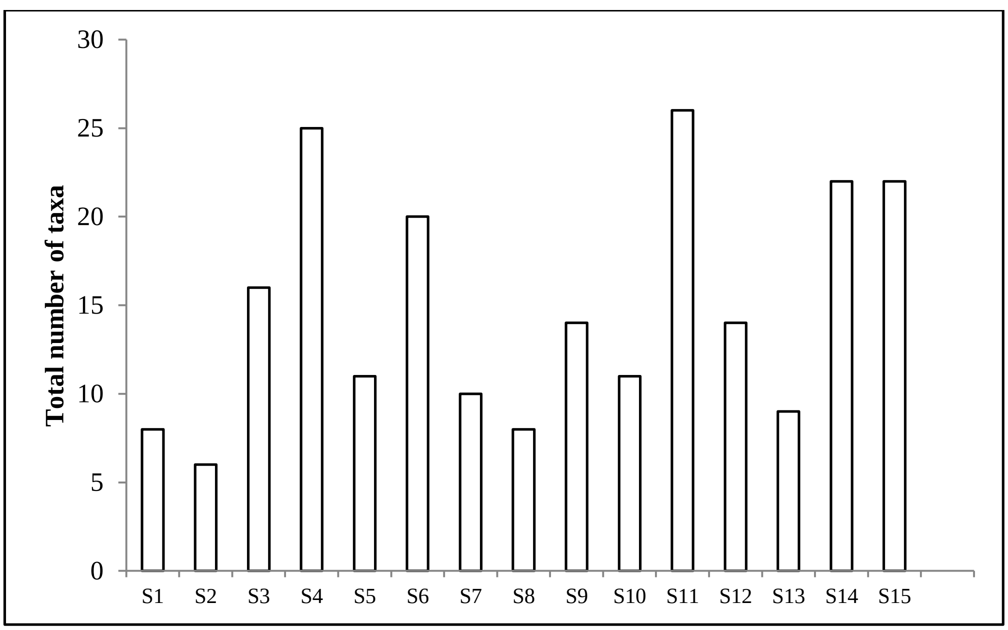

Figure 4-9 Total taxa richness in each site

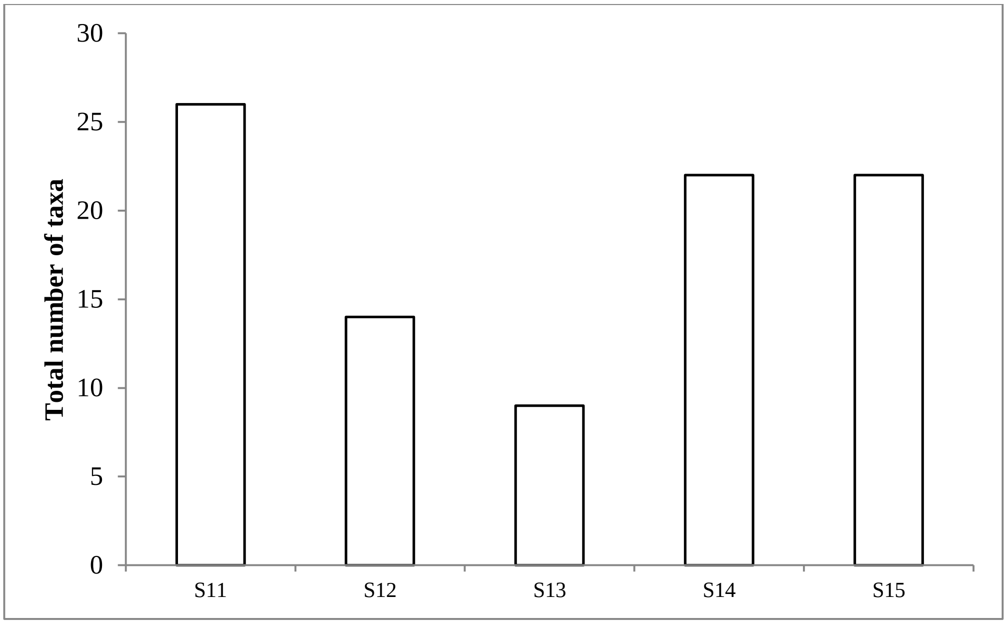

Figure 4-10 Total number of taxa in each site of region 1

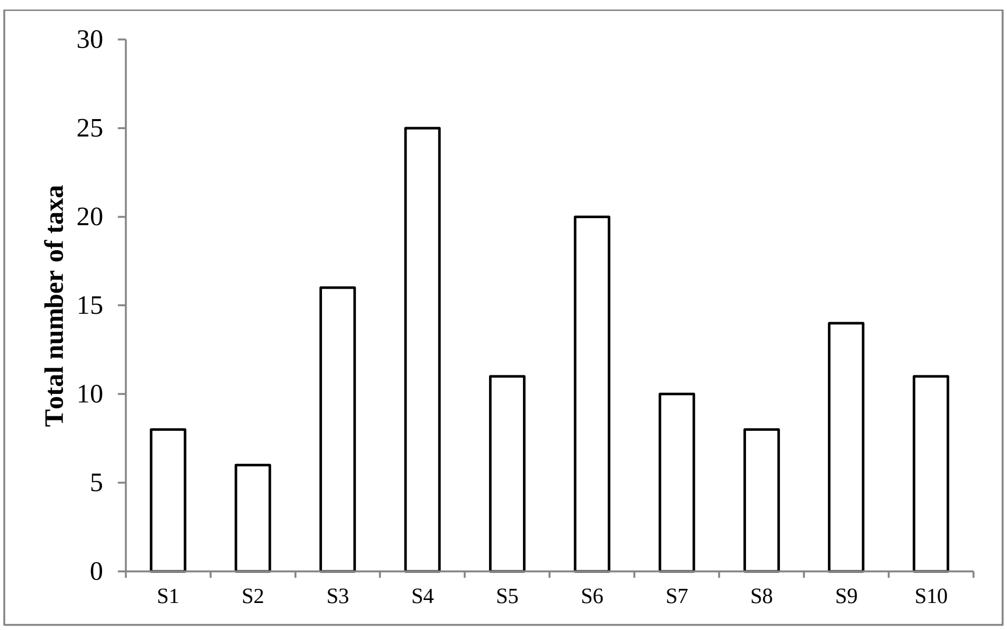

Figure 4-11 Total number of taxa in each site of region 2

In region 1, S11 (reference site) was rich in overall variety of macroinvertebrate whereas S13 was poor in variety of macroinvertebrate. Site, S14 and S15 were equally rich in overall variety of macroinvertebrate (Figure 4-10).

In region 2, S4 (Reference site) had higher degree of taxa richness whereas S2 had poor in total taxa richness. It was the potential result due to alternation in channel flow because there was heavy rainfall before few days of sampling (Figure 4-11). Total richness increases slightly up to site S4 and it decreases with the increase in elevation. Earlier studies in Nepal had also shown a decline in macroinvertebrate distribution and taxon richness with the increase in altitude (Rundle et al. 1993, Ormerod et al. 1994, Suren 1994).

4.6.1.2. Number of EPT taxa

Considering elevation as stressor, a number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) were in increasing trend. Generally, the Figure 4-12 depict that the number of EPT taxa increases with the increase in elevation. Number of ephemeroptera (mayflies), plecoptera (Stoneflies), and trichoptera (Caddisflies) was highest in S14 and S15 whereas S12 had comparatively lowest then remaining other two sites. (Figure 4-13). The number of EPT taxa was highest in S3 and lowest in S9 (Figure 4-14). The hill was made up of loose coarse and porous material which is very prone to soil erosion (Annex C). During the time of sampling, left bank of S9 was found disturbed by natural activity (landslide followed by local soil erosion).

The metrics such as total number of taxa, number of EPT taxa, and number of Ephemeroptera, Plecoptera, trichoptera taxa were all expected to decrease with the increase in perturbation (US EPA 1999, 2008). The prediction was supported by Daufresne et al. (2003), Bradley and Ormerod (2001), and Durnace and Ormerod (2007). Daufresne et al. (2003) observed 7 macroinvertebrate taxa that were lost from the stream associated with 1.5 ^{o}C increases over the period of 1980-1999. In the current study, overall EPT taxa were least in Annapurna Conservation Area region 2 (APA) compared to Manaslu Conservation Area (MCA), region 1 because region 2 had higher anthropogenic activities compared to region 1.

Figure 4-15 depicts that the number of Plecoptera was highest in S14 and S15 where as in other remaining sites it was minimal. Similarly, number Ephemeroptera was in increasing order up to S14. However, in region 2 number of Ephemeroptera was slightly fluctuating. Landslide was observed in S9 and S10. Natural disturbances have potentially impacted and have number of Ephemeroptera, Plecoptera and Trichoptera taxa decreases drastically in S9 and S10.

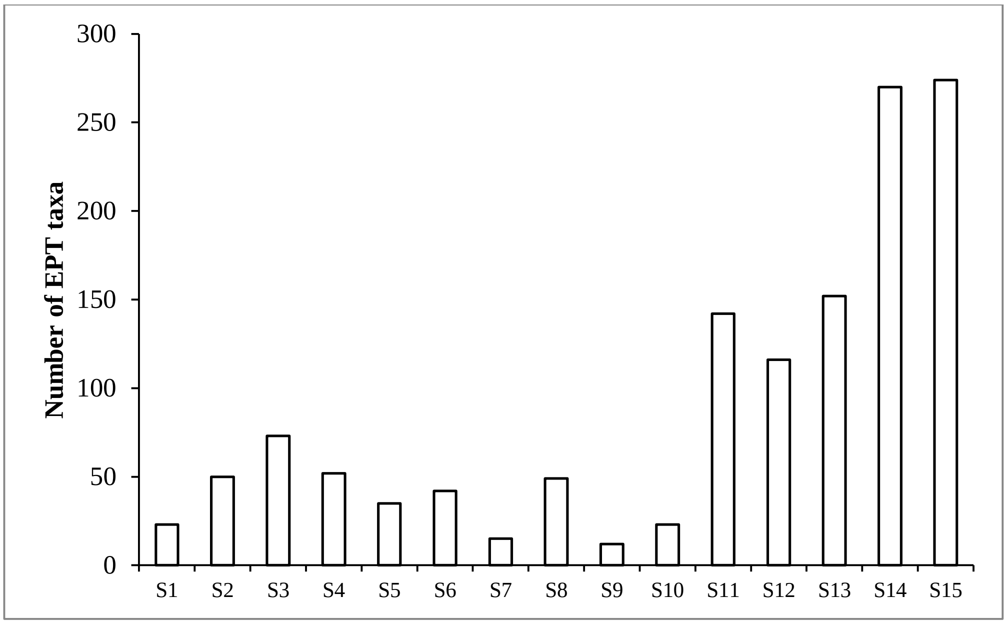

Figure 4-12 Number of EPT taxa of each site

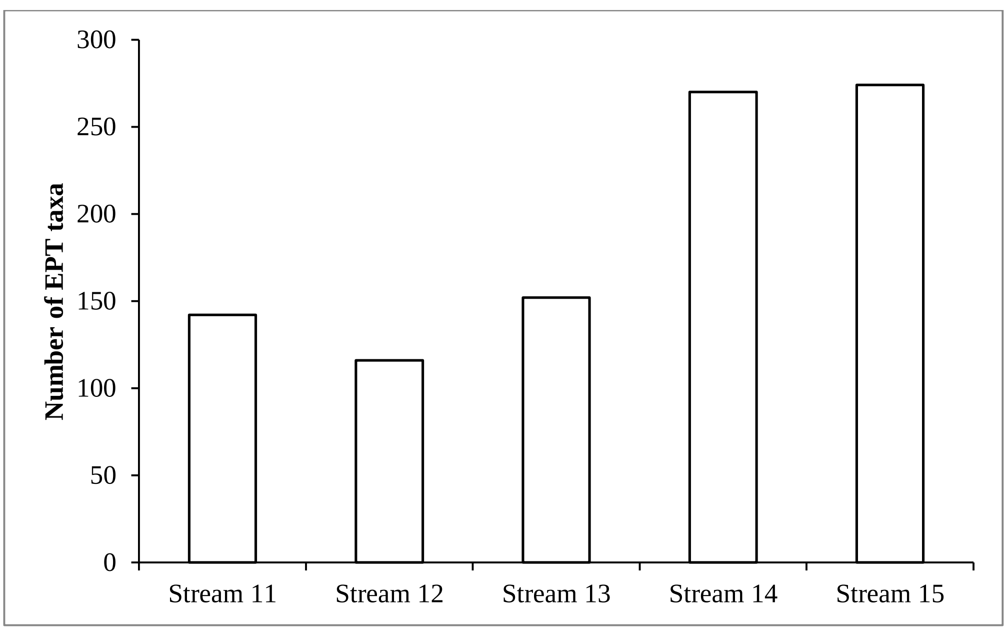

Figure 4-13 Number of EPT taxa in each site of region 1

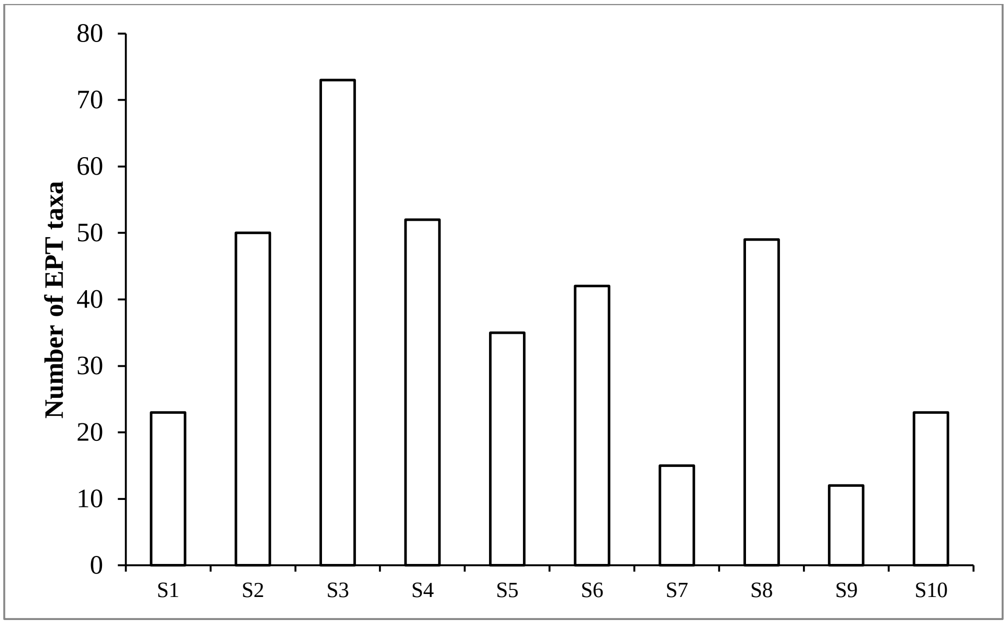

Figure 4-14 Number of EPT taxa in each site of region 2

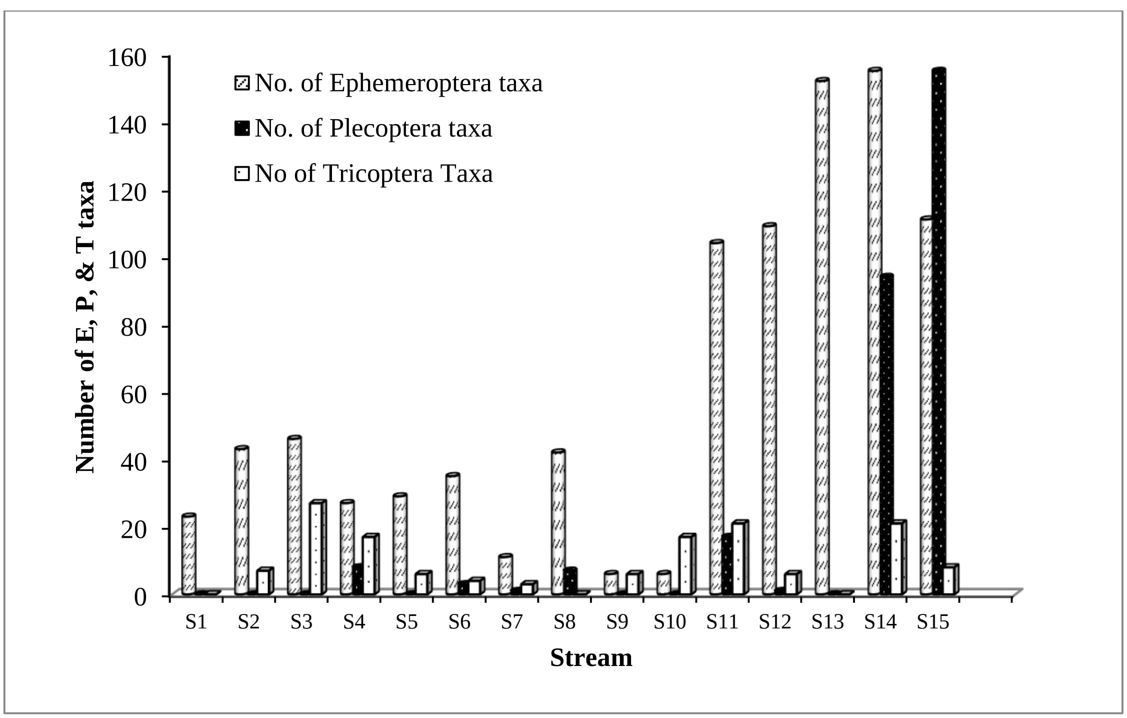

Figure 4-15 Number of EPT taxa in each site

4.6.2 Composition measures

The composition measure of major macroinvertebrate orders of each site is illustrated in Figure 4-16. EPT taxa have the highest composition in each site. Composition of Odonata, Coleoptera, and Heteroptera (OCH) was very low in higher elevation. OCH taxa were in higher composition of each site in lower elevation but as the elevation increases the OCH was decreased and the fulfilment was done by the EPT and Diptera in higher elevation (Figure 4-16). The others taxa includes Tricaldida, Lipidoptera and Trombidiformes.

The taxa composition of different sites shows much more similar from lower to higher altitude. Comparing the macroinvertebrate composition of each site of region1, portray that S11 (reference Site) had the good composition of all major orders. Only EPT, OCH and Diptera were present in S13 with no any combination of other orders (Figure 4-17). Site S5, showed highest order diversity compared to other sites. The composition of S8 was highly dominated by EPT taxa (Figure 4-18).

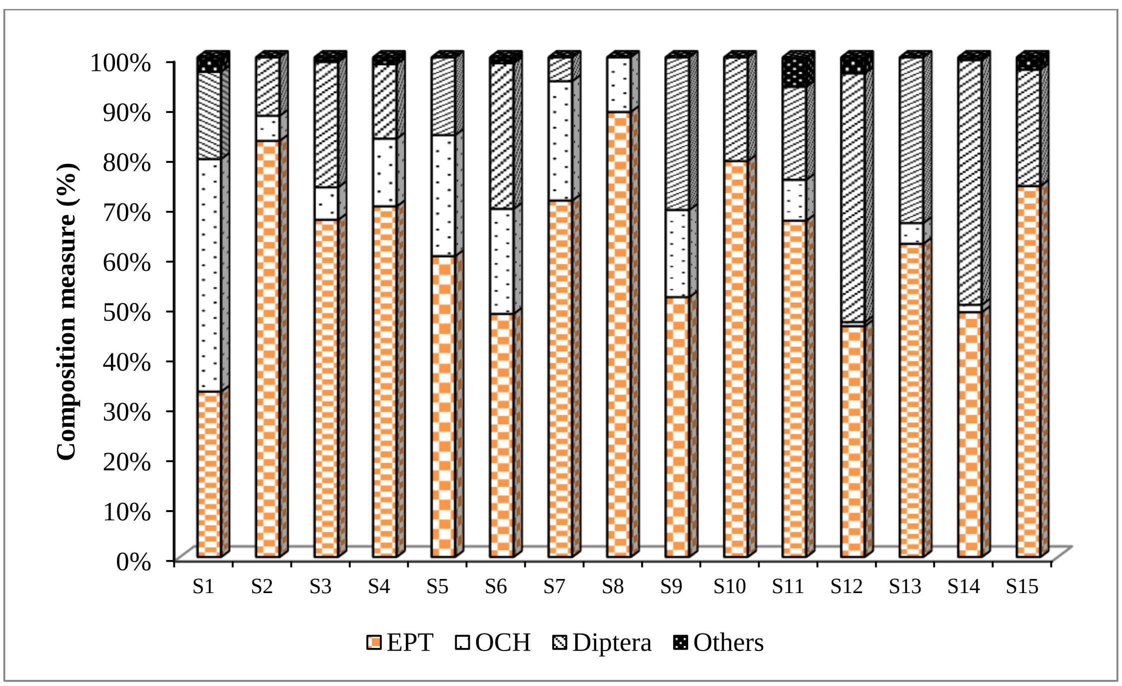

Figure 4-16 Composition measure of each site

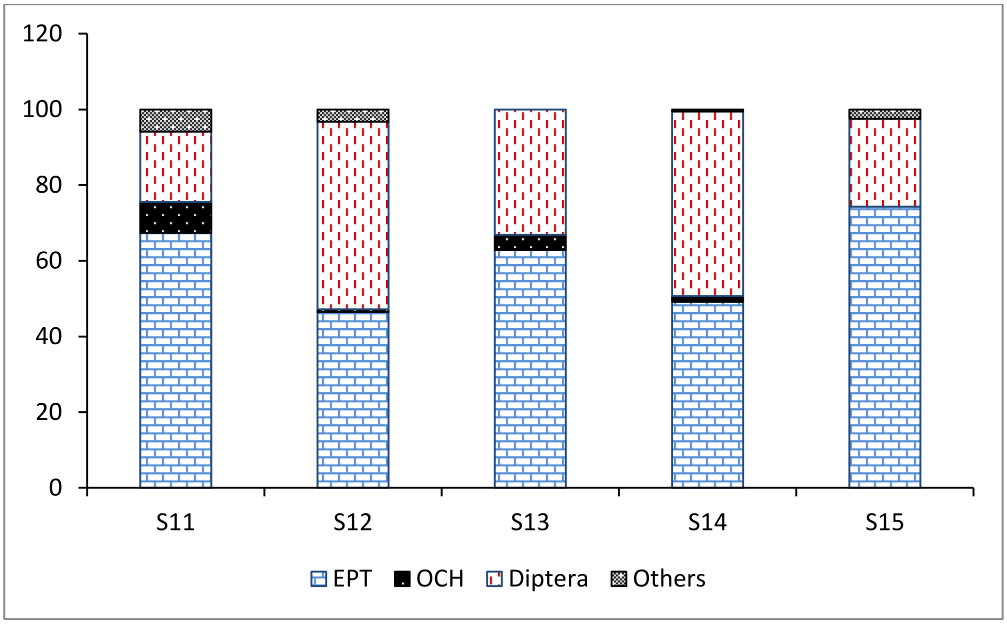

Figure 4-17 Composition measure of region1

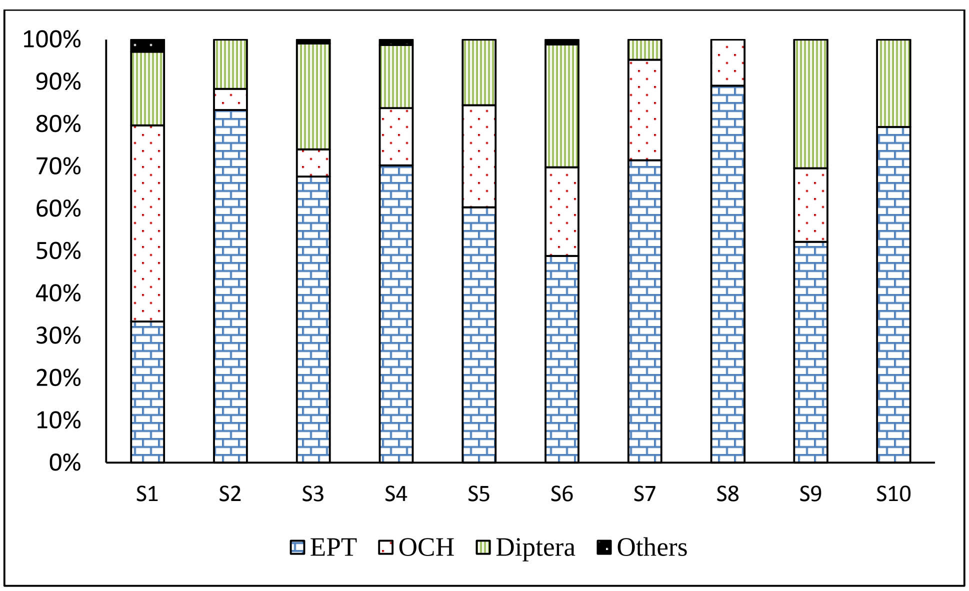

Figure 4-18 Composition measure of region 2

EPT composition

The EPT composition on any site is expected to decrease with the increase in disturbance (USEPA 1999, 2008) because EPT taxa composition is very sensitive towards temperature and flow regime (Durance and Ormerod, 2007; Burgmer et al., 2007; Parmesan, 2006). However, the current study revealed that the composition of EPT and dipteral was similar at different temperature regimes (5.2 -27.8 ^{o} C) at different elevation (Figure 4-19). This similarity in taxa community composition at different temperature and altitude can be explained in two ways:

1. **Shifting of EPT taxa**

   As Hamilton et al., (2010) observed the shifting of taxa to higher altitudes from lower altitudes as a response to climate change. One of the consequences of such movements is that communities at higher latitudes tend to become more similar to communities at lower elevation (Bonada et al. 2007). Baetidae was observed in all the sites range from 700 m to 3700 m (Figure 4-20 and 4-21).

2. **Replacement of OCH by EPT**

   Current study shows that the OCH composition is low in higher altitude; however, EPT taxa took the place of OCH in the higher altitude.

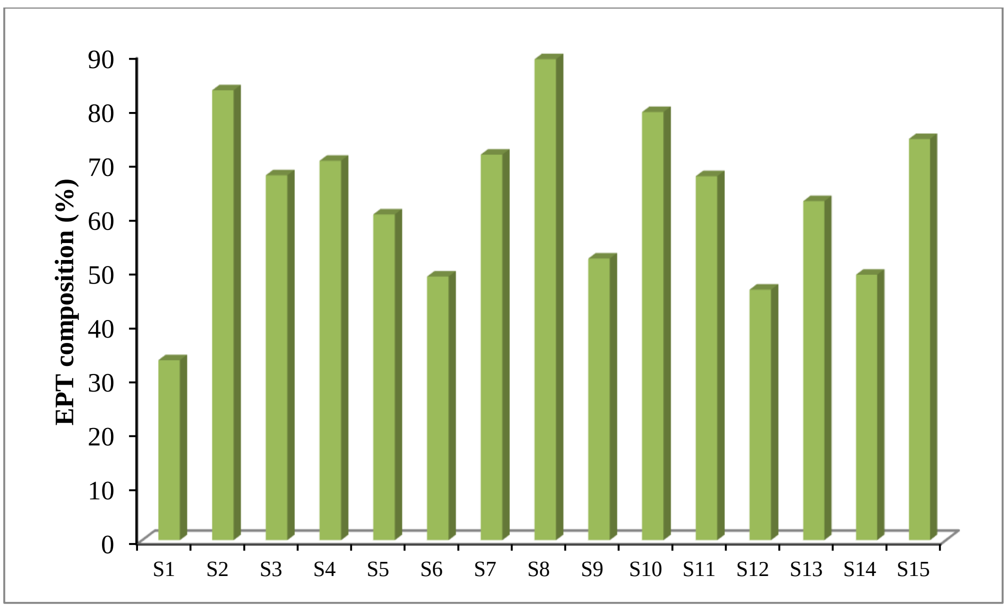

Figure 4-19 EPT composition measure in each site

4.6.3 Tolerance / intolerance measures

4.6.3.1 Inclusive tolerance and intolerance measure

According to the number of sites sampled in both regions, taxa were categorized into 4 category on the basis of temperature sensitivity, such as extremely tolerant, tolerant, sensitive, and extremely sensitive taxa. Temperature sensitivity of taxa and their sensitivity to organic pollution were moderately but significantly correlated (Hamilton et al. 2010).

Inclusive tolerance / intolerance measure

In region2, taxa such as, Baetidae, Heptageniidae, Simuliidae, Chironomidae, Gomphidae, Euphaeidae, and Hydropsychidae were observed to be extremely temperature tolerant taxa which were present in all sties from region 2 (Altitudinal range from 700 to 1300m; temperature range 27.8-19 ^{o}C). Perlidae was the only taxa which was available in all Sites from altitudinal range 800 to 1300m. It was considered as temperature tolerant since it was observed in temperature between 25.7- 19 ^{o}C. Rhycophilidae, Uenoidae, Limniphilidae and Ephemerellidae were sensitive to the temperature. They were observed in temperature between 21.6 -19 ^{O}C (1000-1200m). Leptophelbidae, Perlodidae, Limoniidae, and Planariidae were identified as the very sensitive towards temperature. They were observed from the temperature range 20-19 ^{O}C which were at the altitudinal range from 1200 to 1300m (Figure 4-20).

In region1, taxa such as Baetidae, Chironomidae, Simuliidae, Ceratopogonidae and Tipulidae were observed as extremely temperature tolerant. These taxa were observed in all sites of region 1 with altitude and temperature range from 1300 to 3700m and 10.2-5.2 ^{o}C respectively. Planariidae was the only taxon which was observed from 1500 to 3700m elevation. It was considered as temperature tolerant since it was available in temperature range between 10 to 5.2 ^{O}C. Heptageniidae, Chloroperlidae, Leuctridae, Nemouridae, Philopotamidae, and Taeniopterygidae were identified as sensitive to temperature because it was observed from temperature range from 6.1-5.2 ^{O}C. Empidiae, Rhyacophilidae, and Brachycentridae were considered extremely sensitive taxa. They were identified at temperature at 5.2 ^{O}C (Figure 4-21).

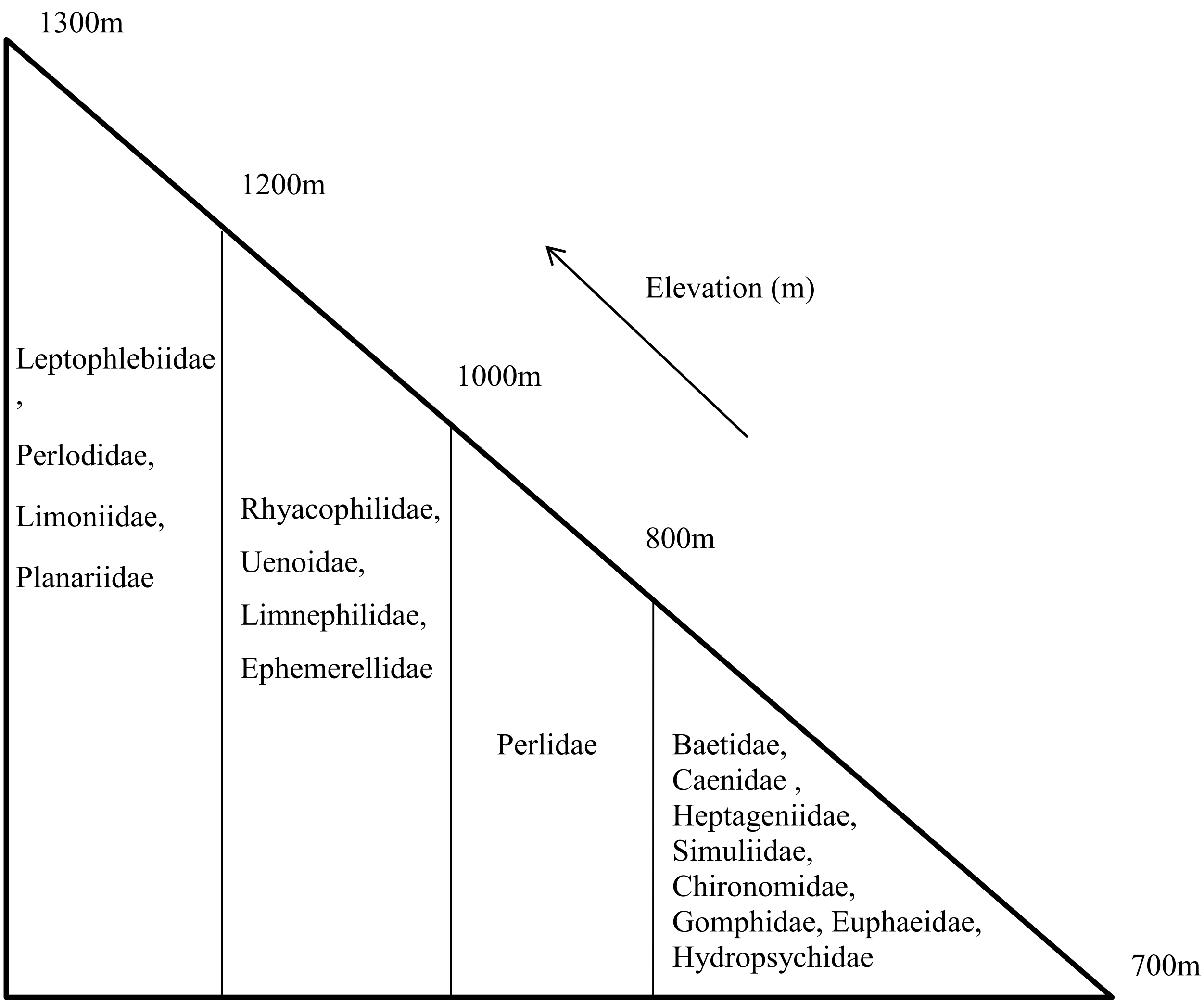

Figure 4-20 Inclusive temperature tolerant and intolerant measure of region 2

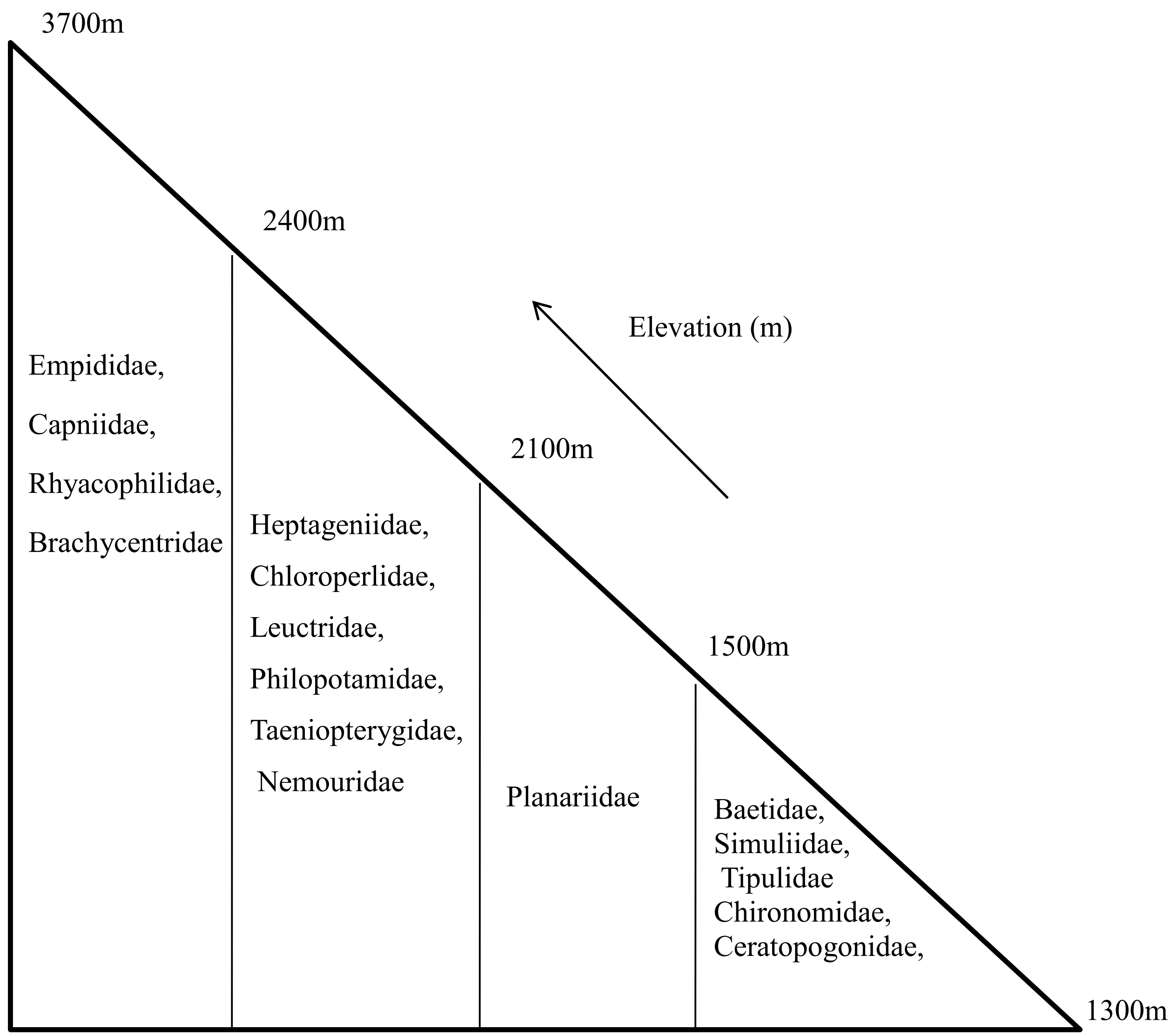

Figure 4-21 Inclusive temperature tolerant and intolerant measure of region 1

4.6.3.2 Exclusive tolerance and intolerance measure

Taxa present in the lower level of triangle were found within 700 to 800 m altitude of temperature difference from 27.8-23.6^{o}C. Neoephemeridae, Siphlonuridae, Perlidae, Nemouridae, Chloroperlidae, Brachycentridae, Goeridae, Limnocentropodidae, Calamotoceridae, Blephariceridae, Lipidoptera and Hydrochidae were introduced from 800m to 1000m altitudinal range. They were identified at temperature between 25.7-24.3 ^{o} C. Similarly, Ephemeridae, Ephemerellidae, Nemouridae, Uenoiidae, Athericidae, Sciritidae, Trichoniscidae, Pleidae and Hydrophilidae were documented between altitudinal range from 1000m to 1200m and temperature range of 21.6-19.5 ^{o}C. Moreover, Ephemerellidae, Leptophlebiidae, Planariidae, Limnoiidae, and Perlodidae were documented only at range of 1200 to 1300m which lies in between 20-19^{o}C (Figure 4.22).

Taxa such as Baetidae, Heptageniidae, Leptophelbiidae, Chironomidae, Simuliidae, Ceratopogonidae, Tipulidae, Blephariceridae, Limonidae, Perlidae, Perlodidae, Chloroperlidae, Leuctridae, Glossosomatidae, Hydropsychidae, Limnocentropodidae, Epiophlebiidae, Gomphidae, Hydrachnidiae, Elmidae, Scirtidae, Dryopidae, Noteridae, Planariidae were observed in elevation between 1300m to 1500m with in temperature around 10.2-10 ^{o}C in region 1. Psychodidae , Limoniidae, and Tabanidae were two taxa introduced at elevation between 1500m -2100m with in temperature 10-9^{o}C. Taxa such as Ephemerellidae,Thaumaleidae, Limnophilidae, Philopotamidae, Taeniopterygidae, Nemouridae, and Ceratopgonidae were found in altitude between 2100-2400m of temperature between 6.1-5.2 ^{o} C. Empididae, Capniidae, Rhyacophilidae, Brachyacentridae, Psychodiidae were extremely sensitive and were documented at altitude between 2400m to 3700m (Figure 4-23).

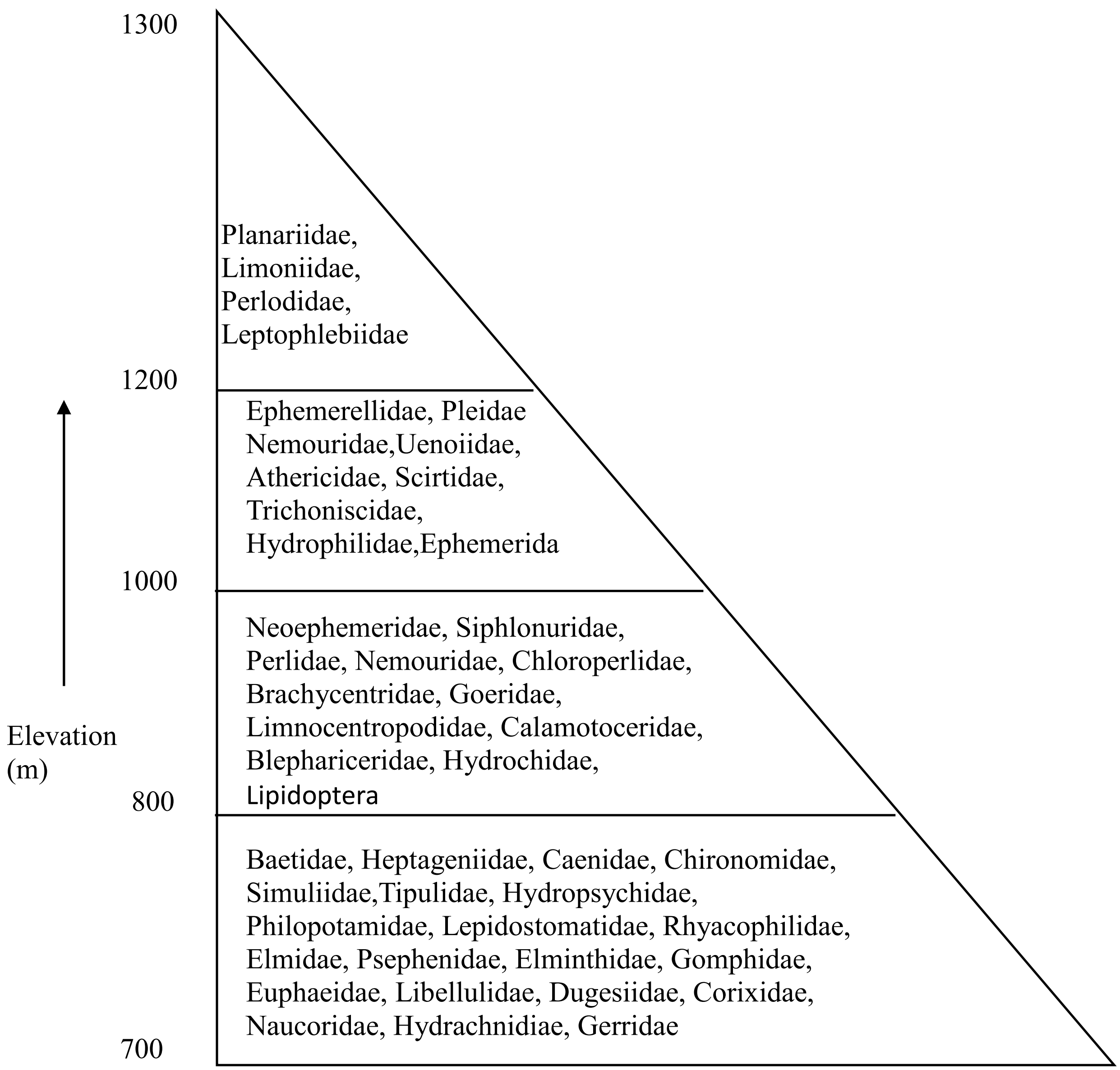

Figure 4-22 Exclusive temperature tolerant and intolerant measure of region 2

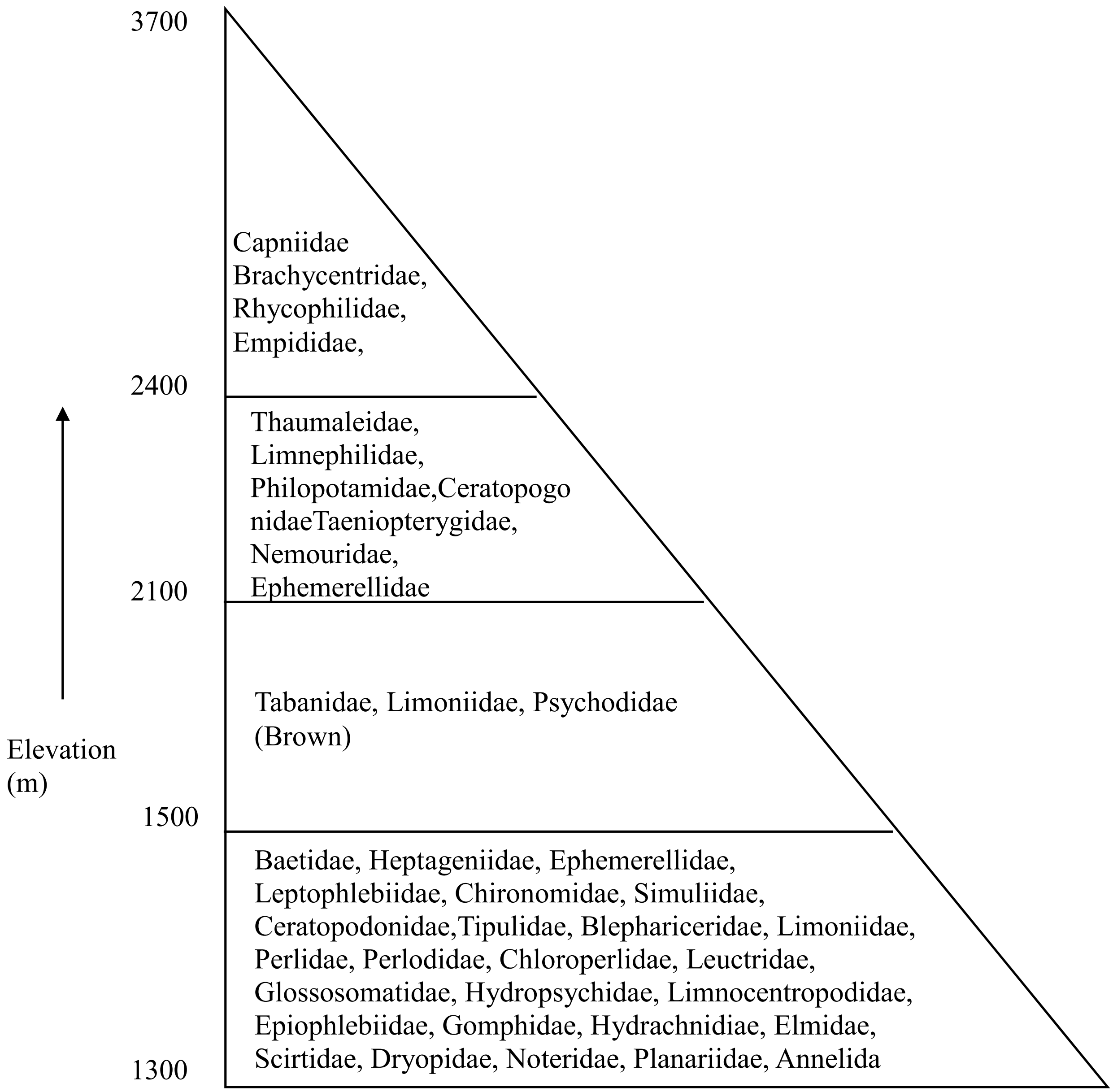

Figure 4-23 Exclusive temperature tolerant and intolerant measure of region 1

Current study revealed that the temperature tolerant taxa such as Baetidae, Simuliidae, Chironomidae, and Tipulidae were common in all sampling sites (Figure 4.20, 4.21, 4.22, 4-23). Baetidae and simulidae taxa were observed as the dominant taxa in 9 out of 15 sites at different elevations indicating the dominancy of tolerant taxa (Table 4-3). This domination of tolerant taxa within the different temperature and altitudinal range was one of the indicators of influence of climate change (increasing temperature and variable precipitation) in rivers and streams. Similar finding was documented by Parmesan (2006), Durance and Ormerod (2007), and Burgmer et al. (2007) where the dominance of tolerant taxa (tolerant to temperature and flow regime) increases with the increase in disturbances.

Current study revealed that temperature sensitive taxa such as Brachycentridae, Rhycophilidae, Empididae, Capniidae, Leptophlebiidae, Planariidae, Limoniidae, and Perlodidae were found at different elevations but in a discontinuous manner (Figure 4-20, 4-21, 4-22, and 4-23). This presence, or least presence, and/or absence of taxa at different elevations (Annex B) indicated shifting of sensitive taxa to favorable environment indicating the climate induced change in river ecosystems. Similar, result was documented by earlier studies (USEPA 2000, 1999, Daufresne et al. 2003, Golladay et al. 2004, Parmesan 2006, Burgmer et al. 2007). Long term study of macroinvertebrates with the temperature influence documented the loss of taxa per ^{o} C rise in temperature (Daufresne et al. 2003, Durance and Ormerod 2007 and Lawrence et al. 2010). In the current study, the temperature was increased by around 1^{o}C in both the regions indicating that sensitive taxa (Brachycentridae, Rhycophilidae, Empididae, Capniidae, Leptophlebiidae, Planariidae, Limoniidae, and Perlodidae) were vulnerable to climate change.

4.6.4 Feeding groups

The distribution of macro invertebrate functional feeding groups of each sites reflect aquatic ecosystem attributes. Site, S15 had all functional feeder groups where as there were sites which only had 2-3 functional feeding groups (Figure 4-24).

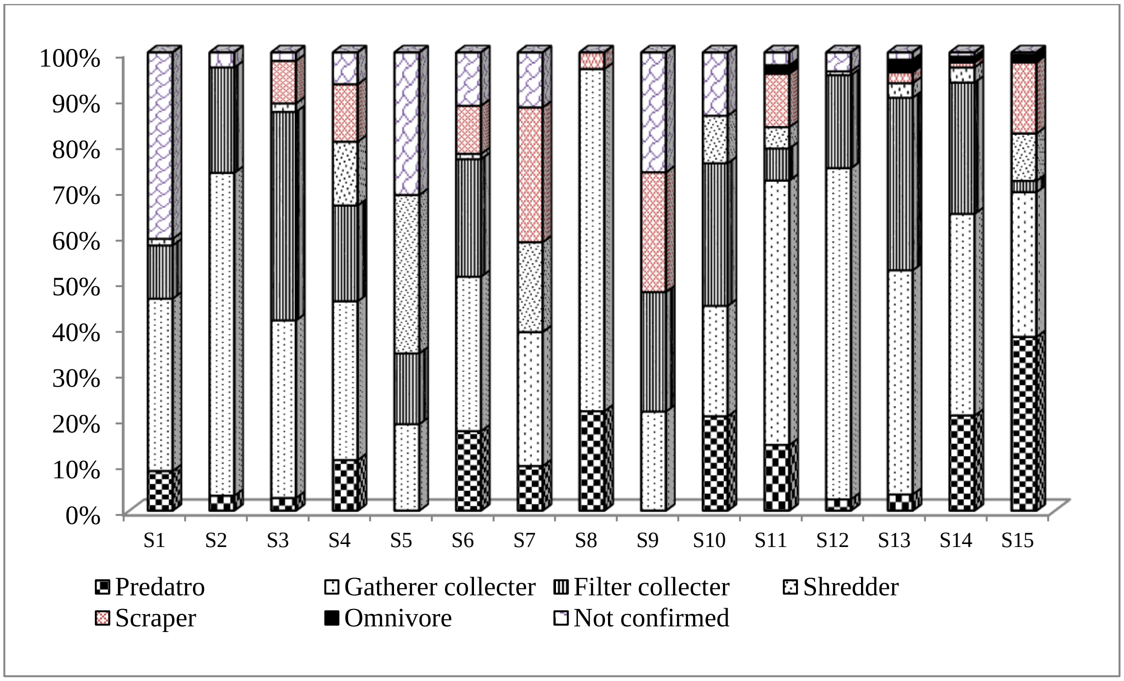

Figure 4-24 Composition of feeding habits of macroinvertebrates in each site

The highest percentage of the macroinvertebrates that scrape or graze upon periphyton were identified in S7 and then in S9 whereas in S1, S2, S5, and S10 scraper was not observed. It was due to less presence of periphyton in streams (Figure 4-25). There was no filterer collector was observed in S7 and S8 because streams were slow moving which does not had bed rocks. High numbers of individual Baetis (mayflies), and Chironomidae contributed to the numerical dominance of the collector-gatherer in S3 and S13. In both of these sites the canopy coverage was good as compared with others. These invertebrates filter FPOM (Fine Particulate Organic Matter) from either the water column or sediment (Figure 4-26). Increase in temperature may increase phytoplankton and periphyton productivity which leads to increase in grazers and scrapers (Gafner and Robinson 2007, Tuchman et al. 2002, Doods and Welch 2000). Even slight change in temperature can create high degrees of changes in tropic level.

In S7 there were higher percentage of shredders and scrapers and S5 have higher percentage of shredders. This higher percentage of scrapers and shredders in sites indicates the greater amount of algal growth on rocks and more leaf litter available in sites. The canopy coverage of both sites were relatively high because of which, there was more leaf litter available. Heptageniidae was the primary contributor to the scraper in S5, S7 and S9. Hydropsychidae and Simuliidae were the most important contributors to the filter collector in S3 and S10.

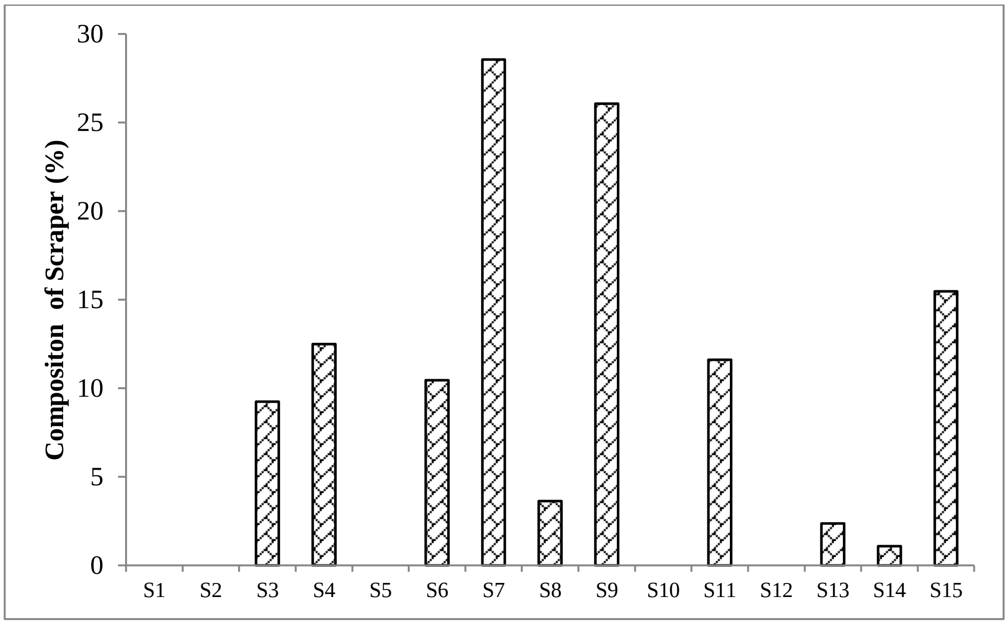

Figure 4-25 Composition of Scraper in each site

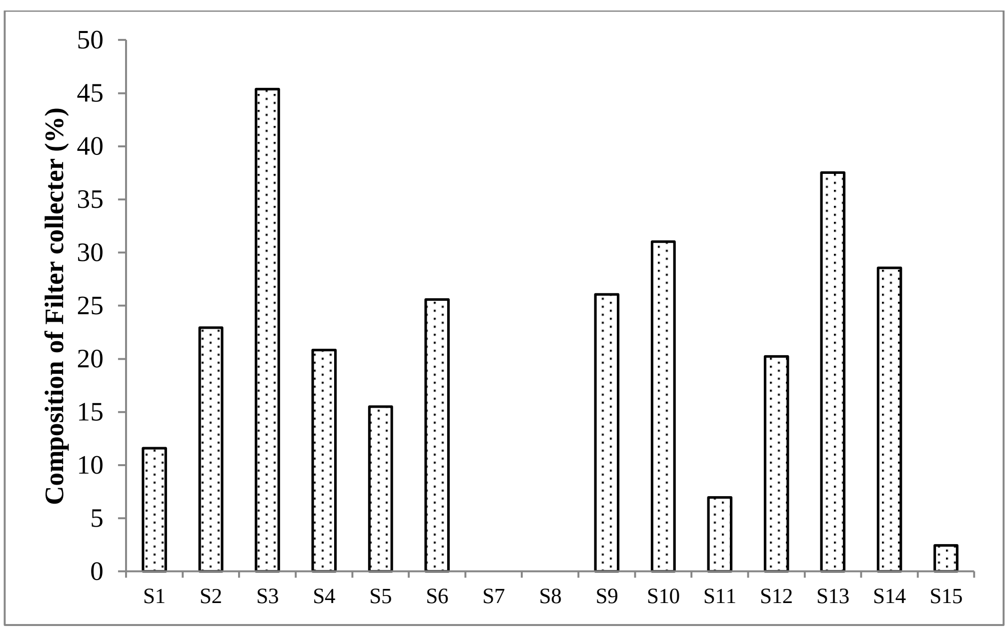

Figure 40-26 Composition of filterers in each sites

4.6.5 Diversity Measure

Shannon diversity index values were generally low indicating a stressed environment or physically controlled by a few individuals (Odum 1971). The diversity increases and then decreases with the increase in elevation. The Shannon weiner diversity index (H') ranged from 0.34 to 1.68 at order level whereas diversity index ranged from 0.49 to 2.71at family level (Figure 4-27). The highest diversity at order and family level was found in S4 (reference site) where as diversity was very low in S13 at both levels. Because the habitat was highly disturbed in the sampling site such as both banks of S13 were highly eroded and unstable. Low diversities have been reported in areas with stress from rigorous physical environment and pollution (Boesch 1972). Studies comparing rivers across the globe have shown macroinvertebrate family richness to be linearly related with stream temperature, with diversity increasing with increasing temperature (Jacobsen *et al*. 1997).

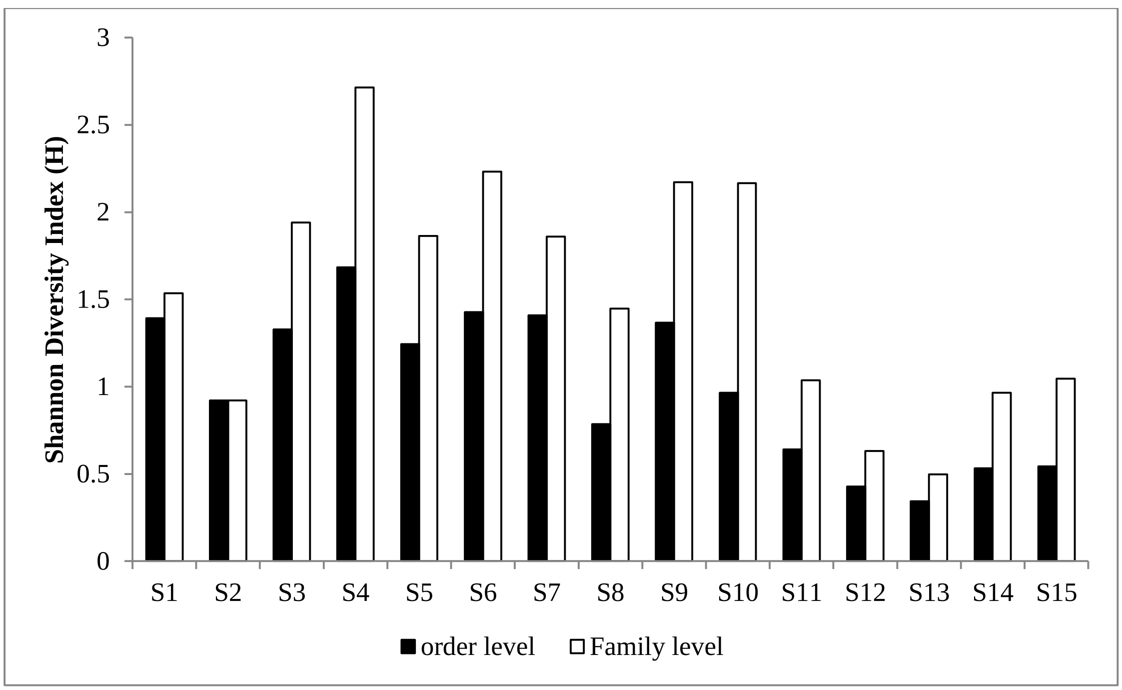

Figure 4-27 Order and Family level taxa diversity in each sites

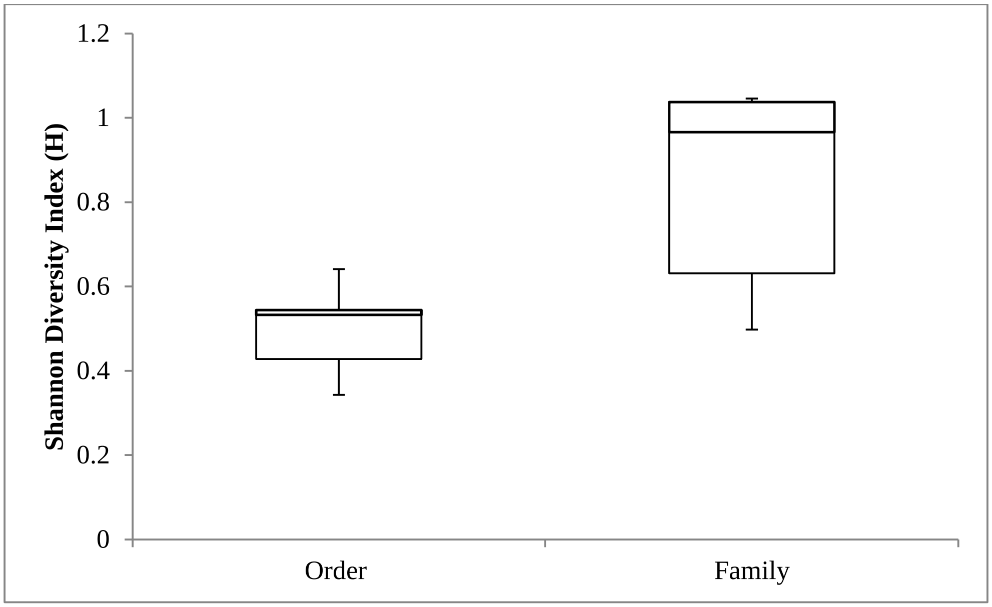

Figure 4-28 Box and whisker-plots of Shannon diversity index at order and family level of region 1

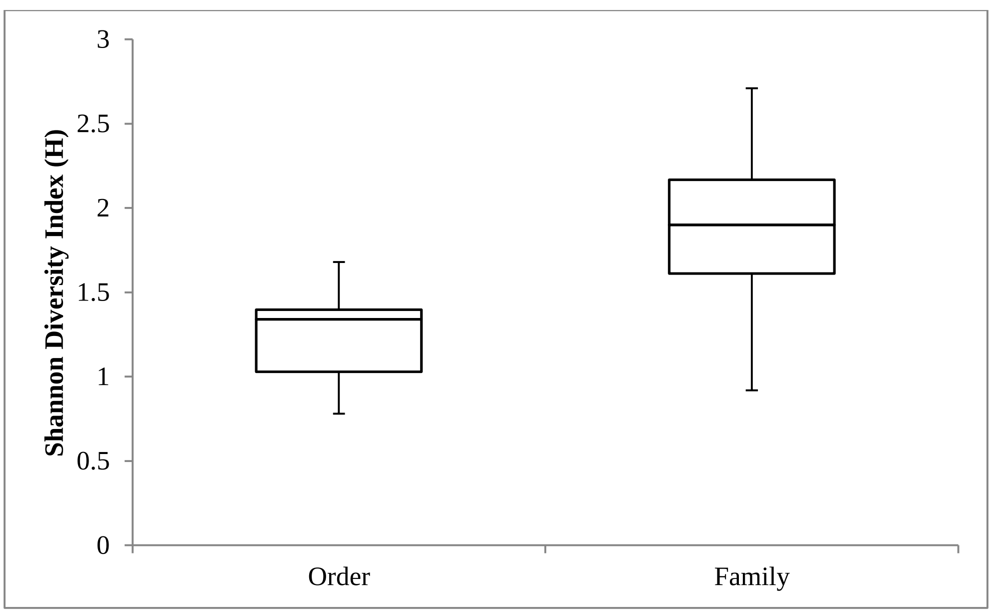

Figure 4-29 Box and whisker-plots of Shannon diversity index at order and family level of region 2

4.6.6 Abundance measure

Ephemeroptera and Diptera were the two orders which were relatively abundant in all sites of region 1 except in site S13. In site S15 Plecoptera was more abundant around 42.11% than other sites (Figure 4-30). Trichoptera was relatively abundant in S10 and S9. Site S6 was relatively fair in the heterogeneity of taxa (Figure 4-31). Thermal regime influences the distribution and abundance of aquatic species in relation to temperature tolerances and evolutionary adaptations (Matthews 1998, Hawkins et al. 1997, Vonnate and Sweeney 1980, and Vannote 1978).

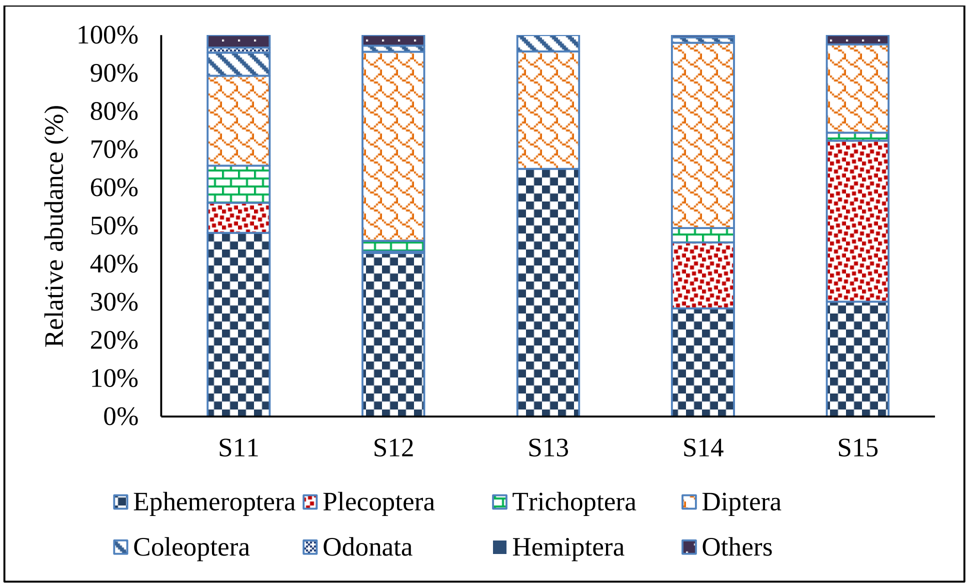

Figure 4-30 Relative abundance of taxa in each site of region 1

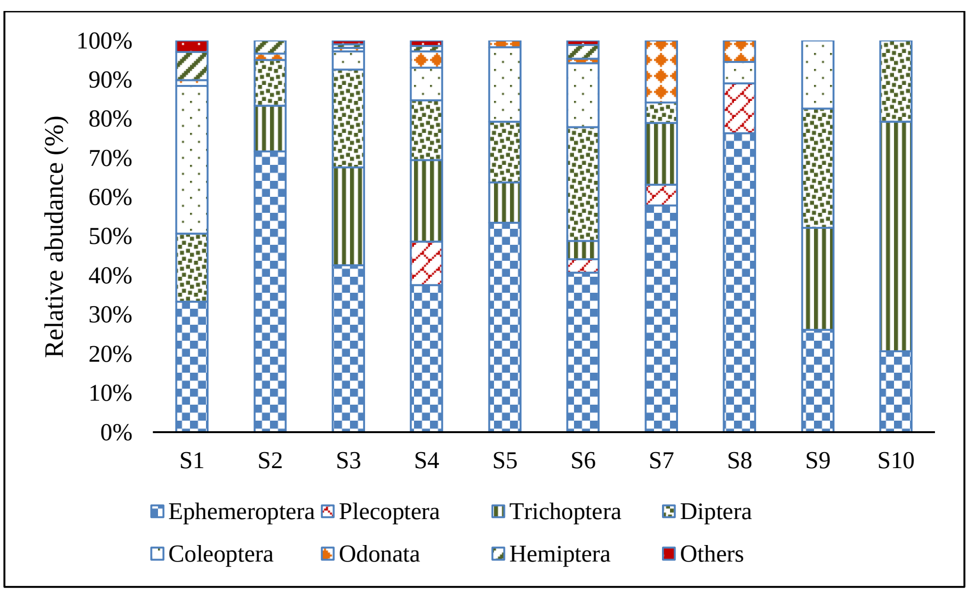

Figure 4-31 Relative abundance of taxa in each site of region 2

4.6.7 Correlation Analysis

The relationship between total taxa richness and temperature was examined using linear regression (Figure 4-32). The correlation between them was modestly negatively related (R^2= 0.183, r = - 0.42). The relation between taxa diversity and elevation shows modest inverse relation (R^2= 0.235, r = - 0.52) i.e. diversity decrease with the increase in elevation (Figure 4-33). Ignoring the minus sign the calculated value 0.52 exceeds the tabulated critical value 0.51 for (n-2) = 13 at P= 0.05 therefore H_o hypothesis is rejected and inverse correlation is statistically significant.

EPT taxa richness shows a strong negative correlation (r= -0.77) with water temperature. Ignoring the minus sign the calculated value 0.77 exceeds the tabulated critical value 0.641 for (n-2) = 13 at P= 0.01 therefore H_o hypothesis is rejected and inverse correlation is statistically highly significant. EPT taxa are generally pollution sensitive which requires higher DO, neutral pH and cold water which are all temperature dependent. That means EPT taxa richness decreases with the increase in temperature (Figure 4-34). EPT taxa richness was strongly correlated (r= 0.87) with altitude (Figure 4-35). The calculated value of r= 0.91 exceeds the tabulated value at n-2=13 of r= 0.641 at P= 0.01therefore the correlation is statistically highly significant.

EPT taxa richness decreases with the increase in total nitrogen input in sites (Figure 4-36). They are strongly inversely correlated (r= -0.79). From above relationship between EPT taxa richness and altitude, it shows that they have strong positive correlation between each other. EPT composition shows modest positive correlation with temperature (Figure 4-37). Temperature regime determines distributions of species in relation to temperature tolerance and adaptations combined with competitive interactions, effects on food supply, and other factors (Sweeney and Vannote 1978, Vannote and Sweetney 1980, Matthews 1998).

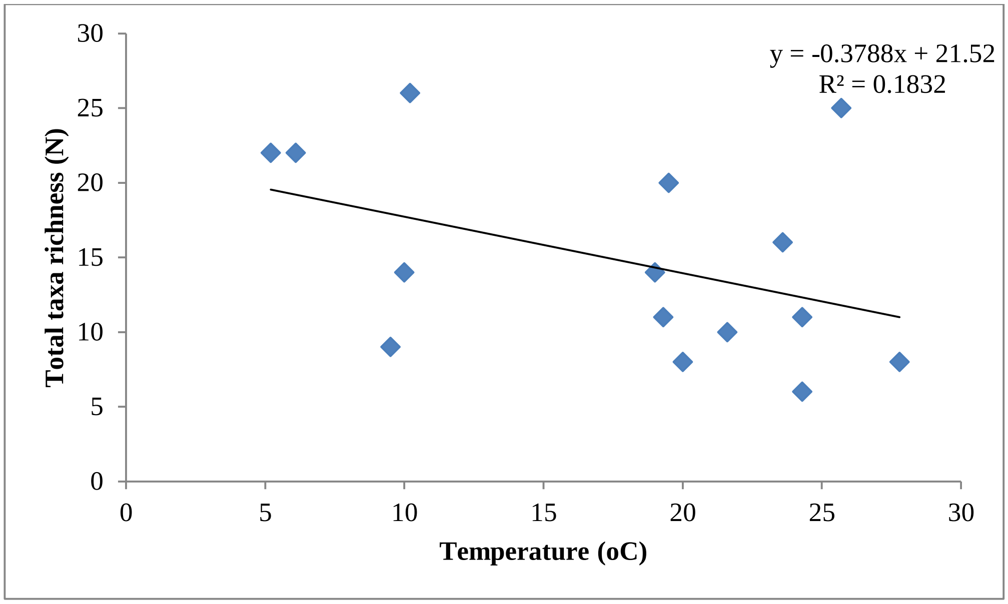

Figure 4-32 Correlation between Total taxa richness and water Temperature

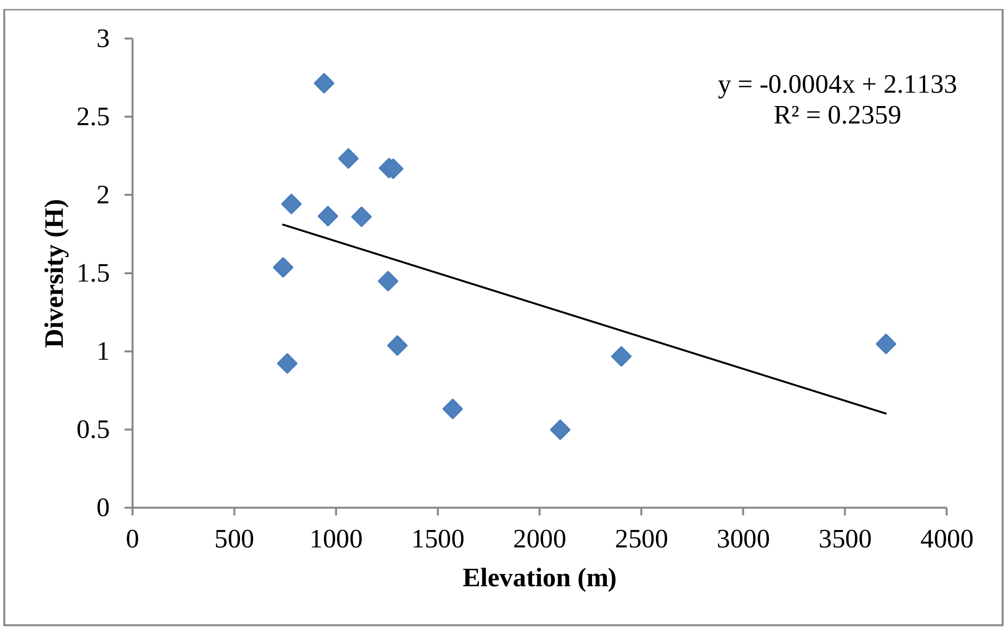

Figure 4-33 Correlation between taxa diversity and elevation

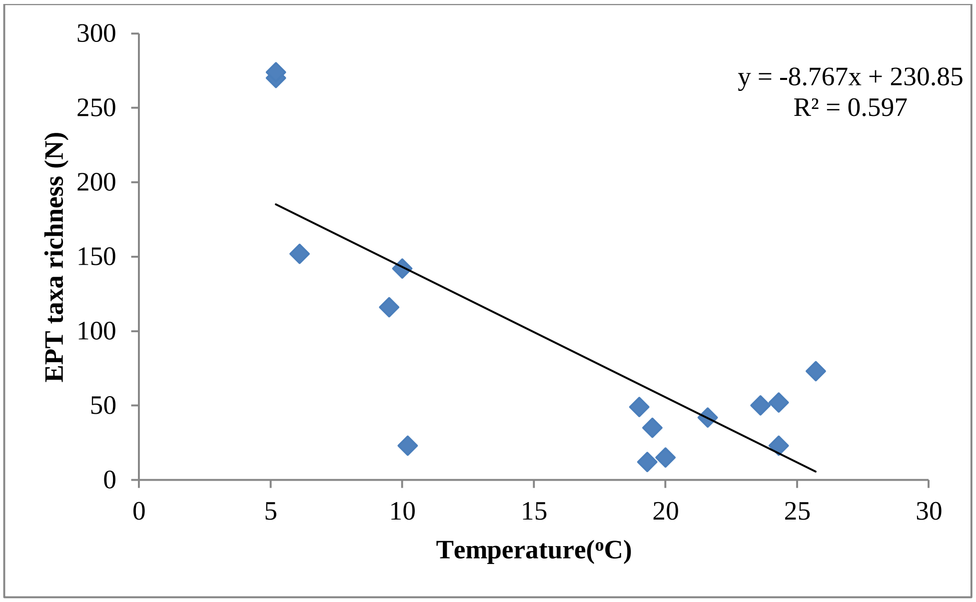

Figure 4-34 Correlation between EPT taxa richness and water temperature

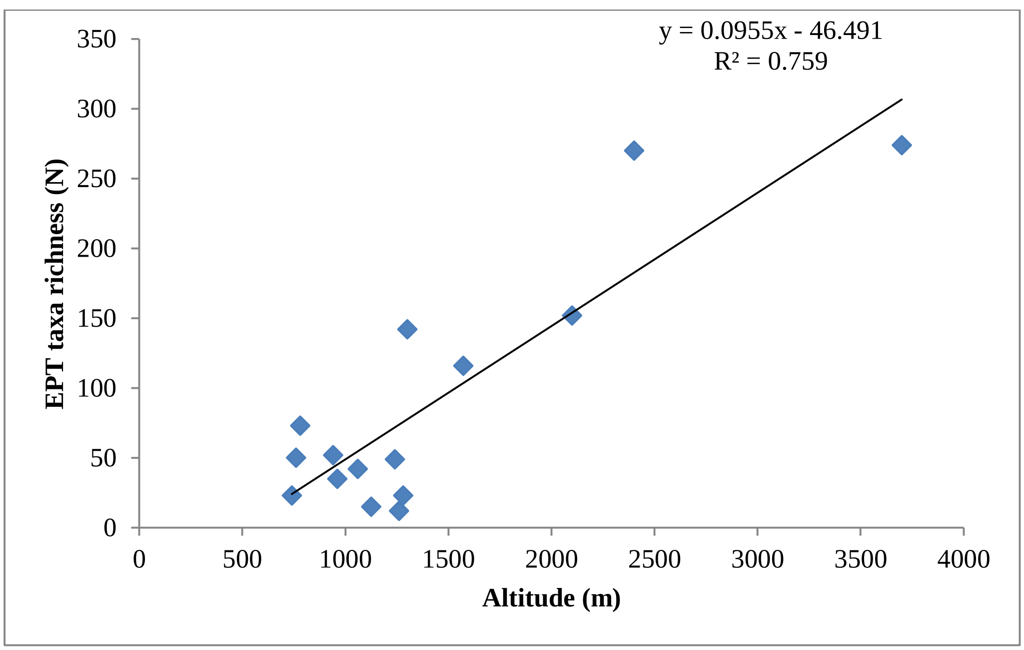

Figure 4-35 Correlation between EPT taxa richness and elevation

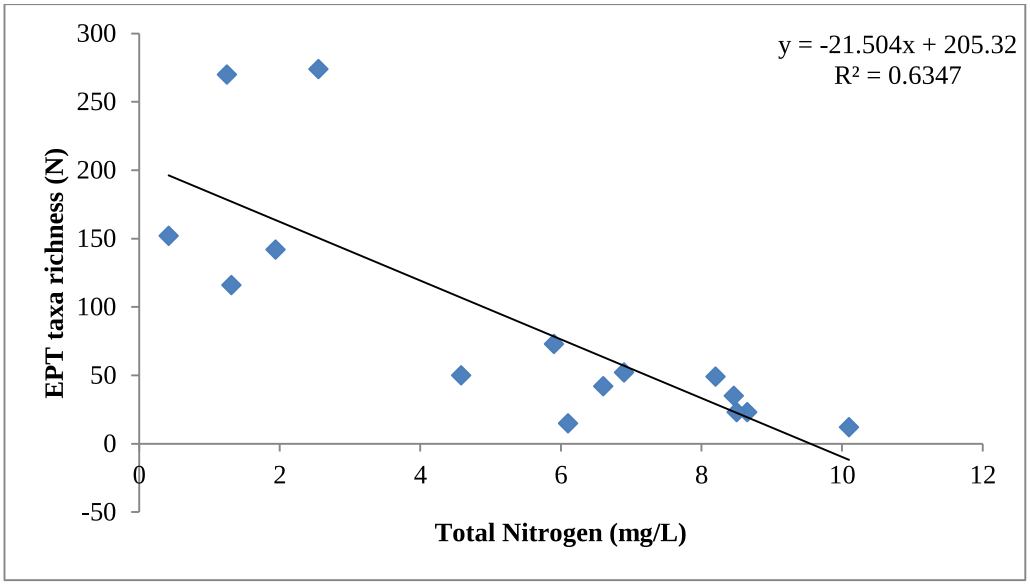

Figure 4-36 Correlation between EPT taxa richness and Total nitrogen

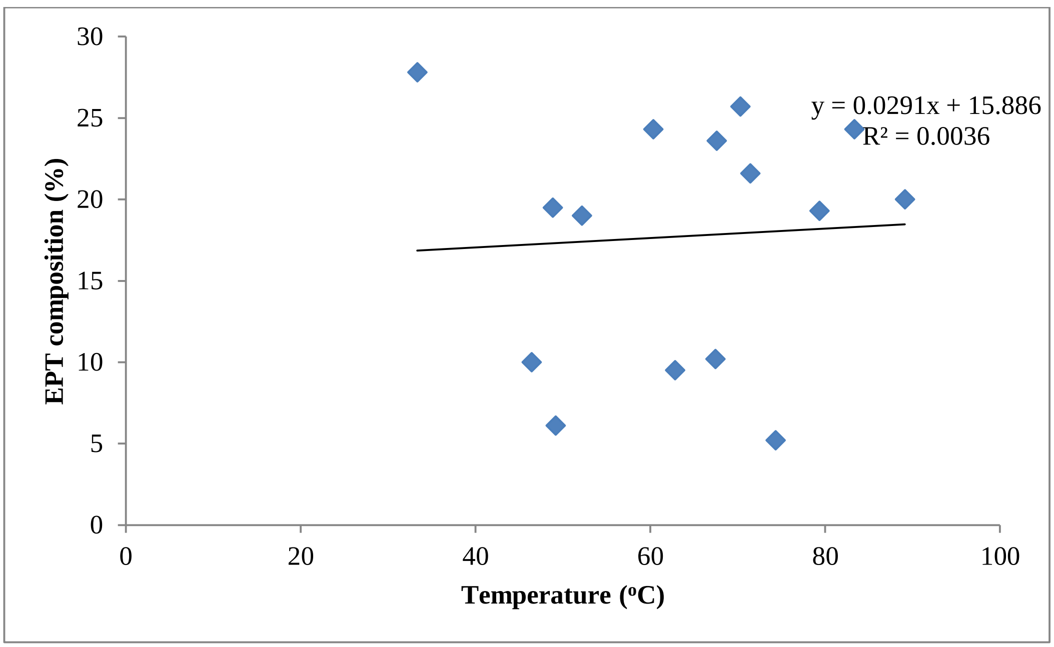

Figure 4-37 Correlation between EPT compositions and water Temperature

CHAPTER 5: SUMMARY AND CONCLUSIONS

The main objective of this study was to assess the water quality of fifteen streams at varying altitudes (700 m – 3700 m) from Manaslu Conservation Areas (MCA) and Annapurna Conservation Area (ACA) using benthic macroinvertebrates (BMI) as indicators; and analyze the precipitation and temperature trend in the study areas in the last 30 years. Multi habitat sampling (MHS) method was used for the collection of BMI. The application of biotic indices (NEPBIOS, BMWP/ASPT, and HBI) resulted in generating further insights on the health status of streams from two different watersheds in Nepal. This dissertation included baseline information on the biological assessment and it will be useful in the prediction of impacts of climate change in the future studies.

Benthic macroinvertebrates (BMI) are highly sensitive to changes (biological, chemical, and physical) in their natural habitat, they are capable of detecting the health status of rivers/streams. There was a strong positive correlation between altitude and EPT taxa richness. However, there was strong negative correlation between temperature and EPT taxa richness. The EPT and diptera composition of lower altitude resembles the higher streams; this similarity in taxa composition of macroinvertebrate indicates the taxa shifting to higher altitudes. The EPT taxa abundance and diversity was higher in all the streams, and OCH abundance and diversity was gradually decreasing with the increase in altitude. The taxa families such as leptophlebiidae, perlodidae, limoniidae, Planariidae, empididae, rhyacophilidae, capaniidae and brachycentridae observed as extremely sensitive to temperature. Moreover, the taxa such as baetidae, simuliidae, chironomidae, and tipulidae are observed as the temperature tolerant and observed in all altitudinal ranges.

Based on the hydro metrological assessment, the average annual air temperature was increased by 1.97 ^{0}C and 0.86 ^{0}C in MCA and ACA respectively in the last 30 years. The average annual precipitation was fluctuating and decreasing in the MCA; but there is not any pattern seen in ACA in the last 30 years.

To be more precise in prediction about the climate change impacts study using benthic macroinvertebrates, it is recommended to identify the organisms to the species level. Species level provides precise information on climate change than family level. In addition, collecting the second time data from the same location is highly recommended for the precise comparison of change of taxa composition and richness. It is also recommended to increase the number of streams or perhaps increase the number of sites in each stream.

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ANNEXES

ANNEX A**:** Selected sampling site

Serial Number	**Conservation Area (River Basin)**	**Streams Name**	**Site Code**	**Geographical Coordinates**	**Altitude (m)**
1	Annapurna Conservation Area	Chinne	S1	28^0 14.042 N 83^0 41.170 E	740
2		Rati	S2	28^0 13.886 N 83^0 42 884 E	760
3		Jare	S3	28 ^{0}13.865 N 83^0 42.869 E	780
4		Ambot	S4	28^0 13.869 N 83^0 42.869 E	940
5		Bhadra	S5	28^0 15.775 N 83^0 43.320 E	960
6		Bhurundi	S6	28^0 18.558 N 83^0 46.341 E	1060
7		Chimrum	S7	28^0 19 747 N 83 ^{0}47.804 E	1125
8		Dhoti	S8	28 ^{0}17.957 N 83 ^{0}46.341 E	1255
9		Sadi	S9	28 ^{0}19.996 N 83 ^{0}47 832 E	1260
10		Thado	S10	28 ^{0}20.731 N 83^0 48.035 E	1280
11	Manaslu Conservation Area	Bhalu	S11	28°21’11.0" N 84°58’33.7"E	1300
12		Ghatte	S12	28°23’14.1" N 84°83’34.7"E	1572
13		Pumgong	S13	28°31’51.8" N 84°49’32.0"E	2100
14		Tarang	S14	28°30’52.5" N 84°5’2356.2"E	2400
15		Melanchu	S15	28°30’15.8"N 84°48’23" E	3700

ANNEX B**:** Taxa list in each site

Taxa list	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**	**S 9**	**S 10**	**S 11**	**S 12**	**S 13**	**S 14**	**S 15**
Baetidae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Heptageniidae	0	0	1	1	1	1	1	1	1	0	1	0	0	1	1
Caenidae	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0
Neoephmeridae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Ephemeraidae	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
Ephemerellidae	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0
Leptophelbidae	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
Siphlonuridae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Perlidae	0	0	0	1	0	1	0	1	0	0	1	0	0	1	1
Perlodidae	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1
Nemouridae	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1
Chloroperlidae	0	0	0	1	0	0	0	0	0	0	1	1	0	1	1
Leuctridae	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
Taenioptera	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Capniidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Hydropsychidae	0	1	1	1	0	1	0	0	1	1	1	0	0	1	0
Glossosomatidae	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Lepidostomatidae	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0
Philopotamidae	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1
Rhycophiladae	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1
Brachycentridae	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1
Limnocentropodidae	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0
Calamotoceridae	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0
Leptoceridae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Hydraenidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Limnephilidae	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0
Goeridae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Uaenoidae	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0
Simulidae	1	1	0	1	1	1	0	0	0	1	1	1	1	1	0
Chironomidae	1	0	0	1	1	1	0	0	1	1	1	1	1	1	0
Chironomidae red	1	0	1	0	0	0	1	0	0	1	0	0	0	1	0
Tipulidae	1	0	0	1	0	0	0	0	0	0	1	1	1	1	0
Athericidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Limonidae	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0
Ceratopogonedae	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
Thaumaleidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Belphariceridae	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Psychodidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

Tabanidae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Empididae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Elmidae	0	0	1	1	0	0	0	1	1	0	1	0	0	0	0
Psephenidae	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0
Hydrochidae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sciritidae	0	0	0	0	0	1	0	0	0	0	1	1	0	1	0
Trichoniscidae	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Dryopidae	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0
Noteridae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Hydrophilidae	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Elminthindae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Euphaeidae	0	1	0	1	1	1	1	0	1	0	0	0	0	0	0
Gomphidae	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0
Epiophlebiidae	0	1	0	0	0	0	0	0	0	0		0	0	0	0
Libellulidae	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Gerridae	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Naucoridae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Corixidae	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Dugesiidae	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Planariidae	0	0	0	0	0	0	0	0	1	0	1	1	0	1	1
Lipidoptera	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Hydrachnidiae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Annelida	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1

NOTE: “0” = Absent and “1”= Present

ANNEX C: Photos of studied sites

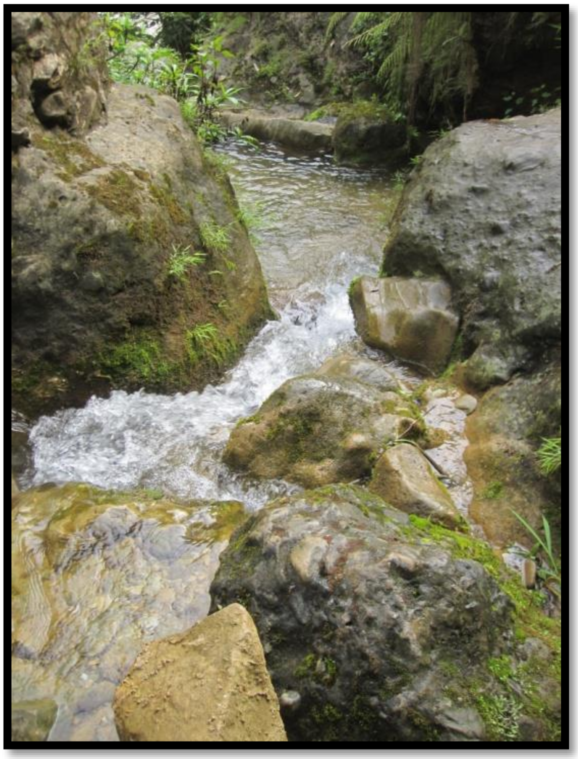

Figure 1: Chinne Khola- S1

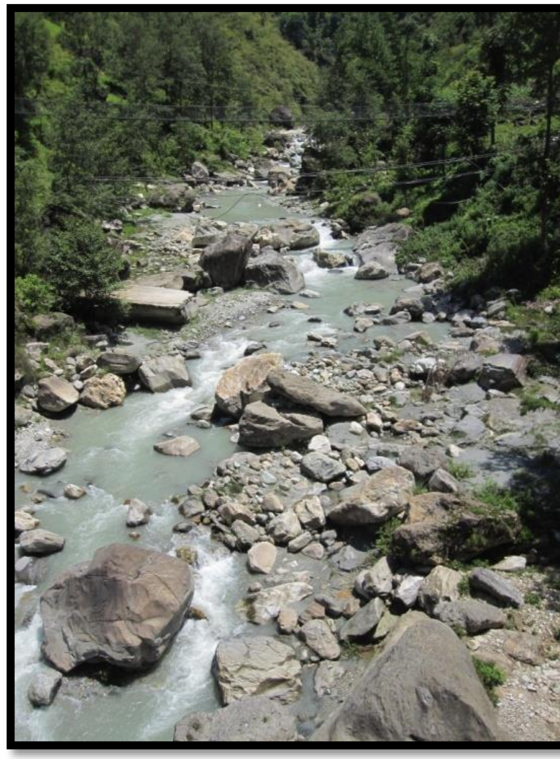

Figure2: Rati Khola- S2

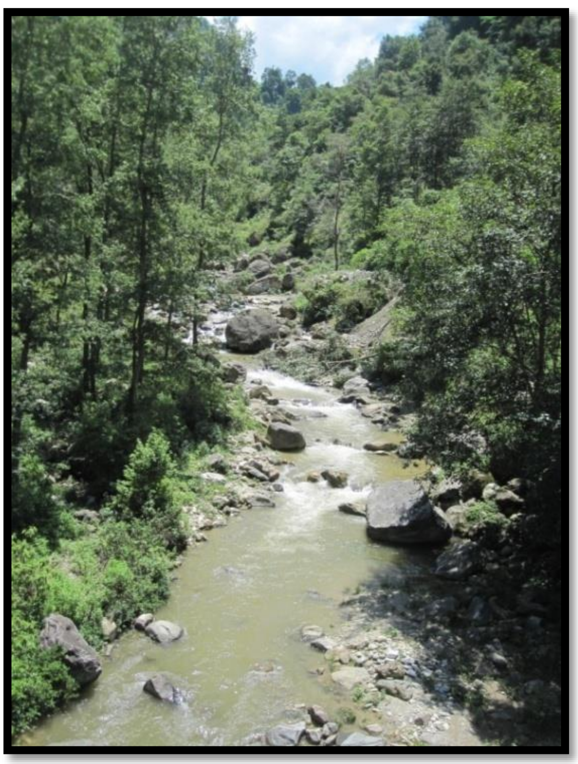

Figure3: Jare Khola-S3

Figure 4: Ambot Khola-S4

Figure 6: Bhurundi Khola-S6

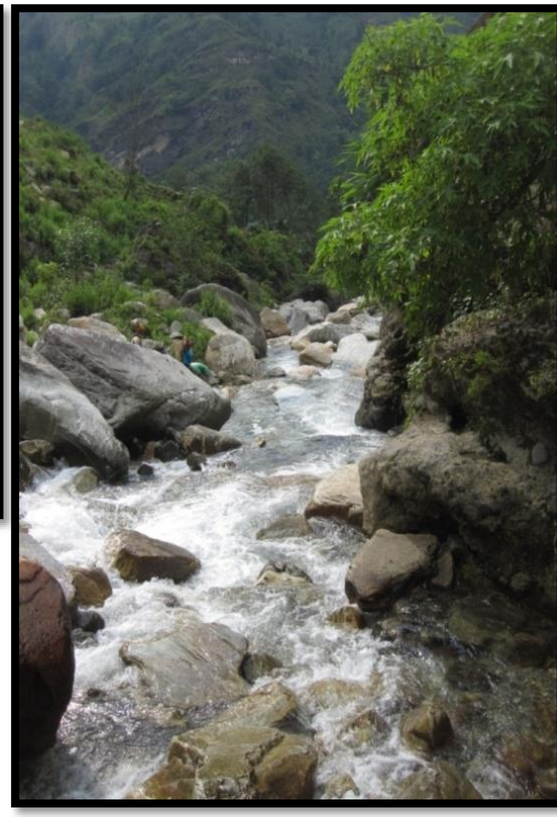

Figure 8: Dhoti Khola-S8

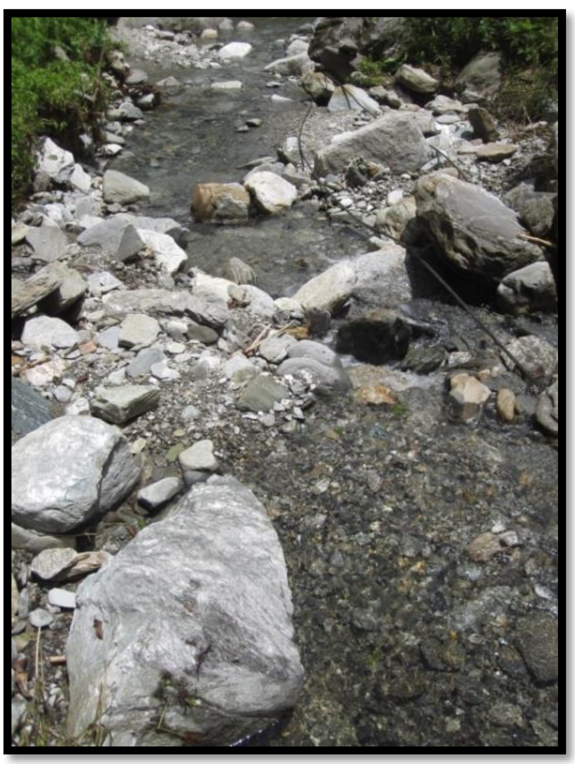

Figure 9: Sadi Khola-S9

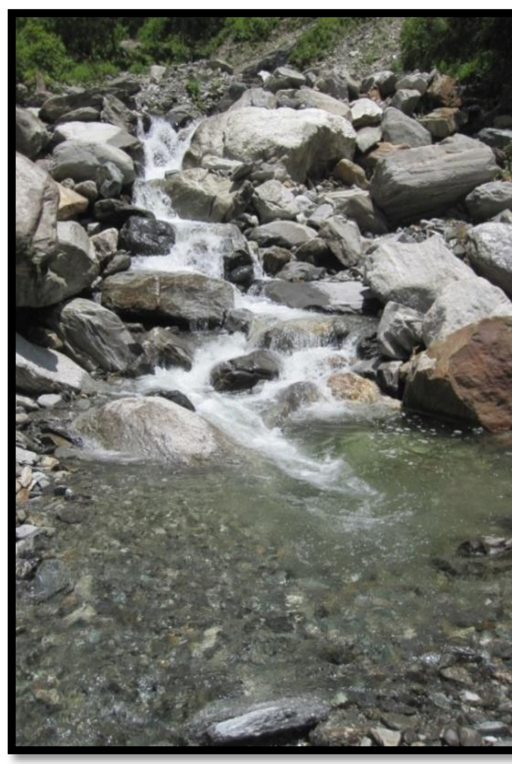

Figure 10 Thado Khola-S10

ANNEX D: Photos relevant to research work

Figure 5: Detection of Coliform with the help of P/A vial

Figure 6: Sample showing presence of Coliform

Figure 7: Macroinvertebrate observed on site

Figure 8: Trichoptera observed on site

Figure9: Consulting local people

Figure 10: Site 4

Figure 11: Working in team

Appendix-table1

Site name	date	sample code	investigator

	1	2	3	4
MINERAL HABITATS 5% steps; indicate microhabitats <5% with 'X', indicate artificial microhabitats with 'X' in column 'man-made'	% of coverage - 5% steps	SU (number of sampling units)	Comments	'man-made'
Hygropetric Sites water layer on solid substrates				□
Megalithal >40 cm large cobbles, bolders and blocks, bedrock				□
Macrolithal >20 cm to 40 cm coarse blocks, head-sized cobbles (with variable percentages of cobbles, gravel and sand)				□
Mesolithal >6 cm to 20 cm fist to hand-sized cobbles (with variable percentages of gravel and sand)				□
Microlithal >2 cm to 6 cm coarse gravel (size of a pigeon egg to child's fist) (with variable percentages of medium to fine gravel)				□
Akal >0.2 cm to 2 cm fine to medium-sized gravel				□
Psammal >6 µm to 2 mm sand				□
Psammopelal mixture of sand with mud				□
Pelal <6 µm mud (including organic mud and sludge)				□
Argyllal silt, loam, clay (inorganic)				□
sum=	100 %			
BIOTIC HABITATS 5% steps; indicate microhabitats <5% with 'X', indicate artificial microhabitats with 'X' in column 'man-made'	only biotic habitats			
Micro-algae diatoms and other algae				□
Macro-algae filamentous algae, algal tufts				□
Submerged macrophytes macrophytes, including moss and Characeae				□
Emergent macrophytes e.g. *Thypha, Carex, Phragmites*				□
Living parts of terrestrial plants fine roots, floating riparian vegetation				□
Xylal (wood) tree trunks (dead wood), branches, roots				□
CPOM deposits of coarse particulate organic matter, as e.g. fallen leaves				□
FPOM deposits of fine particulate organic matter, detritus				□
Debris organic and inorganic matter deposited within the splash zone area by wave motion and changing water levels, e.g. mussel shells, snail shells				□
Sewage bacteria and -fungi e.g. *Sphaerotilus, Leptomitus*, sulfur bacteria (e.g. *Beggiatoa, Thiothrix*), sludge				□
sum =	variable			

ANNEX F: NEPBIOS list

TAXON / NEPBIOS		Abd	TAXON / NEPBIOS		Abd	HABITAT	%
Aeshnidae	6		Limnocentropodidae	9		**Mineral**	
Aphelocheiridae	7		Limoniidae	8	2	Hygropetric	
Athericidae	10		Lymnaeidae	6		Boulders	
Baetidae	7	152	Micronecta	4		Cobbles	
Bezzia-Group	2		Muscidae	3		Stones	
Bithyniidae	5		Naucoridae	4		Pebbles	
Blephariceridae	10		Nemouridae	9		Gravel	
Brachycentridae	7		Neoephemeridae	9		Sand	
Caenidae	6		Nepidae	4		Sandy mud	
Calopterygidae	4		Noteridae	4		Mud	
Chironomidae *red*	1	22	Notonectidae	3		Clay	
Chironomidae *not red*	5		Odontoceridae	5			
Chlorocyphidae	9		Palaemonidae	4		**Biotic**	
Chloroperlidae	5		Peltoperlidae	10		Micro algae	
Coenagrionidae	4		Perlidae	8		Macro algae	
Corbiculidae	5		Perlodidae	9		Submerged macroph.	
Corduliidae	4		Philopotamidae	7		Emerged makrophyte	
Corixidae	6		Physidae	3		Living terrest. plants	
Corydalidae	2		Planariidae			Wood	
Culicidae	5		Planorbidae	4		CPOM	
Dryopidae	4	1	Pleuroceridae	4		FPOM	
Dytiscidae	6		Polycentropodidae	7		Debris	
Ecnomidae	8		Potamidae	7		Sewage bacteria	
Elmidae	7	1	Protoneuridae	5			
Ephemerellidae	6		Psephenidae	7			
Ephemerellidae (*Drunel. sp.*)	7		Psychodidae (white)	2			
Ephemeridae	10		Psychomyiidae	6			
Epiophlebiidae	8		Ranatridae	4			
Euphaeidae	7		Rhyacophilidae	8			
Gammaridae	4		Salifidae	3			
Gerridae	4		Scirtidae	8	8		
Glossiphoniidae	7		Simuliidae	7	49		
Glossosomatidae	9		Siphlonuridae	10			
Goeridae	4		Sphaeriidae	5			
Gomphidae	6		Stenopsychidae	6			
Gyrinidae	10		Stratiomyidae				
Helicopsychidae	10		Taeniopterygidae	10			
Heptageniidae	10		Tabanidae	2			
Heptageniidae (*Epeorus sp.*)	9		Thiaridae	4			
Heptageniidae (*Iron sp.*)	9		Tipulidae	8	1		
Hept. (*Rhithrogena sp.*)	8		Tubificidae	1			
Hydraenidae	6		Veliidae	4			
Hydraenidae (*Ochthebius sp.*)	10						
Hydrobiosidae	10		**Other Taxa ⇩**				
Hydrometridae	6		[illegible]		6		
Hydrophilidae	6						
Hydropsychidae	6						
Hydroptilidae	10						
Lepidostomatidae	5						
Leptoceridae	7						
Leptophlebiidae	10						
Leuctridae / Capniidae	6						
Libellulidae	6						
Limnephilidae	9						

ANNEX G: Habitat Assessment Field Data Sheet- High Gradient Streams
Front page

HABITAT ASSESSMENT FIELD DATA SHEET—HIGH GRADIENT STREAMS

STREAM NAME	LOCATION	
SITE ID # ________ REACH ID ________	STREAM CLASS	
UTM N ________ UTM E ________	RIVER BASIN	
STORET #	AGENCY	
INVESTIGATORS		
FORM COMPLETED BY	DATE ________ TIME	REASON FOR SURVEY

Parameters to be evaluated in sampling reach

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/ Available Cover	Greater than 70% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are <u>not</u> new fall and <u>not</u> transient).	40-70% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at <u>high</u> end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Velocity/Depth Regime	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (Slow is < 0.3 m/s, deep is > 0.5 m.)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/ depth regime (usually slow-deep).
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Form # EH-________

Back page

HABITAT ASSESSMENT FIELD DATA SHEET—HIGH GRADIENT STREAMS

Parameters to be evaluated broader than sampling reach

Habitat Parameter	Condition Category: Optimal	Suboptimal	Marginal	Poor
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Stability (score each bank) Note: determine left or right side by facing downstream.	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
9. Vegetative Protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Total Score ___

Form # EH2 -

ANNEX H: Physical Characterization/Water Quality Field Data Sheet
Front Page

PHYSICAL CHARACTERIZATION/WATER QUALITY FIELD DATA SHEET (FRONT)

STREAM NAME	LOCATION
STATION # ________ RIVERMILE ________	STREAM CLASS
LAT ________ LONG ________	RIVER BASIN
STORET #	AGENCY
INVESTIGATORS	

FORM COMPLETED BY	DATE ________ TIME ________ AM PM	REASON FOR SURVEY

WEATHER CONDITIONS	Now / Past 24 hours: ❑ / ❑ storm (heavy rain) ❑ / ❑ rain (steady rain) ❑ / ❑ showers (intermittent) ___%❑ / ❑___% %cloud cover ❑ / ❑ clear/sunny Has there been a heavy rain in the last 7 days? ❑ Yes ❑ No Air Temperature____° C Other________
SITE LOCATION/MAP	Draw a map of the site and indicate the areas sampled (or attach a photograph)
STREAM CHARACTERIZATION	Stream Subsystem ❑ Perennial ❑ Intermittent ❑ Tidal Stream Origin ❑ Glacial ❑ Non-glacial montane ❑ Swamp and bog ❑ Spring-fed ❑ Mixture of origins ❑ Other________ Stream Type ❑ Coldwater ❑ Warmwater Catchment Area________km^2

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PHYSICAL CHARACTERIZATION/WATER QUALITY FIELD DATA SHEET (BACK)

WATERSHED FEATURES	**Predominant Surrounding Landuse** ❑ Forest ❑ Commercial ❑ Field/Pasture ❑ Industrial ❑ Agricultural ❑ Other ____________ ❑ Residential **Local Watershed NPS Pollution** ❑ No evidence ❑ Some potential sources ❑ Obvious sources **Local Watershed Erosion** ❑ None ❑ Moderate ❑ Heavy
RIPARIAN VEGETATION (18 meter buffer)	**Indicate the dominant type and record the dominant species present** ❑ Trees ❑ Shrubs ❑ Grasses ❑ Herbaceous **dominant species present** ____________
INSTREAM FEATURES	**Estimated Reach Length** _____ m **Estimated Stream Width** _____ m **Sampling Reach Area** _____ m^2 **Area in km^2 (m^{2}x1000)** _____ km^2 **Estimated Stream Depth** _____ m **Surface Velocity (at thalweg)** _____ m/sec **Canopy Cover** ❑ Partly open ❑ Partly shaded ❑ Shaded **High Water Mark** _____ m **Proportion of Reach Represented by Stream Morphology Types** ❑ Riffle _____% ❑ Run _____% ❑ Pool _____% **Channelized** ❑ Yes ❑ No **Dam Present** ❑ Yes ❑ No
LARGE WOODY DEBRIS	**LWD** _____ m^2 **Density of LWD** _____ m^2/km^2 (LWD/ reach area)
AQUATIC VEGETATION	**Indicate the dominant type and record the dominant species present** ❑ Rooted emergent ❑ Rooted submergent ❑ Rooted floating ❑ Free floating ❑ Floating Algae ❑ Attached Algae **dominant species present** ____________ **Portion of the reach with aquatic vegetation** ____ %
WATER QUALITY	**Temperature** _____ °C **Specific Conductance** _____ **Dissolved Oxygen** _____ **pH** _____ **Turbidity** _____ **WQ Instrument Used** ____________ **Water Odors** ❑ Normal/None ❑ Sewage ❑ Petroleum ❑ Chemical ❑ Fishy ❑ Other ____________ **Water Surface Oils** ❑ Slick ❑ Sheen ❑ Globs ❑ Flecks ❑ None ❑ Other ____________ **Turbidity (if not measured)** ❑ Clear ❑ Slightly turbid ❑ Turbid ❑ Opaque ❑ Stained ❑ Other _____
SEDIMENT/ SUBSTRATE	**Odors** ❑ Normal ❑ Sewage ❑ Petroleum ❑ Chemical ❑ Anaerobic ❑ None ❑ Other ____________ **Oils** ❑ Absent ❑ Slight ❑ Moderate ❑ Profuse **Deposits** ❑ Sludge ❑ Sawdust ❑ Paper fiber ❑ Sand ❑ Relict shells ❑ Other ____________ **Looking at stones which are not deeply embedded, are the undersides black in color?** ❑ Yes ❑ No

INORGANIC SUBSTRATE COMPONENTS (should add up to 100%)			ORGANIC SUBSTRATE COMPONENTS (does not necessarily add up to 100%)		
Substrate Type	**Diameter**	**% Composition in Sampling Reach**	**Substrate Type**	**Characteristic**	**% Composition in Sampling Area**
Bedrock			Detritus	sticks, wood, coarse plant materials (CPOM)	
Boulder	> 256 mm (10")				
Cobble	64-256 mm (2.5"-10")		Muck-Mud	black, very fine organic (FPOM)	
Gravel	2-64 mm (0.1"-2.5")				
Sand	0.06-2mm (gritty)		Marl	grey, shell fragments	
Silt	0.004-0.06 mm				
Clay	< 0.004 mm (slick)				

A-6 *Appendix A-1: Habitat Assessment and Physicochemical Characterization Field Data Sheets - Form 1*