

**ECOLOGICAL STUDY OF SURFACE WATER
BODIES IN SAGARMATHA NATIONAL PARK AND
BUFFER ZONE, NEPAL**



**A THESIS SUBMITTED TO THE
CENTRAL DEPARTMENT OF BOTANY
INSTITUTE OF SCIENCE AND TECHNOLOGY
TRIBHUVAN UNIVERSITY
NEPAL**

**FOR THE AWARD OF
DOCTOR OF PHILOSOPHY
IN BOTANY**

**BY
NARAYAN PRASAD GHIMIRE
JULY, 2014**

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LETTER OF APPROVAL

07/07/2014

On the recommendation of Prof. Dr. Pramod Kumar Jha and Prof. Dr. G.U. Caravello, this Ph.D thesis submitted by Narayan Prasad Ghimire, entitled “**Ecological study of surface waterbodies in Sagarmatha National Park and Bufferzone, Nepal**” is forwarded by Central Department Research Committee (CDRC) to the Dean, IOST, T.U.

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Nepal

DECLARATION

Thesis entitled “**Ecological study of surface waterbodies in Sagarmatha National Park and Bufferzone, Nepal**” which is being submitted to the Central Department of Botany, Institute of Science and Technology (IOST), Tribhuvan University, Nepal for the award of the degree of Doctor of Philosophy (Ph.D), is a research work carried out by me under the supervision of Prof. Dr. Pramod Kumar Jha, Central Department of Botany, Tribhuvan University and co supervised by Prof. Dr. G.U. Caravello, Environment Medicine and Public Health Department, Padua University.

This research is original and has not been submitted earlier in part or full in this or any other form to any university or institute, here or elsewhere, for the award of any degree.

.....
Narayan Prasad Ghimire

RECOMMENDATION

This is to recommend that **Narayan Prasad Ghimire** has carried out research entitled the thesis entitled “**Ecological studies of waterbodies in Sagarmatha National Park and Bufferzone, Nepal**” for the award of Doctor of Philosophy (Ph.D) in **Botany** under our supervision. To our knowledge, this work has not been submitted for any other degree.

He has fulfilled all the requirements laid down by the Institute of Science and Technology (IOST), Tribhuvan University, Kirtipur for the submission of the thesis for the award of Ph.D degree.

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July, 2014

This work has been dedicated to my Parents

Bamdev Ghimire and Kamala Ghimire

and

my Wife *Neeta Gyawali (Ghimire)*

Letter of Approval

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.....
Narayan Prasad Ghimire
July, 2014

ABSTRACT

Sagarmatha National Park (SNP), located in southern slope of Sagarmatha (Mt. Everest) in eastern Nepal is a popular international eco-touristic destination. The Park provides a unique opportunity to study and observe diverse flora, fauna, environment and socio-culture, at the same time facing the problem of environmental degradation because of increased tourism. In the last few years, water quality in the SNP has been found degraded because of enhanced flow of tourists and their activities. To assess the quality of water bodies, physical, chemical, microbiological, algal and aquatic micro-invertebrate analyses were done during 2008-2011.

Changes in pH, increase of total nitrogen as nitrate (TN-NO₃), total phosphorous as phosphate (TP-PO₄) were noted in the waterbodies in SNPBZ. Total nitrogen in water samples was lower than the WHO standard but an increase in the nitrate-nitrogen has been recorded when compared with the earlier reports. Similarly total phosphorous value was found increased. Iron (Fe) concentration also increased when compared with earlier report. Iron (Fe) content in eighteen samples has been found more than WHO and Nepalese standards for drinking water.

The trend in metal content in waterbodies in Sagarmatha National Park and Buffer Zone was in the following order: Pb>Cu>Zn >Mn>Mg>Fe>Na. Sodium (Na), Magnesium (Mg), Lead (Pb), Manganese (Mn), Copper (Cu) and Zinc (Zn) were found within the limit set for drinking purpose. Results reveal that quantity of these heavy metals has increased in the last few years.

During the present investigation, a total 59 species of algae have been reported from Sagarmatha National Park and Buffer Zone, Nepal. Among them Chlorophyceae, Bacillariophyceae, Cyanophyceae were the most dominating families. One species belonging to family Xanthophyceae is also enumerated from this region. Gokyo lake (1st and 3rd) located at more than 4600m altitude had more algal species than other Gokyo lakes. Generally unicellular, colonial algae and desmids were found to be dominant in stagnant water where as filamentous green algae were common in both running and stagnant waterbodies. Six species (*Euastrum oblongum*, *Penium cylindrus*, *Spirogyra amplexans*, *Euastrum coralloides*, *Cymbella lanceolata* and *Oscillatoria insignis*) were found new record for Nepal.

Five orders of micro-invertebrate (Ephemeroptera, Plecoptera, Tricoptera, Trichedida and Diptera) belonging to fourteen families (Baetidae, Heptageniidae, Amelidae, Nemouridae, Capniidae, Perlidae, Leuctridae, Leptoceridae, Rhyacophilidae, Glossosomatidae, Planariidae, Chironomidae, Simuliidae and Tripulidae) were recorded during the present study in different waterbodies (lakes, springs and rivers) of the SNPBZ. Baetidae family was found as the dominant family in SNPBZ region.

Contamination of faecal coliform in most waterbodies in the SNPBZ area was low. *Escherichia coli* and *Streptococcus faecolies* bacteria were recorded in 13 % of water samples collected from SNPBZ which could be due to the activities of visitors and increase in human waste especially human excreta. Many of the toilets in SNPBZ are not maintained, completely full and have effluent leaking to nearby water bodies.

The best part of the agriculture here is its organic form. Average rate of use of organic fertilizer is 8 t/ha, that is more than the recommended dose. At this rate, the nitrogen, phosphorous and potassium to the agricultural field comes around 97, 54.4 and 136.8 kg/ha. To meet the high demand of potato in hotels and tea shops people might have used organic fertilizer at the rate higher than recommended dose for potato crop to maximize the yield.

Non-scientific management of solid waste (no separation of waste and construction of collection pit near water course); open defecation and poor condition of septic tanks; and direct disposal of toilet waste to water courses or on the exposed surface, are major sources of surface water pollution. Some sites along the trekking routes showed faecal contamination. The surface water quality in general still stands good in terms of standard for drinking water (WHO, Nepal standard) but degradation process has started. High solid waste generation due to high tourism flow, no proper management practice of solid waste, open defecation, construction of garbage pit near the water course were found the root causes for water pollution.

LIST OF ACRONYMS AND ABBREVIATION

AAS	Atomic Absorption Spectrophotometer
ANOVA	analysis of variance
APHA	American Public Health Association
BPP	Biodiversity Profiles Project
CBS	Central Bureau of Statistics
CITES	Convention on International Trade in Endangered Species
°C	Degree Celsius
μl	micro litre
μS/cm	micro simon per centimetre
Alt.	Altitude
CCA	Canonical Correspondence Analysis
DCA	Detrended Correspondence Analysis
DO	Dissolved Oxygen
DNPWC	Department of National Park and Wildlife Conservation
EDTA	Ethylene Diamine Tetracetic Acid
<i>E. coli</i>	<i>Escherichia coli</i>
EBC	Everest Base Camp
Ev-K2-CNR	Everest –Karkurom
FFI	Fluvial Functioning Index
Fig	Figure
GIS	Geographical Information System
GLOFs	Glacier Lake Outburst Floods
GoN	Government of Nepal
HH	Household

IUCN	The world Conservation Union
Lat.	Latitude
MoFS	Ministry of Forest and Soil conservation.
m.	Meter
mg/l	Milligram per litre
MPN	Most Probable Number
N, P, K	Nitrogen, Phosphorous and Potassium
NTB	Nepal Tourism Board
PCA	Principal Component Analysis
SNPBZ	Sagarmatha National Park and Buffer Zone
SPCC	Sagarmatha Pollution Control Committee
TDS	Total Dissolved Solids
USEPA	United States Environment Protection Agency
VDC	Village Development Committee
WHO	World Health Organisation
WWF	World wide Fund for Nature

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CHAPTER 1: INTRODUCTION

1.1 Background

Water is the most important natural resource in the country having 2.7% of the world's water resources, second only to Brazil. Wetlands directly support millions of people and provide goods and services to the world. Wetlands perform important role in hydrological and chemical cycle so are often described as “kidney of landscape” and have extensive food webs and support rich biodiversity, so called “biological supermarket” (Mitsch & Gosselink 1993). There are many communities who rely entirely upon wetlands for their subsistence.

Ramsar Convention 1971 article 1.1 defines wetland as “Areas of marsh, fens or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meter.”

National wetland policy 2003 defines wetland as “wetlands denote perennial water bodies that originate from underground sources of water or rains. It means swampy areas with flowing or stagnant fresh or salt water that are natural or man-made, or permanent or temporary. Wetlands also mean marshy lands, riverine floodplains, lakes, ponds, water storage areas and agricultural lands.”

Water is Nepal's precious natural resource coming through rainfall, glaciers and groundwater. Mean annual rainfall is about 1,700 mm, 75% of which occurs during the monsoon season from June through September. The average annual renewable water volume of the country is about 224 billion m³ (Yogacharya 1998). Of these, rivers are the most important running surface water in terms of water volume and potential development. There are over 6,000 rivers in Nepal with an estimated total length of more than 45,000 km (CBS 1995). All large rivers are fed by snowmelt from the Himalayas, and hence they are perennial. The country has 660 lakes with stagnant surface water of more than one hectare in area.

Himalayan region ‘the third pole’ and the water tower of Asia, is the most glaciated area in the world outside polar region, having stocks of water in the form of ice and snow. All Nepal's rivers flow into Ganga, bearing cultural and religious significance.

Water is an essential element for living organisms and constitutes an integral part of our environment. It is important for agriculture, industries and ecosystems and treated as a basic requirement for overall development of country.

Tourism in Nepal has been a great source of foreign exchange. Tourism contributes 2.5 to 4.0% to the foreign exchange earning of Nepal. Panoramic view of snow cap, white water river, clean environment, live glacier, glacier lakes, unique flora and fauna, scenic beauty of Himalayan peak, wonderful ethnic culture, festivals, religion, etc. are the sources of inspiration for tourist to visit Nepal, particularly in mountains.

The Sagarmatha National Park is facing massive and aggressive anthropogenic pressure that can bring serious environmental consequences to the unique ecosystem. In the last one decade, it has been felt that the popular trekking routes have got some adverse environmental effects. Many foreign expeditions that went to the different Himalayan peaks, including Sagarmatha (Mt. Everest), each year are reported to have left a great deal of garbage in the mountains which pollute the environment. Increase in non-biodegradable solid waste such as batteries, bottles and others resulted in environmental degradation (Khanal *et al.* 2010).

Tourism pressure is increasing every year in the Sagarmatha National Park. Tourism in Nepal has been considered as an answer to economic problems without evaluating its impacts on the physical, social and cultural environment, as well as the carrying capacity of the biophysical environment (Caravello *et al.* 2007). Environmental degradation has been recorded in the Khumbu region as a result of massive and aggressive anthropogenic pressure. It has been well noticed that the popular trekking routes in the SNP have got some adverse environmental effects.

On one side, there is economic gain through tourism in the Khumbu region; on the other there are some environmental concerns. Despite involvement of nearly every family in tourism, negative impact has arisen from unequal access to the benefits of tourism in Sagarmatha National Park (Caravello *et al.* 2007). A large number of tourists accompanied with porters and guides produce impacts on environment and society.

The pollution problem is now no longer confined to solid waste. Water resources along the trails are being contaminated from improper discharge, human waste and

garbage dumping. Sewage and toilet waste can be found piped into nearby streams and rivers (DNPWC 2007).

In 1988, number of tourists visited SNP was 11366, it reached to 31201 in 2008 and each trekker staying in the park for 14 to 15 days in average. In 2012, the number of international tourists reached to 36518 in the National Park. These tourists are mostly either in spring or autumn seasons creating a pressure on resources. This large number of tourists and trekkers leave a large amount of garbage and human excreta in the SNP. Human waste had not been taken seriously as source of pollutants, but the accumulated solid excretes in the glaciers and base camp was so unmanaged that it started polluting the environment. In fact, almost all local Sherpa houses are converted into lodges/houses for visitors (DNPWC, 2003) and this number is increasing year to year due to increasing. Nearly, people of two third of households inside the park work as guide, porter or lodge, tea- houses, shop owner, etc.

Tourists and trekkers used to dispose their wastes in the glaciers and on the trek sides. As a result beauty of the Everest region degraded because of large quantity of solid wastes disposed. Waste collection in the Everest region started by cleaning expeditions and environmental groups, and the Government of Nepal introduced regulation to prevent pollution. Sagarmatha Pollution Control Committee (SPCC) was formed in 1990 with the main objective to keep the SNP pollution free. Annually, the SPCC disposes a considerable amount of burnable and non-burnable garbage produced by trekkers and mountaineers from the whole Khumbu. For example, the SPCC disposed 458.51 t of burnable waste in 2004-05. Out of burnable waste, 19.41 t were received from different mountaineering groups (SPCC 2004-05).

In the past decades, the extensive deforestation and intensive farming on steep slopes, heavy pressure on soil, water and biological resources and adverse impacts of the large development projects on the mountain environments have resulted in overall environmental degradation and depletion of the natural resources of the region which ultimately effected the whole ecosystem (like, soil erosion, loss of biological diversity) (Bayer 2005).

1.2 Justification

- Very few studies have been done on ecological aspect in the National Park. There is growing realization that the park is getting degraded due to solid waste disposal in the area by the tourists and mountaineers.

- Overall situation of surface water ecology will help the National Park authorities in development of appropriate management strategies in maintaining healthy wetland ecosystem in the park.
- The findings will also aware the local communities and help them to develop local tourism management plan that is more eco friendly and conscious in water resource conservation.

1.3 Hypothesis

- The Physico-chemical and biological parameters of surface water bodies of SNPBZ are significantly affected by anthropogenic activities.
- Uncontrolled tourist flow, haphazard solid waste disposal, not scientific separation of solid waste and discharge of toilet waste directly to water bodies are the main causes of water pollution in SNPBZ.

1.4 Objectives

A general objective of the present work was to analyze the ecological status of the surface water bodies (lakes, springs and rivers) in the Sagarmatha National Park and Buffer Zone. The specific objectives were:

- ⇒ To analyze physical, chemical and biological characteristics of surface water in SNPBZ.
- ⇒ To identify sources of water pollution in SNPBZ.
- ⇒ To develop water body management strategy and model.

1.5 Limitations

Though the current work initiated new dimension in the field of ecological study at high altitude in Nepal, however, there are few limitations:

1. The entire research is based on one visit in tourist season every year hence monthly variation in physicochemical parameters and seasonal impact on water bodies were not considered.
2. Some of the water samples were taken in frozen condition that limits measurement of DO in the field.
3. Limited numbers of samples were brought to Kathmandu for metal analysis due to difficulties in transportation.

CHAPTER 2: LITERATURE REVIEW

There are very limited studies on ecology of water bodies in high altitude, particularly in Khumbu region (Mt. Everest region). The studies were conducted by foreigners but not regularly and systematically. The literature on ecology of water bodies are presented here under three section; 1) Limnological study, 2) Biological study, and 3) Environmental impacts and degradation

2.1 Limnological study

Ecology of water bodies represents a term used for the composite analysis of physical, chemical and biological measurements as well as associated aquatic environment. Water quality of almost all major rivers is greatly changed due to disposal of domestic wastes, sewage, herbicides, pesticides, insecticides, fertilizer, industrial pollutants, etc.

Earlier studies were mainly focused on the chemistry and biological components of the surface water of the riverine system. Phytoplankton and chemical nature of water were studied earlier for water ecology by a number of researchers (Pearsall (1923), Clarke (1924) Reinhard (1931). Other investigators like Spencer (1950), Trazwell and Palmer (1951), Berner (1951), Brook (1985), Yeatman (1956), Read and Olive (1956), Mayewski *et al.* (1986), Panno *et al.* (1998, 2000) also added information on the ecological studies of the water bodies. Large numbers of studies with chemical properties of surface water have been done in Europe, America and Africa (Golterman 1975 and Livingstone 1963). In India, Chackrabarty *et al.* (1959), Chacko and Ganapati (1949), Bhatta and Pathak (1992), Paul and Verma (1990) contributed on water ecology of different rivers like Jamuna, Adyar, etc.

A number of studies on lake water in different regions of the globe have been performed on relationship between water chemistry and biota (e.g., Macek *et al.* 2006; Llamas & Vinocur 2007; Diaz *et al.* 2007; Kumke *et al.* 2007), and to evaluate their sensitiveness towards anthropogenic stressors like water exploitation, land use change, tourism and recreational use (Mc Garrigle & Champ 1999), pollutant deposition (Allan 1999; Wolfe *et al.* 2001), and, more recently, climate change (Filippelli *et al.* 2006; Sommaruga 2007).

Galloway *et al.* (2004) showed that human activities increasingly dominate the nitrogen (N) budget at the global and at most regional scales, and the fixed forms of N are accumulating in most environmental reservoirs also in remote areas. Asia is foreseen to have the largest increase in N emission and deposition by 2050, and similar changes are predicted for Central and South America (Galloway *et al.* 2004). The Himalaya can be considered as still pristine region from the point of view of anthropogenic N inputs and atmospheric pollution in general. Nevertheless, regional N budgets as those provided by using output from global chemistry transport models, Phoenix *et al.* (2006) estimated future rates and distributions of N deposition within biodiversity hotspots, showing that the average deposition rate across these areas could be more than double by 2050 with respect to 1990s. Among these hotspots, for Himalaya it is estimated that the percent area receiving greater than $10 \text{ kg N ha}^{-1} \text{ y}^{-1}$ in 2050 will be 10 times that of 1990 (Phoenix *et al.* 2006). It must be highlighted that $10 \text{ kg N ha}^{-1} \text{ y}^{-1}$ has been indicated as a critical threshold above which elevated concentrations of NO_3 in surface waters may occur (Dise & Wright 1995).

Limnological studies in the Himalayas have been carried out since the beginning of the century (Sars 1903; Hutchinson 1937). For example, Khan and Zusti (1980), Sharma and Pant (1985), Vass *et al.* (1989), Zusti (1991) added limnological information (physical, chemical and biological environment) on high altitude lakes of northwest Himalaya of Kashmir and Sikkim. Swar (1980), Jones *et al.* (1989), Bhandari (1993) also added information on the limnology on the lower altitude lakes in Nepal. Major lowland rivers have been studied in Nepal (Upadhyaya and Roy 1982; Tiwari and Ali 1987, Aryal and Lacoul 1996). All the studies showed that pollution is increasing through time.

2.2 Biological research in water bodies

2.2.1 Algae

Algae in Nepal, particularly at high altitude, have not been studied adequately so far. Very low abundance of phytoplankton was usually reported from highland Nepal. Loffler (1960) studied the lakes of Khumbu valley and mentioned very poor phytoplankton assemblages. More than 176 taxa from high altitude Himalayan region of eastern and central Nepal were recorded by Hirano (1963, 1984), which is the

major contribution in Nepalese algae. Other studies conducted on algae are by Suxena and Venkateswarlu (1968), Suxena *et al.* (1972), Hickel (1973), Subba Raju & Suxena (1979), Watanabe (1982), Aizaki *et al.* (1987), Shrestha and Manandhar (1983), Ishida (1986), Habib (1997), Rothfritz *et al.* (1997), Baral *et al.* (1988), Tekeuchi *et al.* (1998), Baral (1999), Rai (2005), Rai *et al.* (2010) and Rai and Mishra (2010).. Ruggia *et al.* (1998) identified thirteen species; most of them were not previously recorded in the Khumbu region. Kumar and Rai (2005) also recorded 13 taxa of Chlorophyceae from Sikkim –Himalayas. Juetner *et al.* (2000, 2004) also reported eight new species *Gomphonema* and one species of *Nevicula* from Himalayan stream. Li *et al.* (2004, 2007) studied *Gomphonema* and *Cymbelloid* (diatoms) from Mount Everest region. Rothfritz *et al.* (1997) have reported different diatoms from different parts of the country. Seventeen fresh water diatom species were collected from the eastern terai region, Nepal.

Suxena and Venkateswarlu (1968) studied diatoms in Everest National Park. Subba Raju and Suxena (1979) also added some blue green algae from Dudhkoshi. Watanabe and Komarek (1994) made contribution to the Cyanophyceae from water bodies from Sagarmatha National Park. Komarek and Watanabe (1998) enumerated different blue-green algae from the Sagarmatha National Park.

Lacoul & Freedman (2006) studied the distribution of *Ranunculus trichophyllus* in high altitude lakes in response to the physical and chemical properties of the lake. Presence of angiosperm to the height of 4200 m was interesting phenomenon. He found that presence of this species is significantly associated with the ice free season implying the growing trend of increasing temperature as a factor for the growth. Rai *et al.* (2010) made the checklist in the distribution of blue-green algae in Nepal which is a one of the major contribution in the Cyanophyceae.

2.2.2 Microbiological research

Garratt (1981) found up to 1,100 coliform bacteria per 100 ml in areas of the Dudhkoshi directly below the Namche and concluded that maintenance of drinking water quality within park is a significant problem.

Examination of the drinking water in the Everest region revealed upto 4000 /coliform bacteria per litre of water (Khadka 1990). Streams and rivers in the main tourist area

such as Namche, Lobuche and Pheriche were contaminated by bacteria and reported that many more streams and rivers are at risk of contamination.

Clark (1995) used a portable autoclave and incubator to document fecal contamination at Mt. Everest base camp and found that fecal organisms could still be detected in melt water at some distance from areas of contamination. The study also revealed that the spring at Namche contained >300 fecal coliform bacteria per 100ml.

The samples in Namche bazaar had high contamination of bacteria due to anthropogenic and animal excreta with the estimate of 100-200000 CFU/100ml of *E. coli* (Baroni *et al.* 1998, Caravello *et al.* 2007, Jha *et al.* 2009).

2.3.3 Micro-invertebrate

There is very little study on the micro invertebrates of high altitude water bodies in Himalayan region. Information was provided by different researchers in high land water ecology about Copepoda, Cladocera, and Daphniidae by Brehm (1936) from the high land water.

Hutchinson (1937) reported abundant and varied benthic fauna (Turbicididae, Chironomidae, Amphipods and Molluscs) in high altitude lakes water from Tibet. Reiss (1968) and Roback and Coffman (1987) also added a major contribution by providing a great information about benthic organisms specially chironomidae in high altitude water bodies from Himalayan water. Löffler (1969) concluded presence of low density of Enchytraeidae in the Khumbu valley. Entonostrea also reported from Ngozumpa glacier of the Khumbu valley by Dumont and Van de velde (1977).

Only known studies are from lake sediments of Gokyo and Imja lakes. Nine lakes were studied located at altitudes from 4830 to 5580 m (Manca *et al.* 1998). Lake organisms mainly depend on accumulation of organic materials on the lake bed as a source of food. Organic materials from the surrounding land are carried with runoff by lake inlets into the lakes. There is low level of nutrients in the water and also in the sediments and extreme physical and chemical conditions cause a low number of systematic entities.

Ruggia *et al.* (1998) collected different groups of fauna from the water bodies in Khumbu valley. Among them, *Arctodiaptomus jurisovitchi*, some Nauplii and only

Copepod were found. Among the Cladocera, two species of *Daphnia* were found from eight lakes of the Khumbu valley. Diptera, Chironomidae and few Oligochaeta (Lumbriculidae) were also reported as bottom fauna from these study sites.

Sharma *et al.* (2010) studied the ecology of water of Gokyo lake and found that Plecoptera (stonefly), Ephemeroptera, Trichoptera, Diptera were the most dominating groups of micro-invertebrate of water bodies of Gokyo lakes. Lakes and streams in Gokyo wetlands had differences in richness and assemblage composition of microinvertebrates. Streams were dominated with Planariids; but also had mites, heptagenids, baetids and simuliids. A well developed diatom flora, e.g., *Eunotia*, *Pinnularia*, *Fragilaria* s.l. *Achnanthes* s.l. and *Cymbella* s.l, exist in springs and other air exposed wet habitats. There were many other undescribed species of diatoms from the area.

2.3 Environmental Impacts and Degradation

Freshwater ecosystems are directly and indirectly affected by human activities which have brought contamination, depletion and degradation of water quality. Freshwater ecosystems also connect and support many social, economic and environmental spheres making them crucially important both as a source and resource.

In the recent years, emphasis has been given to the soaring number of tourists and mountaineers in Nepal damaging the ecology of the Himalayas (Shrestha 1976; Sharma 1989). The heavy influxes of mountaineers and trekkers in Himalayas have increased demand for forest resources in the ecologically fragile and sensitive area (Shrestha 1976).

Long term detail study about park and people by different researchers concluded that Sagarmatha National Park and Buffer Zone is facing many environmental challenges (Bayers 1987; Fisher 1990; Brower 1991; Stevens 1993, Boselli *et al.* 1998, Hamilton 2002, Harmon and Worboys 2004, Salerno *et al.* 2009). Increasing number of tourists in SNP is altering its land cover pattern, trail and overall environment of the park (Bayers 1987; Sherpa 2000, Nepal 2004; Bayers 2005; Bajracharya *et al.* 2009; Bajracharya *et al.* 2010). Natural resources in the Everest region are not free from depletion and degradation. The water resources in the region are degrading due to increased influx of tourism (Caravello *et al.* 2007). Nowadays this trend is increasing.

There lies complexity of the causes and consequences of degradation of water resources in Everest region because of tourism and recently noticed effects of climate change. Tourism in the Everest region has grown rapidly in recent decades and at the same time the water quality has started deteriorating. Meanwhile, the effect of global warming is higher in this fragile ecosystem (Watanabe *et al.* 1994; Chikita 1999; Richardson & Reynolds 2000; Cenderelli & Wohl 2001; Cendrelli & Wohl 2003; Kattelmann 2003; Ives 2005; Liu *et al.* 2006; Bajracharya *et al.* 2007; Bolch *et al.* 2008; Dahal 2008; Bajracharya *et al.* 2010; Budhathoki *et al.* 2010).

Many researchers reported that foreign expeditions that go to the different Himalayan peaks each year leave a great deal of garbage—tins, cans, bottles, plastic bags, and papers—on trails and campsites which make serious problem to quality of environment in high altitude region (Basnet 1993; Bishop and Naumann 1996; Kuniyal 2002; Kuniyal 2005). In addition, they dispose human excreta that contribute to degradation of the environment at high altitude (Tabei 2001).

Shrestha (1976) reported that ecological degradation in Nepal Himalayas has become a great concern in the context of sustained and balanced development of the country. The main problems in this context seem to be the increasing amount of erosion, landslides, pollution and flood hazards.

Baroni *et al.* (1998) analyzed overcrowded camp sites at base camp; careless handlings of waste materials and inadequate attention to the personal hygiene causing sanitation problems, aesthetic deterioration and exacerbation of existing village health problems.

According to Tabei (2001) 51 kg of garbage in general was thrown by each member of expedition team in Mt Everest. In addition they dispose human excreta (faeces and urine) that further degrade the quality of environment at high altitude. Tabei (2001) estimated that 1549 kg of human wastes were produced by 13 climbing parties at the Everest base camp between 1996 –1997 and 2469 kg from seven parties in 1998. Generally the human excreta is carried down to Gorakhshep and buried there. The amount of urine per person per day is 1.5 times more at the high altitude, and comes around 2.16 liter per day. According to Tabei (2001), the amount of urine left on the Khumbu glaciers up till 1999 was 614,520 liter by climbers, and 921,780 liter by Sherpas. These excreta flow down and contaminate rivers. Gokyo lake is visited by

thousands of pilgrims annually and the waste discharge from hotel and Dharmashala (small houses constructed near the holy places for services of the pilgrims) reach to the water bodies enhancing pollution (Karki *et al.* 2005). Bathing and washing in the Gokyo Lake and waste of camping have also added pollution to the lake.

Chalise *et al.* (2003) reported that reliable estimates of low flow of water are extremely important for the Hindu Kush–Himalayan (HKH) region as people in this region are facing growing problems of water during dry periods in terms of both quality and quantity. Furthermore, increasing evidence of decrease in snow cover and retreat of glaciers due to global warming have been reported from various parts of the Hindu Kush–Himalayan (HKH), which has serious implications for low flow in the region.

Bayers (2005) studied the human impacts on alpine ecosystem in the Sagarmatha (Mt. Everest) National Park, Nepal and reported that overharvesting of alpine plants for fuel and lodge buildings, accelerated the erosion. Most of the impacts are linked to the exponential growth of unregulated tourism. There is general impression about the pollution, particularly solid waste pollution in the Khumbu region, and data on solid waste disposals are available. However, research on other aspects of pollution (air, soil, water, etc) are very limited. There is information about the stream water quality of Khumbu region (Reynolds *et al.* 1998) and inorganic and organic micro pollutants (Camusso and Galassi 1998). The environmental pollution problem is now no longer confined to solid waste. Water resources along the trails are being contaminated from improper discharge, human waste and garbage dumping. Sewage and toilet waste can be found piped into nearby streams and rivers (DNPWC 2007).

Lachapelle (1995, 1998) concluded that sanitation issues in Sagarmatha National Park remain a persistent problem. The state of some of the public and trekking lodge toilets within SNP is alarming. Many of the toilets are not maintained, completely full and have effluent leaking into nearby water resources. Furthermore, neither the SNP nor the Sagarmatha Pollution Control Committee (SPCC) has adequate budget, staff or technical training to overcome the waste management problems caused by tourism. Both SNP and SPCC have built public toilets in the Park for tourists, porters, park staff and residents.

Lachapelle (2003) also added some information on the human waste in SNPBZ. Khanal *et al.* (2010) reported that the total amount of waste generated in SNPBZ per day amounts to 4614.74 kg. The per capita waste generation of tourist and local people is 0.123 kg/day and 0.109 kg/day, respectively.

Manfredi *et al.* (2010) found that most of the degradable solid waste generated in the park composed of organic matter, paper and kitchen waste while other non-degradable categories of waste consists of glass, metal, and plastic and these waste are not properly managed. Particularly, burning or disposal in open dumps poses a great hazard to environmental, human, and animal health, as most dump sites are situated close to water courses thereby directly contaminating river water. Pollutants and microbiological contamination in water bodies were found and anthropogenic activities and hazardous practices such as solid waste dump sites, open defecation, and poor conditions of existing septic tanks are suggested as possibly affecting water quality.

Study of the effect of climate change on the snow and the glaciers in Nepal were done by different researchers at different time (Watanabe *et al.* 1994; Chikita 1999; Richardson & Reynolds 2000; Cenderelli & Wohl 2001; Cendrelli & Wohl 2003; Kattelmann 2003; Ives 2005; Liu *et al.* 2006; Bajracharya *et al.* 2007; Bolch *et al.* 2008; Dahal 2008; Bajracharya *et al.* 2010; Budhathoki *et al.* 2010). Most of these studies are focused to assess the expansion of glacial lakes (Watanabe *et al.* 1994; Sakai *et al.* 2000), some are focused to assess the risk posed by the possible outburst (GLOFs) of these lakes (Rana *et al.* 2000; Bajracharya *et al.* 2007; Dahal 2008; Bajracharya *et al.* 2010). Other studies focused to assess the sustainability of the mountain ecosystem due to the effect of climate change (Ives 2005). Bajracharya *et al.* (2007, 2010) also studied the climate change effect on the high land lakes. All researchers came to the conclusion that global warming and changing climatic phenomenon were affecting the glaciers in the high Himalaya.

Boselli *et al.* (2010) concluded that sustainable management of the natural resources and rational tourism planning and development are urgently needed to check further environmental degradation and to meet the growing demands of the local population. Warming in the Himalayas is having great impact on the glacier. There is an

overwhelming evidence of rapid deglaciation in the Himalayas. Glaciers are important sources of water to the rivers of Nepal and India (Shrestha *et al.* 2011).

Limnological work in Nepal

In the last four decades, several studies have been done on the water chemistry of the high land (Löffler 1969, Aizaki *et al.* 1987, Shrestha *et al.* 1997, Tartari *et al.* 1998, Lacoul and Freedman 2005; Caravello *et al.* 2007, Sharma *et al.* 2009, etc). They generated the data on morphometry, bathometry and pollution levels for management and protection of the high altitude wetlands of Nepal. Sharma *et al.* (2005) added some information about water chemistry in the central Himalaya. Karki (2007) made the list of Himalayan Wetlands included in Ramsar sites of Nepal with a short description.

Löffler (1969) researched 24 lakes between 4500 and 5600 m a.s.l in the Mount Everest area (Khumbu Valley), producing the first data on morphometry, chemistry and biology of lake systems. He revealed dominance of calcium among the cations and low phosphorus in the lakes of Mount Everest region.

Aizaki (1985) studied trophic status and water quality of Lake Tilicho in Central Nepal Himalaya. The lake is one of the largest glacier-fed lakes with slightly turbid water color and strong chemical stratification. This study revealed a low concentration of total phosphorus (1– 6 mg/l) and total nitrogen (0.16 to 0.25 mg/l) in water.

Okino and Satoh in 1986 observed that morphology, physics, chemistry and biology of the lakes in high altitude were oligotrophic in limnological terms, meaning very slightly polluted based on the studies carried out on chlorophyll *a* estimation, total nitrogen and dissolved oxygen.

Tartari *et al.* (1993) studied water chemistry of lakes in Nepalese side of Everest. The chemical analyses have indicated the prevalence of calcium and sodium as cations and sulphates as anions. Lacoul and freedman (2005) also examined the relationships of aquatic plants with physical–chemical characteristics among 28 lakes within a steep altitudinal gradient ranging from tropical (77 m) to high alpine (4750 m) in the Nepal Himalaya. Species richness and diversity showed an approximately linear decrease with increasing altitude. A canonical correspondence analysis of the entire altitudinal gradient (CCA-1) suggested that the strongest abiotic influences on the distribution of

aquatic plants were associated with water temperature, substrate quality, altitude, pH, transparency and conductivity. Two more-restricted CCA analyses examined a shorter altitudinal gradient of 70–1500 m. The CCA-2 analysis (all aquatic plants) and CCA-3 (only euhydrophytes) revealed that the most important abiotic influences were associated with temperature, lake surface area, suspended solids, bicarbonate and dissolved phosphorus.

Tartari *et al.* (1998) further surveyed the different lakes of the Khumbu valley for limnological investigation which is close to the Pyramid Laboratory. They generated data for calcium, magnesium, sulphate, and potassium as well as biotic component (phytoplankton, zooplankton and benthos) in the lakes. Many studies towards the snow water chemistry from high altitude Himalayan glacier have reported generally low but variable concentration of $\text{NO}_3\text{-N}$ and SO_4 . The deposition of acidic oxides has started to increase (Mayewski *et al.* 1986, Nijampurkar *et al.* 1993).

Jenkins *et al.* (1995) studied the rivers chemistry (F, Fe, Cl, SO_4 , Si, NO_3 , PO_4 , K and Na) of mid-high mountain streams of Himalayas in Nepal. Bicarbonate was the dominant anion and Ca and Mg were the dominant cations. Trace metal concentrations (Al, Sr, Ba, Mn) were also high in agricultural catchments. Bedrock geology creates the main influence on water chemistry. There is generally a decrease in concentration of all ions with altitude.

Raynold *et al.* (1998) analyzed the hydro-chemistry of the streams in Khumbu region and found Ca and Mg as the major cations and bicarbonate as dominant anion. Trace element (Sr, Ba, Mn) concentrations in the upper khumbu were generally low.

Lacoul and Freedman (2005) added important information on the limnology of water bodies along the tropical to alpine gradient of Nepal. Physical and chemical parameters were studied in 34 lentic water bodies distributed along a steep altitudinal gradient ranging from tropical (77 m) to high alpine (up to 4,980 m) environment in eastern Nepal. Bicarbonate and calcium were dominant among anions and cations. Total suspended solids were relatively high in the studied lakes. Suspended solids had a greater influence on water transparency than did algal biomass in the studied lakes. They concluded that high-altitude water bodies were oligotrophic, while those at low altitude were eutrophic. The productivity of high-altitude lakes appeared to be limited by both available phosphorus and nitrogen level.

Caravello *et al.* (2007) reported that the water quality of rivers in the Khumbu valley has deteriorated microbiologically as well as chemically. Though the trace element concentrations in the upper Khumbu valley were generally low compared to other studies (Reynolds *et al.* 1998), however an increase in micro-pollutants was noticed. Paleolimnological reconstructions reveal proxy data of past climatic changes in high altitude regions of Khumbu Valley (Lami *et al.* 2007). Modern phytoplankton data compared with previous data point an increasing trend in lake productivity.

Sharma *et al.* (2009) studied impacts of global climatic change on biodiversity of high altitude lake Gokyo in Everest region. Increased production of non-degradable solid waste has been noticed as source of soil, air and water pollution. Supply of clean water and safe disposal of waste water have been the major issues faced by the people in SNPBZ. Khanal *et al.* (2010) also revealed that the concentration of lead and iron was high in some sampling point whereas nickel was found less than the National Drinking Water Quality Standard.

Lami *et al.* (2010) also studied the different ecological parameters of the water bodies of Khumbu valley (Himalayas) Nepal. They analyzed different chemical characters like pH, conductivity, alkalinity, sulphate, chloride, calcium, magnesium, sodium, potassium, total P, nitrate, ammonium, total organic, total N, reactive Si to link with increasing temperature.

Sharma *et al.* (2012) analyzed the physico-chemical properties of water in the wetlands (Gokyo) of the SNP. The metals As, Cd, Cu, Fe, K, Mn, Na Pb and Zn were analyzed. The accumulation order of the metals in the lake water of Gokyo wetland was: K>Na>Fe>Zn>Mn>Cd. The concentration of Cd and Na was higher in 2008 where as Zn had higher concentration in 2009, but these metals were below the detection limit during the sampling period. The average concentration of Pb in lake water exceeded the level (0.01 mg/l) given by WHO for safe drinking water for the first two sampling period.

Balestrini *et al.* (2012) found that the nitrogen concentration in the running water of the Sagarmatha National Park fell in the lower range of the values reported for comparable environment in Europe. Ammonia level was higher in the rain compared to the surface water. A wet deposition load of nitrogen was remarkably lower than those observed in the high elevation area in the Europe and North America.

CHAPTER 3: STUDY AREA

Nepal is a land-locked country in the central part of the Himalayas, having three physiographical regions: high mountains above 3000m (35% of the total area), middle mountains between 1000-3000m (42% of the total area) and lower altitude churia/terai range below 1000m (23% of the total area). Each region has distinct altitude and climate characteristics, varying from the alpine to sub-tropical condition. Altitude ranges from just 60m in the southern plains to 8,848 m in north, forming a unique geographic nature. A total of 118 ecosystems have been identified with 75 vegetation types and 35 forest types. Both floral and faunal diversity in Nepal are interesting and important (HMG/MFSC, 2002).

The Sagarmatha National Park (SNP) located in the District of Solukhumbu, Nepal, is privileged with the Mount Everest, the highest peak (8,848m) of the world and many other peaks over 7000 m. The Sagarmatha National Park (SNP) was established in 1976 and declared as a World Natural Heritage Site in 1979. The buffer zone was declared in 2002. It is a popular eco-touristic destination for international community.

3.1 Topography

The Sagarmatha National Park (SNP) located in the southern slope of Sagarmatha (Mt. Everest) covers 1148 sq km area. The buffer zone area declared around the Sagarmatha National Park covers 287.04 sq km. This park lies about 140 km east of Kathmandu. It ranges between $27^{\circ} 06'45''$ and $27^{\circ} 30'19''$ N latitude to $86^{\circ} 30'53''$ to $86^{\circ} 99'08''$ E longitude (Figs. 1, 2). The park is characterized by rugged topography, and altitude of park ranges from 2845 m at Jorsalle to 8848 m at the top of the Mt. Everest (the world's highest mountain peak). It comprises three Village Development Committees (VDCs) namely Namche, Khumjung and Chaurikharka. The mountains in Sagarmatha National Park are geologically young and broken up by deep gorges and glacial valleys.

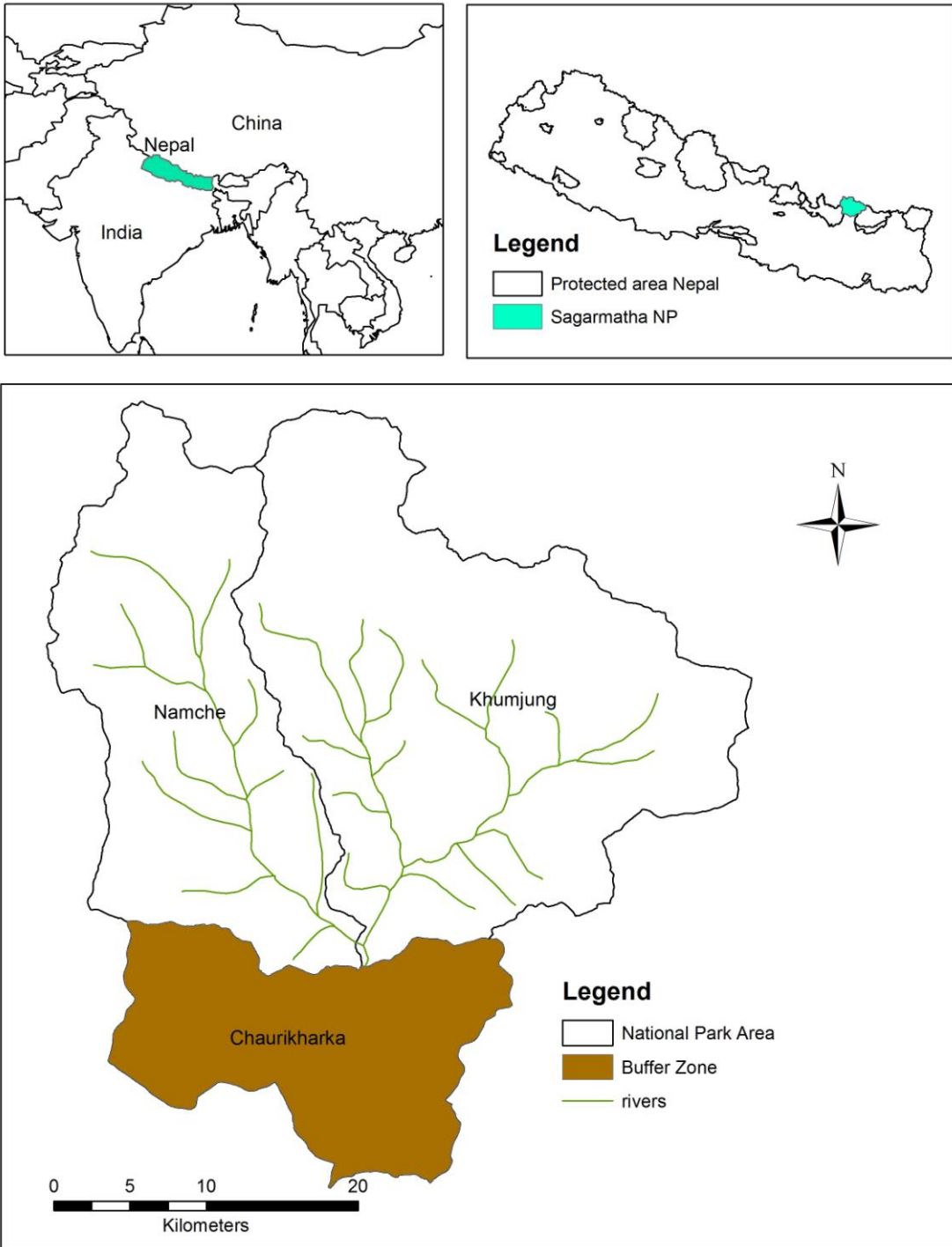


Figure 1: The Sagarmatha National Park and its location in Nepal.

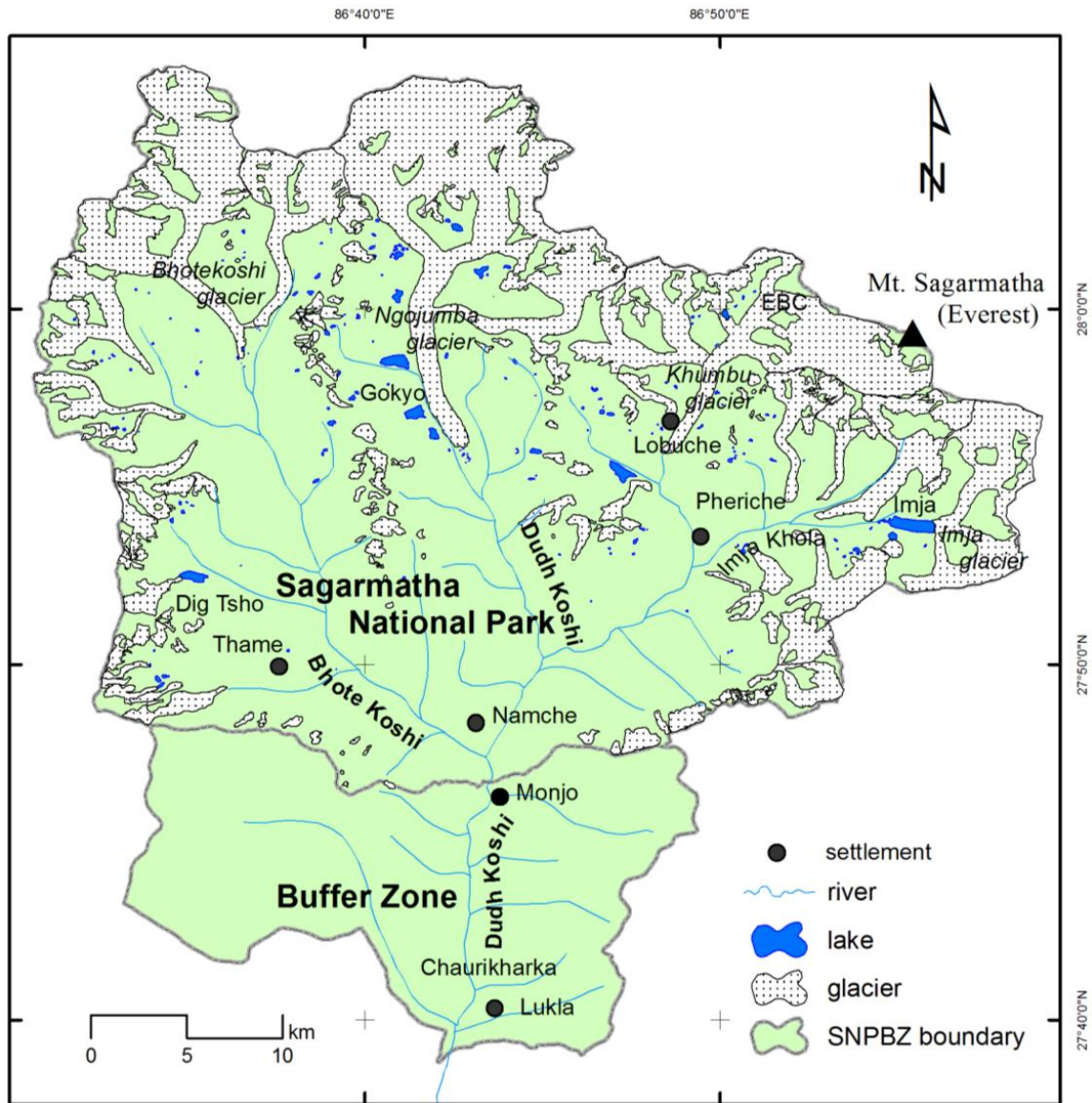


Figure 2: Major settlements and lakes in the study area (SNPBZ).

3.2 Geomorphology

Sagarmatha National Park is characterized by geologically young mountains and glaciers. It consists of varied altitudinal features with peaks higher than 8000m; Everest (8848m), Lhotse (8501m) and Cho Oyu (8188m). These mountain peaks have been uplifted as a result of the collision of the Eurasian and Indian continental plates about 120 million years ago (Molnar 1989).

The deeply incised valleys cut through sedimentary rocks and underlying granites to drain southwards into Dudh Koshi and its tributaries, which form part of Ganga river system. The upper catchments of these rivers are fed by glaciers at the head of four main valleys, Chhukhung, Khumbu, Gokyo and Nangpa La. Lake occur in the upper

reaches, notably in the Gokyo Valley, where they are impounded by the lateral moraine of the Ngozumpa Glacier, extended as long as 20 km and is the longest glacier in the Park.

Soils are mostly of glacial, fluvio-glacial and fluvial in origin reflected by the elevation and climatic factors. Inceptisol is found in the belt from 2000m to 3000m, spodosol in coniferous and birch-rhododendron forests at around 3000m elevation. Likewise, entisol with limited profile of development are seen at above 4500m (Sherpa & Bajracharya 2009).

3.3 Land use

Most of the park (65.6%) comprises barren land above 5,000 m, glacier (16.24%), grassland (6.88%), shrubs or bush (5.9%), ponds (0.59%), settlement and agriculture (0.79%), nearly 3.31% is forested and water bodies (rivers) 0.01% (WWF, 2003).

3.4 Population

Total population of Solukhumbu district is 105886 (51200 male and 54686 female) with total 23785 households. A total of 1999 households with 7161 people live in three VDCs viz. Chaurikharka, Namche and Khumjung where park and buffer zone lie. Main religions in this area practiced are Hindu, Buddhism, Islam, Kirat, Khristian and Prakriti (CBS, 2011). Among the total households (23785) in Solukhumbu, 5842 households did not have toilets and 12564 households have ordinary toilets (simple pit). Similarly 415 households used river/ stream water for drinking while 682 households used uncovered well (Kuwa) (CBS, 2011).

3.5 Climate

The climate in Sagarmatha region has extreme contrast between the humid southern slope influenced by the Indian summer monsoon and arid valleys of the northern slope under the desiccation affects of the Himalaya (Jha, 2010).

About 80% of the precipitation falls in the monsoon season from June to September. Lukla and Namche Bazaar receive 950mm and 860mm precipitation per year and at

higher elevation precipitation decreases. An average minimum temperature occurs in January whereas maximum during August (-7.7 to 16.2°c).

3.6 Hydrology

The Sagarmatha region is drained north to south by three major rivers namely Dudhkosi, Bhotekosi and Imja Khola. Imja Khola originates in Khumbu glacier and Dudhkosi in Ngozumpa glacier. Bhotekosi originates in Tibet and it meets Dudhkosi at Larchadobhan below the Namche Bazar. Several tributaries feed these major river systems. The major lakes in the SNP are Imja and Gokyo.

Gokyo Lake series consists of five different lakes that are glacial in origin. First, second and third of series are hydrologically connected. Fourth lake does not have direct connection, however is thought to have underground connection with the low lying lakes. Fifth lake does not have direct connection with any of the lakes in the Gokyo Lakes series. These lakes are thought to be formed with the impoundment by the lateral moraine of the Ngozumpa glacier that extends as long as 20 km and is the longest glacier in the Park.

Table 1. Morphometric parameters of lakes in Gokyo wetland.

Parameters	1 st Gokyo lake	2 nd Gokyo lake	3 rd Gokyo lake	4 th Gokyo lake	5 th Gokyo lake
Altitude (m)	4710	4728	4734	4834	4950
Catchment area (sq.km)	-	3.13	11.19	14.38	7.6
Area (ha)	14	17	43	65	29
Max. depth (m)	Ca.1m	33.3	43	64.4	30
Max length (m)	Ca.250	740	1000	1290	700
Max. width (m)	6a.60	345	855	670	400

Imja Lake is a glacial lake created after melt water began collecting at the foot of the Imja glacier in the 1960s. A 2009 study described this lake of melt water as one of the fastest-growing in the Himalaya. Held in place by a terminal moraine, Imja Tsho threatens downstream communities with the potential for a glacial outburst flood.

3.7 Tourism

Tourism in Nepal has been a great source of foreign exchange. Sagarmatha National Park attracts a large number of international tourists due to panoramic view

of snow cap, clean environment, beautiful glacier, glacier lakes, unique flora and fauna, scenic beauty of Himalayan peak, wonderful Sherpa culture, festivals, religion, etc. There are two major seasons of tourist inflow in the park: spring and autumn seasons, as a result the park is overcrowded during these seasons and creating a pressure on resources.

Since the opening of Khumbu region to tourists and the first ascent of Everest in 1953, around half a million tourists (national and international) visited the SNP. In 1964, the number of tourists visited the Khumbu was 20 which rose to peak number 26788 in 1999 (Fig. 3). Number of tourists in the Khumbu region slid down after 1999 because of insurgency in Nepal, however an accelerated trend was seen from 2007 (as a result of peace in the country) and reached to 26511 in 2007, 31201 in 2008 and 29036, in 2009, 32084 in 2010 and 36518 in 2012. In addition to the international tourists, a large number of people as porter and guide accompany tourists and national researchers.

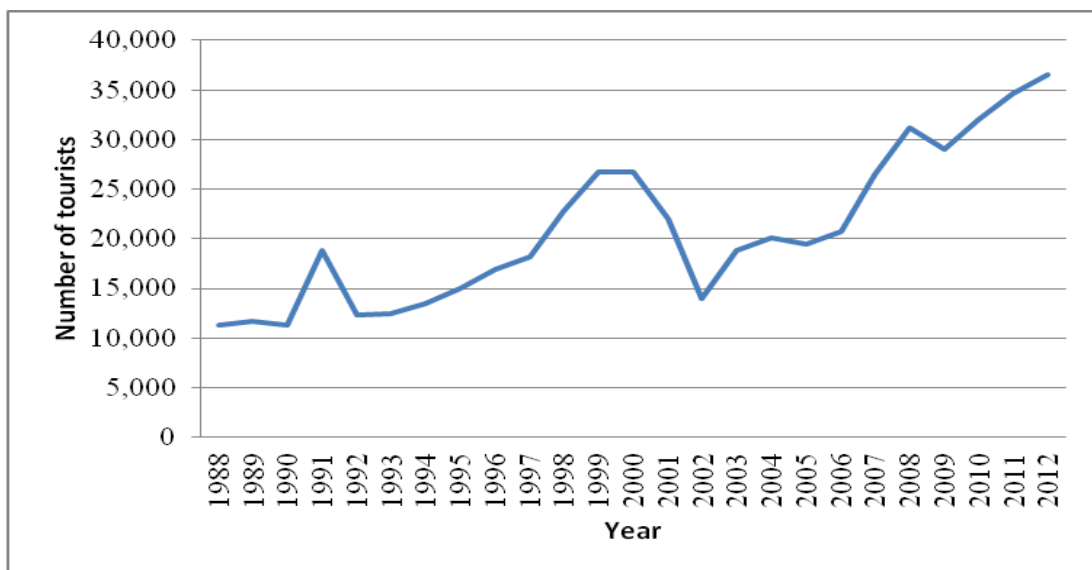


Figure 3: Number of tourists visited in Sagarmatha National Park in 1988 to 2012 (Source NTB 2013)

3.8 Biodiversity

There are eight type of vegetation in the park (BPP, 1995). These vegetation types are:

- Upper alpine meadow
- Dry alpine scrub

- Moist alpine scrub
- Birch Rhododendron forest
- Fir forest
- Upper temperate blue pine forest
- Temperate mountain oak forest
- Lower temperate oak forest

Nearly 1,074 species of plants have been recorded from the park and 160 species of the Vascular plants, 6 gymnosperms, 109 dicots and 45 monocots have been recorded from the park (Bhuju *et al.* 2007). Eleven (11) endemic species of the flowering plants have been recorded from the park (MoFSC, 2002). Twenty six (26) species of mammals, 162 species of birds and 13 species reptiles and amphibian have been recorded from park (DNPWC, 2003). Out of these fauna, 6 species of mammals and 2 species of birds fall under the protected category under NPWC Act 1973. Similarly, 13 species of mammals found in SNP are listed in CITES.



a) Panoramic scene of Gokyo lake series in SNP.



b) Gokyo 3rd Lake in SNP.

Plate 1: Study area.



a) Imja Lake at the foot of the Imja glacier.



b) Gokyo 1st Lake.

Plate 2: Study area

CHAPTER 4: MATERIALS AND METHODS

Eight visits were made to Sagarmatha National Park for the field work. Out of these eight visits, the first visit was reconnaissance visit to allocate the sampling point and develop sampling strategy. Six visits were made for data collection. Out of these four visits water samples were collected in three different visits and social survey was done in the remaining visits. The sampling sites were mostly selected on trekking routes from Lukla to Everest Base camp and to Gokyo and Imja valley (Fig. 4).

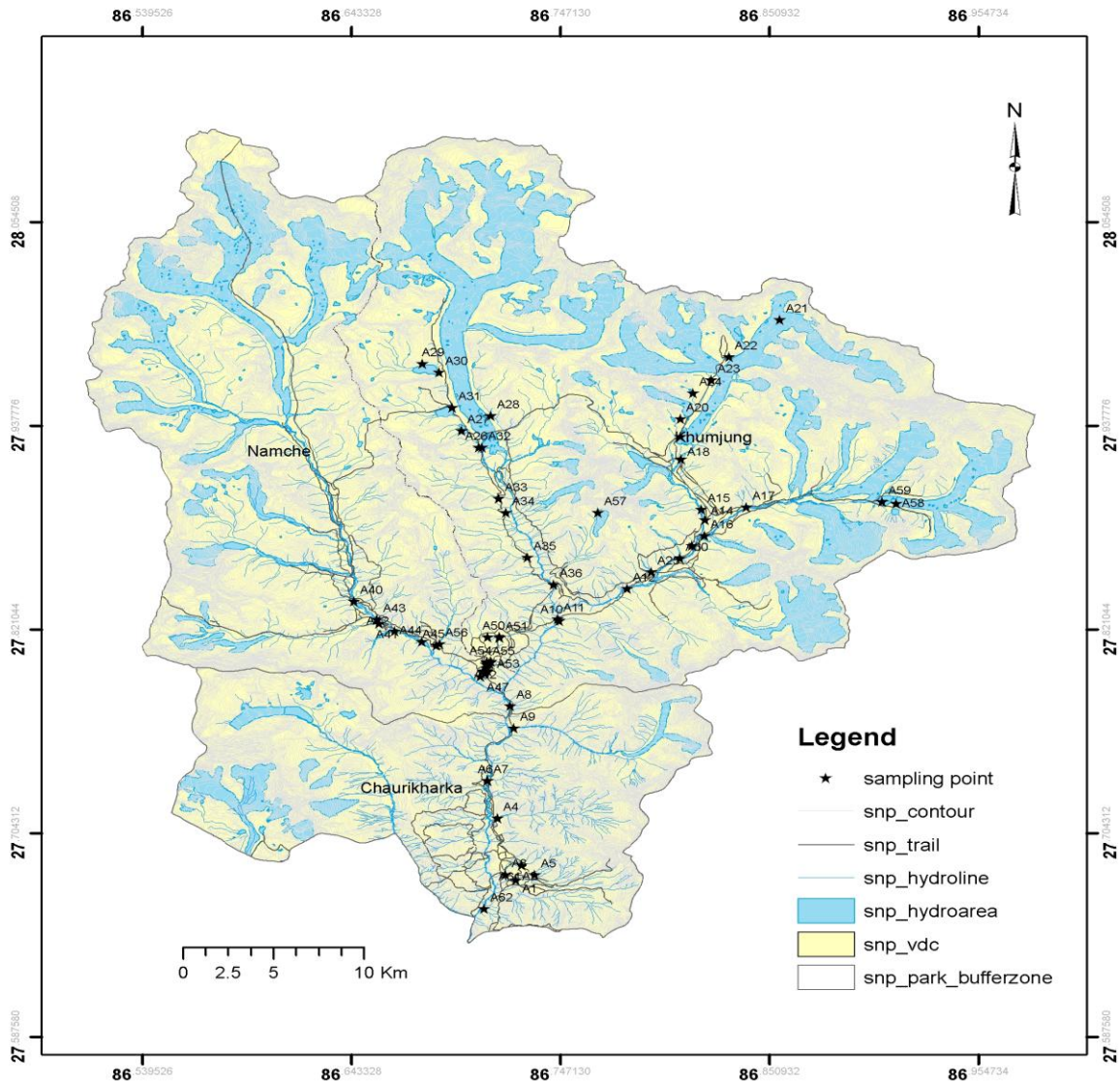


Figure 4: Water sampling sites in the SNPBZ for physical and chemical study of water.

The study was conducted from 2007 to 2011. Each year the study was conducted during the tourist season. Six visits to SNPBZ were made in Oct. 2007 **May 2008**, **October 2008**, **May 2009**, **October 2010** and **October 2011**. The sampling sites were objectively chosen so as to cover the major areas assumed to be affected due to

anthropogenic activities which covered the points along the trekking routes from Lukla to Everest Base Camp, Gokyo, Imja Lake and Thame. The criteria of selection of sampling points were based on outflow region of lakes, vicinity of tourist trail located on the banks of water bodies and sources of major river system.

Total 186 water samples from thirty nine locations were collected and analyzed in three consecutive years 2008, 2009 and 2010 (15th May-4th June 2008, 28 Oct.-17 Nov. 2008, 3-26 June, 2009 and 16- 31 May 2010).

Table 2: Description of the sampling sites of lakes for water study in SNPBZ.

Sample code	Site	Lat (°)	Long (°)	Alt. (m)
A22	Gorekshep lake	27.98278	86.83073	5145
A23	Between Pyramid and Gorekshep	-	-	5100
A24	Pyramid lake	27.96185	86.81293	5053
A26	1 st lake of Gokyo (outlet)	27.93088	86.70663	4661
A27	2 nd lake of Gokyo (outlet)	27.94033	86.69785	4716
A28	3 rd lake of Gokyo outlet	27.94887	86.7125	4720
A29	4 th lake Gokyo (mid of lake)	27.971933	86.6866	4850
A30	4 th lake Gokyo (outlet)	27.97383	86.6868	4860
A31	3 rd lake of Gokyo (inlet)	27.95375	86.69333	4740
A58	Imja lake near outlet	27.89873	86.91375	5011
A59	Imja lake outlet	27.89967	86.90692	5007

(- = not recorded)

Table 3: Description of the sampling sites of rivers for water study in SNPBZ.

Sample code	Site	Lat (°)	Long (°)	Alt. (m)
A7	Dudh Koshi at Phakding	27.73983	86.71077	2587
A8	Dudh koshi above Jorsalle	27.7825	86.72218	2777
A10	Dudh koshi at Punki Tenga	27.83152	86.74657	3298
A12	Dudh koshi at Pangboche and Deboche	27.84985	86.78017	3760
A13	Dudhkoshi between Pheriche and Pangboche	27.88681	86.81836	4170
A15	Lobuche khola from side of Pheriche	27.93848	86.80726	4290
A16	Imja khola below Denboche village	27.88023	86.81877	4165
A17	Imja just upper Denboche village	27.89652	86.83938	4383
A19	Lobuche entry point of Chola pass	27.93705	86.80658	4843
A20	Lobuche khola near Lobuche	27.94707	86.80658	4919
A21	Snow melt from Everest Base Camp	28.00387	86.85597	5331
A32	Outlet of Ngozumpa glacier	27.93088	86.70822	4656
A36	Dudhkoshi at Phorse Tenga	27.85207	86.74365	3604
A40	Bhotekoshi above Thame	27.84258	86.6445	3805
A43	Bhotekoshi between Thamo and Thame	-	-	3700
A44	Bhotekoshi near Thamo	27.81933	86.67817	3410
A62	Dudh koshi below Surke	27.6664	86.70925	1941

(- = not recorded)

Table 4: Description of the sampling sites of springs for water study in SNPBZ.

Sample code	Name of Site	Lat (°)	Long (°)	Alt. (m)
A1	Ghatte khola	27.68272	86.72495	2850
A2	Hadi khola	27.68262	86.72503	2593
A3	Muse khola	27.68577	86.71978	2767
A4	Thado koshi	27.7183	86.71577	3289
A5	Ghatta khola	27.68585	86.73437	4279
A6	Thado khola at Phakding	27.73988	86.71093	4610
A9	Monju khola	27.76977	86.72398	4020
A11	Phunki Tenga spring	27.83253	86.74562	3929
A14	Pheriche spring	27.8893	86.8188	4325
A18	Lobuche spring (lower)	27.92405	86.8069	4015
A25	Pangboche spring	27.85933	86.79223	3353
A33	Machhermo khola	27.90133	86.7165	3440
A34	Luza khola	27.8935	86.72013	3414
A35	Dole river	27.86775	86.73077	3708
A37	Namche spring	27.80268	86.70852	3692
A38	Namche spring (mid)	27.80418	86.71028	3405
A39	Origin of Namche spring	27.80415	86.71032	3389
A41	Thame khola (spring)	27.82995	86.65692	3112
A42	Thame khola (KBC)	27.82548	86.66473	3440
A45	Theso khola	27.81728	86.68557	2661
A46	Mislung (Tap)	27.80248	86.7109	4977
A47	Lobuche spring (upper)	27.79935	86.7074	4110
A48	Mislung spring	27.80201	86.71095	2860
A49	Tok-tok khola	27.822	86.71095	2850
A57	Amphulapchacho	27.8933	86.76578	2593
A60	Somera	27.86728	86.80635	2767
A61	Lukla Tamang spring	27.69125	86.72777	3289

4.1 Physico-chemical analysis

Parameters like pH, temperature, total dissolved solids (TDS) and conductivity were measured on the spot with the help of water analyzer kit (Deluxe Water and Soil Analysis Kit, Model 191, India).

Other parameters were analyzed to determine the quality of water: total nitrogen, total phosphorous, heavy metals Lead (Pb) and Manganese (Mn), and metals Sodium (Na), Copper (Cu), Zinc (Zn) and Iron (Fe).

4.1.1 Total Nitrogen and Total Phosphorous

Water samples were collected from the water bodies in polythene bottle of capacity 125 ml. The samples were brought to Kathmandu and analyzed in Ecology lab, Central Department of Botany, Tribhuvan University, Kathmandu. Nitrogen and phosphorus contents in water samples were measured by colorimetric method following Trivedy and Goel (1986).

Four reagents were prepared for estimating nitrogen: i) 25 g pure phenol + 235 ml conc. sulphuric acid, ii) 2.2 g of silver sulphate in 500 ml of water, iii) liquid ammonia (30%), and iv) standard nitrate solution for curve.

Fifty ml sample was taken and added with 50ml silver sulphate solution; this solution was slightly heated and filtered. The sample was evaporated to dryness, cooled and added 2 ml of phenol disulphonic acid and diluted to 50 ml. Six ml of liquid ammonia was added to this solution which turned into yellow color solution. The quantity of nitrate nitrogen was calculated from standard curve after taking the reading of absorbance at 410nm on the spectrophotometer.

Following reagents were prepared for analysis of the phosphorous: i) Ammonia molybdate solution (mixing a & b), a) 12.5 g ammonium molybdate + 87.5 ml distilled water, b) 140 ml of conc. sulphuric acid + 200 ml of distilled water, ii) stannous chloride solution (1.25 g of stannous chloride in 50 ml of glycerol), and iii) standard phosphate solution (for standard curve).

Fifty milliliter filtrate sample was taken and 2 ml of reagent, ammonium molybdate solution was added to it, 5 drops of stannous chloride (reagent ii) was also added to ammonium molybdate solution. A blue color appeared. The reading of absorption was taken on spectrophotometer at 690 nm. Finally the quantity of phosphorous was obtained by making the standard curve of reagent iii (standard phosphate solution).

4.1.2 Metal analysis

Water samples were collected from the water bodies in acid rinsed polythene bottle of capacity 125 ml. Three drops of concentrated nitric acid were used to adjust the pH of the samples below 2 (acidic medium) to preserve it. The samples were brought to Kathmandu and analyzed at Water Engineering Laboratory of Kathmandu and Aquatic Ecology Laboratory, Kathmandu University, Dhulikhel.

Water samples were analyzed for metals such as Sodium (Na), Lead (Pb), Manganese (Mn), Copper (Cu), Zinc (Zn) and Iron (Fe) through Atomic Absorption Spectrophotometer. For analysis of these metals, 200 ml of acidified samples were taken in a beaker and one ml of concentrated HNO₃ was added to it. Samples were heated at about 100°C until it was reduced to the volume 15 ml. Samples were transferred into 25 ml volumetric flask and the double distilled water was added till it became 25 ml. Reading was taken on Atomic Absorption Spectrophotometer (AAS). All the analyses were carried out adopting standard methods of analysis formulated by APHA (2005). Magnesium (Mg) was analyzed by volumetric method. For this, 50 ml of the water sample was taken and added with 2 ml of NaOH solution, mixed with 2-3 drops of indicator. Titration was done against Ethylene diamine tetraacetic acid (EDTA) solution until the color changed. By calculating the volume used in titration, the amount of Mg (mg/l) was calculated by following APHA (2005).

4.1.3 Nutrient analysis of organic fertilizer and Litter

Nitrogen, phosphorus and potassium were analyzed in samples of organic fertilizer and litter. Total nitrogen was measured by Kjeldhal method, phosphorus by Stannus chloride method and potassium by flame photometer method (Jackson 1967).

Total Nitrogen (Kjeldahl Method)

Total nitrogen content of the samples was determined by modified micro Kjeldahl method (Gupta 2000). One gram air dried fine sample was taken in a dry Kjeldahl digestion flask (300 ml) and 3.5 g potassium sulphate and 0.4 g copper sulphate (i.e. catalyst) were added to the mixture. Six milliliter concentrated sulphuric acid was added with gentle shaking. The flask was placed on the heating mantle for digestion. Temperature was raised after 30 minutes of gentle heating. Near the end of digestion process the color changed from black to brownish and finally to greenish. Then the flask was removed immediately from the mantle and allowed to cool down. To the sample digest, 50 ml distilled water was added and the mixture was shaken. A blank without litter as well as fertilizer sample was run for each 20 samples of soil.

The diluted digest was transferred to micro Kjeldahl distillation flask. A beaker (50 ml) with 10 ml boric acid indicator was placed below the nozzle of the condenser in such a way that the end of the nozzle dipped into the indicator solution. After the digest become warm, 30 ml 40% sodium hydroxide was added. The distillate began to condense and the colour of boric acid indicator changed from pink to green. The distillation was continued until the volume of distillate in beaker reached to about 40

ml. Titration: The distillate was titrated with hydrochloric acid (0.01 N). The volume of acid consumed was recorded. The volume of acid consumed by both blank and samples were noted and the total nitrogen content (N%) was calculated by using following formula.

Calculation was done as,

$$N (\%) = [(a-b) \times N \text{ of HCl} \times 1.4 \times V] / (v \times s)$$

Where,

a = Volume (ml) of HCl used with sample

b = Volume (ml) of HCl used with blank

V = Volume (ml) of total digest

v = ml digest distilled

s = wt of sample taken

Phosphorus

Inorganic phosphorus was measured using the method described by Gupta (2000). One gram of sample was taken in 500 ml conical flask and 200 ml of 0.002 N H_2SO_4 was added. The suspension was shaken at least half an hour and was filtered to get a clear solution. Fifty milliliter of the filtered solution was taken in a clean conical flask and 2 ml of Ammonium Molybdate followed by 5 drops of Stannous Chloride solution was added. The reading was taken in spectrophotometer at 690 nm using distilled water as blank with the same amount of chemicals. Then the concentration was found out with the help of standard curve.

Potassium

Fifty gram of air dried sample was taken in 500 ml beaker and added about 100 ml of 40% alcohol. It was shaken well and kept for 15 minutes. The suspension was filtered through Whatmann filter paper no. 50 using Buchner funnel and vacuum pump. The sample was washed 4-5 times with 50 ml of 40% alcohol. The final washing was performed with 50 ml of absolute alcohol to dry the soil. The filter paper was removed and scraped the sample in 250 ml beaker. The Buchner funnel and filter paper was washed with 100 ml ammonium acetate solution for removing any adhered portion of the sample. The sample extract was prepared by leaching with 1N ammonium acetate solution and the suspension was filtered and finally filtered the sample, with additional ammonium acetate through Whatman filter paper No. 42 using Buchner funnel and vacuum pump. The sample was leached 4-5 times with more ammonium acetate and the final volume of the filtrate was made up to 500 ml in a volumetric flask. The concentration of K was found out by photometric method.

$$K (\%) = \frac{\text{g K/L of sample extract} \times V}{10000 \times S}$$

$$K (\text{mg}/100 \text{mg}) = \frac{\text{g K/L of sample extract} \times V}{10 \times S}$$

$$K (\text{meq}/100 \text{mg}) = \frac{\text{g K/L of sample extract} \times V}{10 \times S \times 39}$$

Where, V = total volume of sample extract prepared (150 ml)

S = Weight of sample (50 g) taken

4.2 Biological Analysis

4.2.1 Bacteriological analysis

Water samples were collected from the water bodies in polythene bottle of capacity 125 ml. The samples were preserved below 4°C. The samples were brought to Kathmandu and analyzed in Ecology lab of Central Department of Botany, T.U, Kirtipur where as in the lab of Khunde hospital.

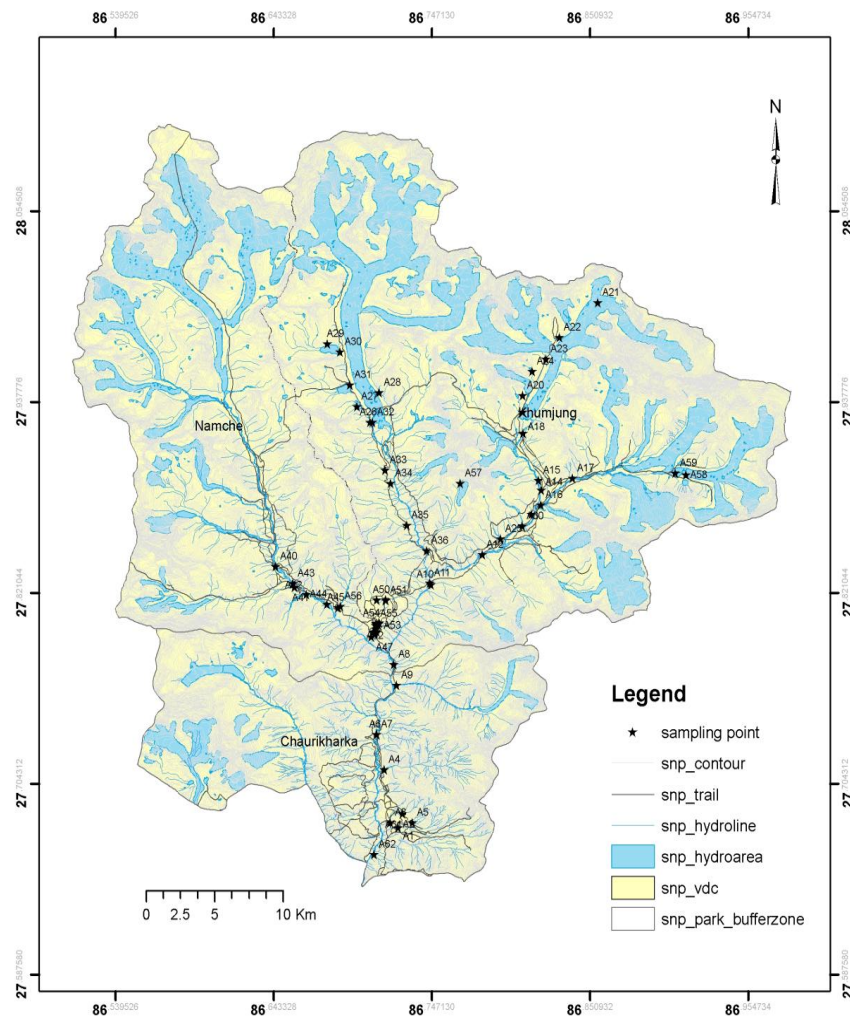


Figure 5: Sampling points for bacterial presence in water bodies in SNPBZ.

Bacteriological analysis was done in a temporary lab established by Ev-K2-CNR at Sherpaland Hotel in Namche, and at Central Department of Botany (Tribhuvan University, Kathmandu). Total coli forms and *E. coli* were determined by following APHA (2005). It was done by most probable number (MPN) method following APHA (2005).

Procedure of the MPN technique: In this method, media Macconkey broth was prepared with inverted Durhams tube and media was sterilized. Triplicate of the test tubes containing three sets were taken, one with 10ml of double strength Macconkey broth, and other two containing 10 ml of single strength Macconkey broth along with Durhams tube were taken. Test tubes were labeled and 10 ml water sample was transferred to each double strength broth tube, one ml sample was transferred using the sterile pipette to each tube of 3 sets (one set of single strength broth tube, and 0.1 ml water was transferred to 3 tubes of remaining last set of single strength broth tube) and then the tubes were incubated for 24 h at 37°C. After incubation gas production and the color change was observed. Number of the positive results from the sets was recorded, and was compared with standard chart to give presumptive *coliform* count per 100 ml water sample with the help of the MPN technique the enumeration of bacterial analysis was done.

MPN test required 3 consecutive steps: Presumptive test, confirmed test and completed test (APHA, 2005) (Fig. 6).

Presumptive test: It is used to detect and estimate the coli form population in water samples. For the estimation of coliform in the water sample, lactose containing broth medium was used. Commonly used medium was Macconkey broth that contains the indicator bromo-cresol purple. An inverted Durham tube was placed in each tube of the medium. Bacteria capable of growth and the production of gas in Macconkey broth, indicated by yellow coloration and collection of gas in Durhams tube, were assumed to be *coliform* bacteria presumptive *coliform*. The number of positive tubes was counted and referred to the standard chart to find most probable number of total *coliform* per 100 ml water sample.

Confirmed test: In this test the tubes from the positive presumptive test were inoculated with selective media like EMB agar and the subculture was inoculated at 44.5°C and 35°C, respectively.

Completed test: The typical colony in pure culture was then sub-cultured in lactose containing broth medium like Macconkey broth, lauryl tryptose broth with inverted Durhams tube and incubated at 37°C and also sub-cultured in tryptose water and incubated at 44.5°C. The presence of *E. coli* was confirmed by the production of gas from lactose and indole from tryptophan.

The most probable number method was the statistical estimation method based on the fact that the greater the number of bacteria in a given sample the more dilution is needed to reduce the density to the point at which bacteria are left to grow in the tube in a dilution series.

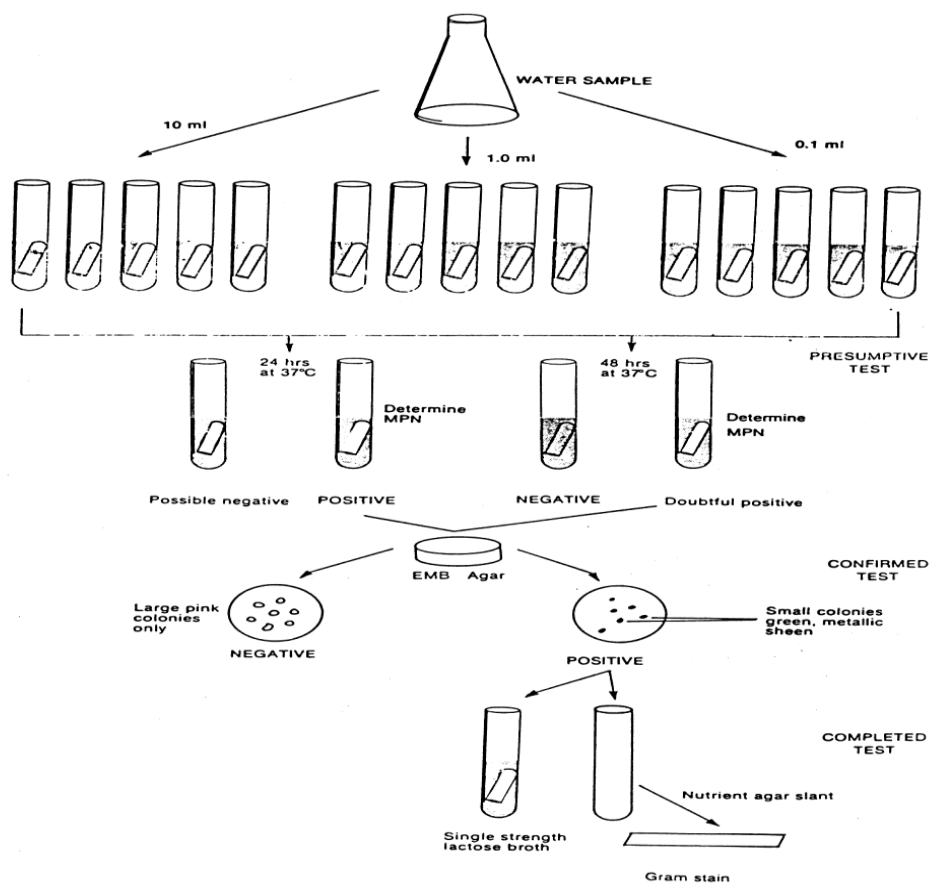


Figure 6: Diagram showing the method of bacterial analysis by MPN method.

4.2.2 Phycological analysis

Samples of algae were collected from different corners of lakes, different sides of rivers as well as moist rocks near water courses between 9:00 to 12:00 am. Samples were preserved in 4% unbuffered formalin and collected into plastic bottle. Identification of species was made using a Leica binocular microscope and consulting relevant monographs. The classification of taxa was done according to Prescott

(1951). Forty five samples (fifteen in each visit) were collected from three visits. Enumeration of algae in water bodies, identification of algae and diatoms in the samples were done.

4.2.3 Aquatic micro-invertebrate analysis

Two methods were used for sampling; a) searching and direct observation: This method was used to find a wide range of aquatic species. The most potential places searched for micro-invertebrates were: stone surface aquatic vegetation and amongst sticks and roots of marginal vegetation; b) Netting method was also used, a mesh bag attached to a triangular metal fitted with handle to collect the species from stream bed as well as uplifting stones by hands. Samples of aquatic invertebrate were collected from different corners of lakes, different sides of rivers as well as moist rocks near water courses between 9:00 to 12:00 am.

After collection the samples of species were transferred to temporary storage containers. All samples were labeled with sample number, date, locality, habitat, types of water bodies, etc. Samples were preserved in 70% ethanol and collected into plastic bottle. All, forty five samples were from three visits and brought to Kathmandu for identification. Identification of species was made by using a Leica binocular microscope and consulting relevant monographs.

4.3 Survey and Analysis of Pollution Sources

This survey was carried out in the Sagarmatha National Park and its buffer Zone (SNPBZ) in 2007 and 2008. Field surveys were done three times (September 2007, April & November 2008) to record the household details, to determine the sources of pollution of water bodies and condition of septic tanks and toilets, as a source of pollution of water bodies. A structural questionnaire was used to interview local people in the study area. At least 20% of the total households were interviewed in each settlement along the trekking route to know the condition of toilets in different houses (large lodge, small lodges, tea shops & residential houses) belonging to diverse economic classes, religions and professional groups. One hundred sixty households of twenty settlements were surveyed for determining total quantity of organic fertilizer produced, composition of organic fertilizer (fecal, dung, litter and domestic waste), impermeability of septic tank of toilet and households without having toilet.

Information collected were: tourist stay and their impacts on environment, production and use of organic wastes, condition of septic tanks, type of septic tank, depth of septic tank, cost for construction of septic tank, use of toilet waste, location of garbage pit, etc.

4.4 Analysis of Fluvial Functioning Index (FFI Index)

Fluvial Functioning Index (FFI) to assess ecological aspects especially for river was published by the Provincial Agency for Environmental Protection of Italy (Siligardi *et al.* 2000) using underlying principle of the EC water framework Directive (European Commission, 2003). In fact, it is a tool approach to present and future management of rivers. FFI method can be a useful tool to assess the most important ecological aspects of the whole course of a river such as riparian areas, morphological characteristics and biological features. It is also useful in order to support an appropriate river basin management. The output of the FFI is a river stretch map indicating the functionality level of the river because this method can be easily implemented into GIS system. For FFI, water bodies were classified into different types on the basis of their threats and disturbances.

The sampling locations were mostly selected along the trekking routes from Lukla to Everest base camp, Gokyo, Imja Lake and Thame. Water bodies (river and spring as well as out and inlet of lake) were classified into different types on the basis of their threats and disturbances. From the conversion table from the FFI, excellent, good, poor and very poor status of the water bodies of different sampling points were calculated, which are the useful tool to assess the most important ecological aspects of the whole course of a river such as riparian areas, morphological characteristics and biological features.

Table 5: Conversion table from FFI value (Siligardi *et al.* 2000).

SN	Level	Score	Judgement
1	1	261-300	Excellent
2	1-2	251-260	Excellent-Good
3	2	201-250	Good
4	2-3	181-200	Good –Fair
5	3	121-182	Fair
6	3-4	101-120	Fair-Poor
7	4	61-100	Poor
8	4-5	51-60	Poor-very Poor
9	5	14-50	Very Poor

For the field, FFI form having 14 parameters / indicators. But before going to field it was important to gather information regarding the major pressure in the catchment, data about the hydrological regime, aerial picture and maps for threats of the area. Parameters 1-4 were related to: bank vegetation, land uses pressure, extent of riparian area, 5-6: physical and morphological structure of bank, 7-11: about the structure of river bed (especially for capacity of the river for self purification), and 12-14 : key biological characters like periphyton, macrophytes, macrobenthos, etc.

For analysis, from the conversion table from of the FFI form, excellent, good, poor and very poor status of the water bodies of different sampling points were calculated (Table 4). The output of the FFI is a river stretch map indicating the functionality level of the river because this method can be easily implemented into GIS system.

4.5 Statistical analysis

4.5.1 One way ANOVA

This tool is used to see the annual variation among the physico-chemical parameters in different years. One way ANOVA was done to analyze if there is significant difference among water parameters (temperature, pH, conductivity, total dissolved solid, nitrate nitrogen and phosphate phosphorous) of different water bodies (lakes, springs and river of different consecutive years (2008, 2009 and 2010) by using the SPSS software.

4.5.2 Multivariate analysis

A Detrended Correspondence Analysis (DCA) was used to identify major gradients of variation in algal species data using CANOCO for environmental parameters and 59 algal species. Unimodal ordination was used because the length of environmental gradient was $> 3-4$ standard deviation, as determined by DCA.

Canonical Correspondence Analysis (CCA) was used to further explore the relationship among the species assemblages and environmental parameters. The forward selection option was used in CCA to determine the minimum set of environmental variable that explained statistically significance proportion of variation in the algal species distribution by using CANOCO.

CHAPTER 5: RESULTS

5.1 Physico-chemical characteristics

5.1.1 Temperature

Among the all water bodies (springs, lakes and rivers), average temperature of water measured during visit 2008- 2010 showed that springs had slightly higher temperature than lakes and rivers (Fig. 7 a).

Lakes

Water temperature varied from 8°C to 12°C with mean temperature 10.15°C. The average temperature was noted highest in Gokyo 3rd Lake (11.33°C), Gokyo 2nd lake (11.50°C) where as minimum temperature was recorded at Imja lake (near outlet) which was 8.43°C (Table 6).

Table 6: Water temperate (°C) recorded in lake Waterbodies in SNPBZ.

SN	Location	2008	2009	2010	Average ± SD
A22	Gorekshep lake	9.5	10.3	7.6	9.13 ± 1.38
A23	Small spring near Gorekshep	11.2	10.0	8.0	9.73 ± 1.61
A24	Pyramid lake	10.0	10.6	8.0	9.53 ± 1.36
A26	1 st lake of Gokyo (outlet)	12.2	10.3	9.4	10.63 ± 1.42
A27	2 nd lake of Gokyo (outlet)	14.2	10.3	10.0	11.50 ± 2.34
A28	3 rd lake of Gokyo outlet	13.5	10.3	10.2	11.33 ± 1.87
A29	4 th lake Gokyo (mid of lake)	14.4	10.0	10.0	11.47 ± 2.54
A30	4 th lake Gokyo (outlet)	14.4	10.2	9.7	11.43 ± 2.58
A31	3 rd lake of Gokyo (inlet)	9.8	10.3	10.1	10.07 ± 0.25
A58	Imja lake (near outlet)	4.5	10.0	10.8	8.43 ± 3.42
A59	Imja lake (outlet)	4.9	10.3	10.2	8.47 ± 3.08
Average		10.7±3.4	10.23±0.17	9.4±1.08	10.15±1.17

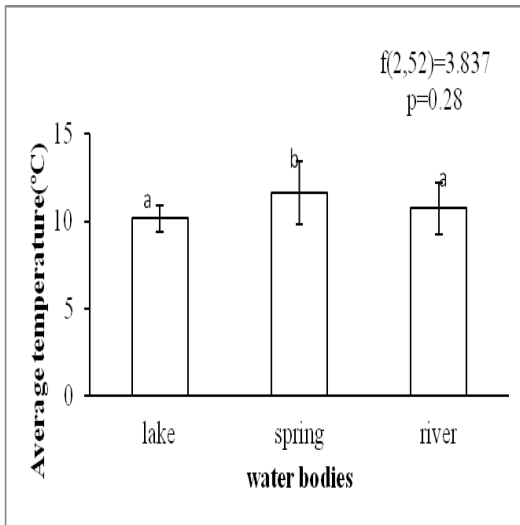


Fig. 7a: Average temperature of different water bodies (lake, spring and river) in Sagarmatha.

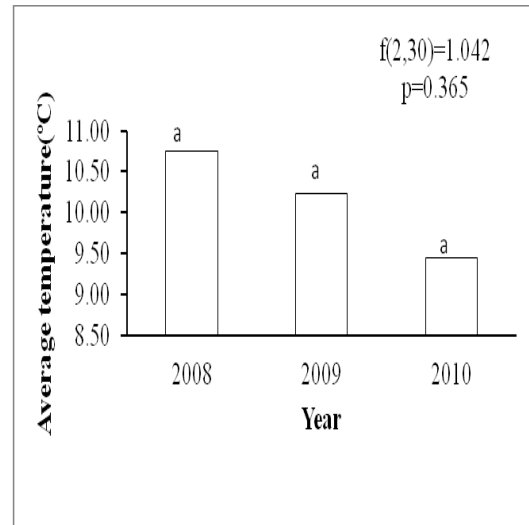


Fig. 7b: Annual mean comparison of lake in 2008, 2009 and 2010 in SNPBZ.

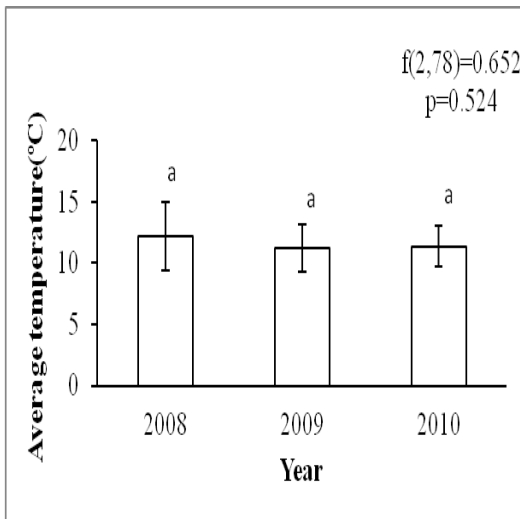


Fig. 7c: Annual mean comparison of spring in 2008, 2009 and 2010 in SNPBZ.

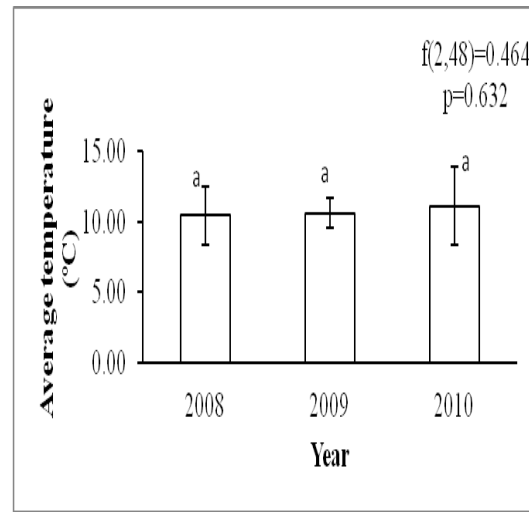


Fig. 7d: Annual mean comparison of river in 2008, 2009 and 2010 in SNPBZ.

Springs

Twenty seven spring water samples were studied and average water temperature was observed from 9°C to 15°C. Highest values were noted in mislung spring (14.67°C) and Thadokhola near Phakding (13.83°C) (Table 7). Somare spring, Phunki Tenga spring, Lobuche showed the lowest temperature among other springs. Mean value of spring temperature showed higher than lake and rivers water (Fig. 7).

Table 7: Water temperature (°C) recorded in spring water in SNPBZ.

SN	Name of Site	2008	2009	2010	Average ± SD
A1	Ghatte khola	14.0	11.5	10.5	12.00 ± 1.80
A2	Hadi khola	13.9	12.0	11.0	12.30 ± 1.47
A3	Muse khola	14.7	12.5	11.0	12.73 ± 1.86
A4	Thado koshi	14.7	11.2	10.5	12.13 ± 2.25
A5	Ghatta khola	14.3	11.3	10.0	11.87 ± 2.20
A6	Thado khola phakding	15.5	13.0	13.0	13.83 ± 1.44
A9	Monju khola	10.5	12.0	12.4	11.63 ± 1.00
A11	Phunki tenga spring	8.6	10.5	10.6	9.90 ± 1.12
A14	Pheriche spring	11.2	10.4	9.5	10.37 ± 0.85
A18	Lobuche spring (Lower)	9.5	10.5	7.1	9.03 ± 1.74
A25	Pangboche spring	11.2	10.5	10.3	10.67 ± 0.47
A33	Machhermo khola	13.0	10.5	9.5	11.00 ± 1.80
A34	Luza khola	12.5	10.5	10.6	11.20 ± 1.12
A35	Dole river	12.0	10.3	10.2	10.83 ± 1.01
A37	Namche spring	9.5	13.0	12.0	11.50 ± 1.80
A38	Spring from mid namche	13.2	12.5	13.0	12.90 ± 0.36
A39	Mouth of namche spring	12.4	12.0	11.5	11.97 ± 0.45
A41	Thame khola (spring)	14.2	11.5	12.0	12.57 ± 1.43
A42	Thame khola (KBC)	12.9	10.0	14.0	12.30 ± 2.06
A45	Theso khola	14.7	8.2	11.0	11.30 ± 3.26
A46	Mislung (Tap)	15.0	14.0	15.0	14.67 ± 0.57
A47	Lobuche spring (Upper)	13.5	12.0	13.2	12.90 ± 0.79
A48	Mislung spring	14.4	14.0	12.5	13.63 ± 1.00
A49	Tok-tok khola	13.5	13.0	13.0	13.17 ± 0.28
A57	Amphulapchacho	4.1	4.1	12.0	6.73 ± 4.56
A60	Somera	8.0	10.5	9.5	9.33 ± 1.25
A61	Lukla Tamang spring	7.7	11.0	11.0	9.90 ± 1.90
Average		12.1±2.7	11.2±1.9	11.3±1.6	11.6±1.8

Rivers

Main rivers are Dudhkoshi, Bhotekoshi, Imja khola and Lobuche. Seventeen samples were measured to analyse the seasonal variation in temperature. All the sites were near to the settlements. The average temperatures were between 8 and 13°C. But, In 2010, some points showed higher than the average readings; temperature of Lobuche river near meeting point of Chola pass 17°C, Bhotekoshi below a bridge between Thamo and Thame 15°C, Dudhkoshi at Phakding 15°C (Table 8).

Table 8: Water temperature (°C) recorded in river water in SNPBZ.

SN	Site	2008	2009	2010	Average± SD
A7	Dudh Koshi at Phakding	9.5	12.5	14.0	12.0 ± 2.29
A8	Dudh koshi above Jorsalle	12.5	12.5	12.0	12.3 ± 0.29
A10	Dudh koshi at Punki Tenga	8.6	11.0	9.2	9.6 ± 1.25
A12	Dudh koshi at Pangboche and Deboche	13.7	11.3	10.0	11.7 ± 1.88
A13	Dudhkoshi between Pheriche and Pangboche	8.5	10.8	9.5	9.6 ± 1.15
A15	Lobuche khola (side of Pheriche)	9.5	10.3	7.2	9.0 ± 1.61
A16	Imja khola below Dengboche village	9.3	10.4	10.0	9.9 ± 0.56
A17	Imja just upper Dengboche village	8.5	10.1	10.0	9.5 ± 0.90
A19	Lobuche near meeting of Chola pass	11.5	10.5	17.0	13.0 ± 3.50
A20	Lobuche khola near Lobuche	10.5	10.3	11.0	10.6 ± 0.36
A21	Snow melt from Everest Base Camp	10.0	10.2	7.8	9.3 ± 1.33
A32	Ngozumpa glacier	6.7	9.5	8.4	8.2 ± 1.41
A36	Dudhkoshi at Phorse Tenga	8.8	10.6	8.7	9.4 ± 1.07
A40	Bhotekoshi above Thame	14.0	9.5	13.0	12.2 ± 2.36
A43	Bhotekoshi below betn Thamo n Thame	11.5	10.5	15.0	12.3 ± 2.36
A44	Bhotekoshi near Thamo	12.5	8.5	14.0	11.7 ± 2.84
A62	Dudh koshi below Surke	12.0	12.0	12.0	12.0 ± 0.00
Average		10.4±2.0	10.6±1.0	11.1±2.7	10.7±1.4

5.1.2 pH

The pH value ranged between 5.2 and 8.7 at different location; however average pH of water was found higher (7.46) in lake than in river (7.17) and springs (6.92). pH trend was found as: Lake>river> spring among the water bodies of the study area (Fig. 8).

Lake: The pH of water was noted between 6.2- 8.7 (Table 9), which indicated well buffer capacity. pH value was noted 8.1 in Gokyo Lake where as 7.0 in Imja khola. But some samples showed high pH; Gokyo lake in 2008 had 8.7 pH. More than 8 value of pH were noted in 2008 in six out of eleven samples (Table 9).

Table 9: Water pH recorded in lake Water in SNPBZ.

SN	Name of Site	2008	2009	2010	Average \pm SD
A22	Gorekshep lake	8.6	7.1	8.3	8.0 \pm 0.79
A23	Small spring near Gorekshep	7.7	7.5	6.5	7.2 \pm 0.64
A24	Pyramid lake	7.0	7.0	7.6	7.2 \pm 0.35
A26	1 st lake of Gokyo (outlet)	8.7	7.8	7.8	8.1 \pm 0.52
A27	2 nd lake of Gokyo (outlet)	8.5	6.7	7.0	7.4 \pm 0.96
A28	3 rd lake of Gokyo outlet	8.3	7.7	7.5	7.8 \pm 0.42
A29	4 th lake Gokyo (mid)	7.7	7.1	7.2	7.3 \pm 0.32
A30	4 th lake Gokyo (outlet)	8.1	6.8	6.9	7.3 \pm 0.72
A31	3 rd lake of Gokyo (inlet)	–	6.7	6.8	7.6 \pm 1.47
A58	Imja lake (near outlet)	7.0	6.7	7.3	7.0 \pm 0.30
A59	Imja lake (outlet)	7.6	6.7	7.4	7.2 \pm 0.47
Average		8.0\pm0.7	7.08\pm0.4	7.3\pm0.5	7.47\pm0.35

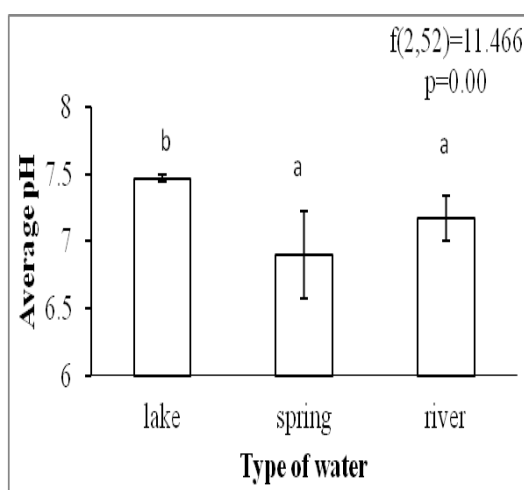


Fig. 8a: Average pH of water in water bodies of SNPBZ.

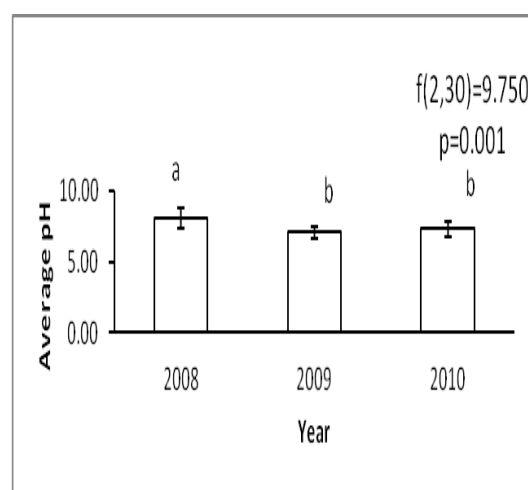


Fig. 8b: Annual mean comparison of pH in lake in 2008, 2009 and 2010.

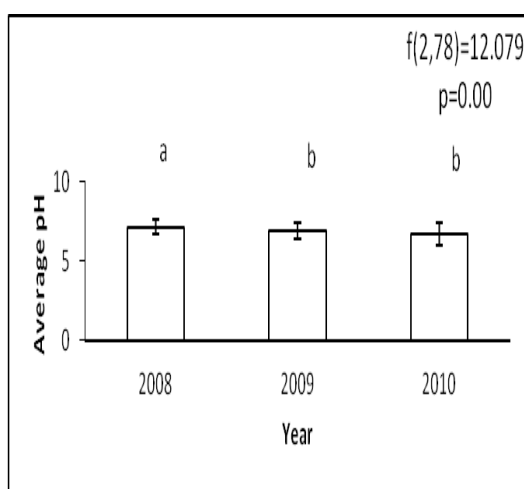


Fig. 8c: Annual mean comparison of pH in spring in 2008, 2009 and 2010.

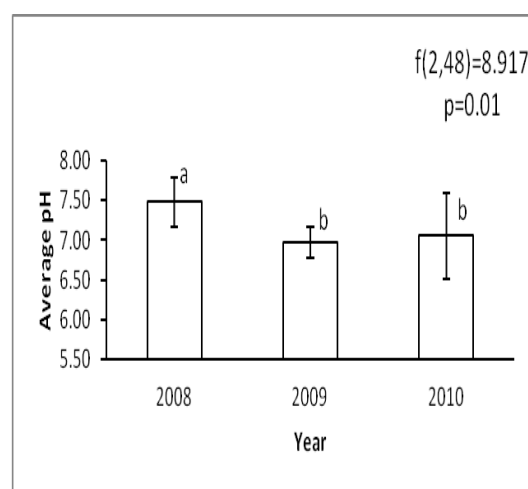


Fig. 8d: Annual mean comparison of pH in river in 2008, 2009 and 2010.

Spring: pH value of spring water bodies were generally noted between 5.2 and 9.0 with an average 6.0-8.0 (Table 9). Some springs exceptionally showed higher pH value; Somare spring had pH 8.5 and 8.2 in 2008 and 2010, respectively. Similarly, 5.7 pH was recorded in 2010 (Table 10). Similarly, Ghattekhol, Hadikhola springs showed significant decrease in pH (2008>2009>2010) (Fig. 8). In all cases, Garbage pits were found close to the spring water resources.

Table 10: Water pH recorded in spring water in SNPBZ.

SN	Name of Site	2008	2009	2010	Average± SD
A1	Ghatte khola	7.4	7.4	7.2	7.3 ± 0.12
A2	Hadi khola	7.4	7.1	6.5	7.0 ± 0.46
A3	Muse khola	7.4	7.1	7.3	7.3 ± 0.15
A4	Thado koshi	7.1	7.2	7.5	7.3 ± 0.21
A5	Ghatta khola	7.3	7.3	6.8	7.1 ± 0.29
A6	Thado khola phakding	6.8	7.2	7.2	7.1 ± 0.23
A9	Monju khola	7.2	7.6	6.5	7.1 ± 0.56
A11	Phunki tenga spring	7.5	7.0	7.4	7.3 ± 0.26
A14	Pheriche spring	7.5	6.7	6.8	7.0 ± 0.44
A18	Lobuche khola (lower)	7.1	6.7	5.1	6.3 ± 1.06
A25	Pangboche spring	7.4	6.6	7.3	7.1 ± 0.44
A33	Machhermo khola	7.1	6.9	6.5	6.8 ± 0.31
A34	Luza khola	7.5	6.6	6.5	6.9 ± 0.55
A35	Dole river	7.6	7.0	5.6	6.7 ± 1.03
A37	Namche spring	6.8	6.6	6.7	6.7 ± 0.10
A38	Namche spring (mid)	7.3	5.2	7.3	6.6 ± 1.21
A39	Mouth of namche spring	7.5	6.5	5.9	6.6 ± 0.81
A41	Thame khola (spring)	7.0	6.7	7.3	7.0 ± 0.31
A42	Thame khola (KBC)	7.2	6.4	6.4	6.7 ± 0.46
A45	Theso khola	7.4	6.5	6.2	6.7 ± 0.62
A46	Mislung (Tap)	7.5	6.6	6.6	6.9 ± 0.52
A47	Lobuche spring (upper)	7.7	7.9	6.2	7.3 ± 0.93
A48	Mislung spring	7.5	7.1	6.4	7.0 ± 0.56
A49	Tok-tok khola	7.0	7.4	5.5	6.6 ± 1.00
A57	Amphulapchacho	7.3	7.3	7.3	7.3 ± 0.00
A60	Somare	8.5	6.6	8.2	7.8 ± 1.02
A61	Lukla Tamang spring	–	6.6	5.7	7.1 ± 1.71
Average		7.4±0.4	6.8±0.5	6.6±0.7	7.4±0.35

River: The pH of water varied from 6.2 to 8.5 indicating neutral to slight basic nature of river water. The values of water pH were within the permissive limit (7-8.5 pH) prescribed for the drinking water. In average, values 7.3 and 7.33 of pH were noted at Lobuche river near Lobuche settlement and Ngozumpa glacier where as 6.8 pH value was noted at Dudhkoshi above Jorsalle (Table 11). But some variation were observed occasionally at different sampling points in different years. Ngozumpa glacier in 2008 had pH 8.5 and Dudhkoshi at Phorse Tenga 6.2 in 2010. The mean pH value of river water was significantly higher in 2008 than in 2009 and 2010 (Fig. 8d).

Table 11: Water pH recorded in river Water.

SN	Name of site	2008	2009	2010	Average \pm SD
A7	Dudh Koshi at Phakding	7.2	7.1	7.1	7.13 \pm 0.06
A8	Dudhkoshi above Jorsalle	7.3	6.8	6.3	6.80 \pm 0.50
A10	Dudhkoshi at Punki tenga	7.3	7.0	6.7	7.00 \pm 0.30
A12	Dudhkoshi at Pangboche and Deboche	7.3	7.2	7.5	7.33 \pm 0.15
A13	Dudhkoshi Pheriche and Pangboche	7.3	7.2	7.0	7.17 \pm 0.15
A15	Lobuche khola (side of Pheriche)	7.7	6.8	8.1	7.53 \pm 0.67
A16	Imja khola below Dingboche village	7.4	6.9	7.0	7.10 \pm 0.26
A17	Imja just above Dingboche village	7.6	6.7	7.2	7.17 \pm 0.45
A19	Lobuche near meeting of Chola pass	7.6	6.8	7.0	7.13 \pm 0.42
A20	Lobuche khola near Lobuche	7.2	6.7	8.0	7.30 \pm 0.66
A21	Snow melt from Everest Base Camp	7.4	6.9	7.5	7.27 \pm 0.32
A32	Ngozumpa glacier	8.5	6.9	6.6	7.33 \pm 1.02
A36	Dudhkoshi at Phorse Tenga	7.7	6.8	6.2	6.90 \pm 0.75
A40	Bhotekoshi above Thame	7.4	7.0	6.4	6.93 \pm 0.50
A43	Bhotekoshi betn Thamo and Thame	7.4	7.3	7.2	7.30 \pm 0.10
A44	Bhotekoshi near Thamo	7.6	7.1	6.9	7.20 \pm 0.36
A62	Dudhkoshi below Surke	7.2	7.2	7.2	7.20 \pm 0.00
Average		7.4\pm0.3	6.9\pm0.1	7.1\pm0.5	7.2\pm0.17

5.1.3 Dissolved Oxygen (DO)

The concentration of dissolved oxygen is directly or indirectly linked with the variation in temperature range, aquatic biodiversity and pollution level. So, DO of water bodies is very essential to understand ecological status of water bodies. Overall, All the water bodies showed average range between 6.5 to 7.6 mg/l but springs had slightly lower average (6.5 mg/l) DO than other water bodies (lakes 7.61 mg/l and rivers 7.4 mg/l) (Fig. 9).

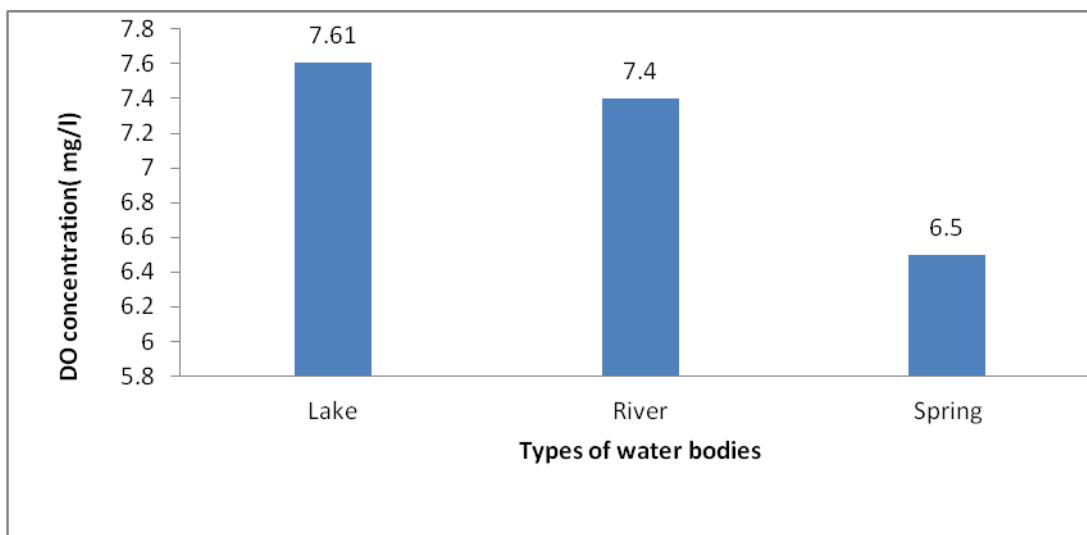


Figure 9: Mean values of dissolved oxygen in water of different water bodies in SNPBZ.

Lakes: Dissolved oxygen of lake water varied from 6.7 mg/l to 8.5 mg/l with mean of 7.61 mg/l. The average DO was noted highest in Gokyo 4th lake (8.5 mg/l), lake between Gorekshep and Pyramid (8.5 mg/l) where as less DO was found at 1st Gokyo lake (6.7 mg/l), 2nd Gokyo lake (7.1 mg/l) and 3rd Gokyo lake (7.0 mg/l) (Table 12).

Table 12: Dissolved Oxygen (DO) in lake water of SNPBZ in 2010.

S. code	Name of Site	DO (mg/l)
A22	Gorekshep lake	7.9
A23	Between Pyramid and Gorekshep lake	8.5
A24	Pyramid lake	8.2
A26	1 st lake of Gokyo (outlet)	6.7
A27	2 nd lake of Gokyo (outlet)	7.1
A28	3 rd lake of Gokyo outlet	7.5
A29	4 th lake Gokyo (mid of lake)	8.2
A30	4 th lake Gokyo (outlet)	8.5
A31	3 rd lake of Gokyo (inlet)	7.0
A58	Imja lake near outlet	7.2
A59	Imja lake outlet	7.5

Spring: The average dissolved oxygen was noted between 5.0 mg/l and 7.8 mg/l. Minimum DO was recorded in Lukla Tamang spring (5.0 mg/l), Followed by Namche spring (5.3 mg/l), Lobuche khola (5.4 mg/l), Somare spring (5.5 mg/l) (Table 12). Similarly, higher value were recorded in Amphulapchacho spring (7.8 mg/l), Theso khola (7.4 mg/l), Thame khola (spring) (7.5 mg/l), origin of Namche spring (7.4 mg/l), Thame khola (below KBC) (7.4 mg/l), etc (Table 13).

Table 13: Dissolved Oxygen (DO) at the Sampling sites of spring water bodies in the SNPBZ.

SN	Name of Site	DO (mg/l)	SN	Name of Site	DO (mg/l)
A1	Ghatte khola	6.5	A37	Namche spring	5.3
A2	Hadi khola	6.0	A38	Namche spring (mid)	5.5
A3	Muse khola	7.2	A39	Mouth of Namche spring	7.4
A4	Thado koshi	6.4	A41	Thame khola (spring)	7.5
A5	Ghatta khola	6.3	A42	Thame khola (KBC)	7.4
A6	Thado khola Phakding	5.6	A45	Theso khola	7.4
A9	Monju khola	7.3	A46	Mislung (Tap)	7.3
A11	Phunki Tenga spring	7.3	A47	Namche spring	5.5
A14	Pheriche spring	6.3	A48	Mislung spring	6.0
A18	Lobuche khola	5.4	A49	Tok-tok khola	6.5
A25	Pangboche spring	7.2	A57	Amphulapchacho	7.8
A33	Machhermo khola	6.4	A60	Somera	5.5
A34	Luza khola	7.0	A61	Lukla Tamang spring	5.0
A35	Dole river	6.9			

Rivers: Seventeen samples from different river section in SNPBZ were studied for the measurement of DO. Value of DO varied from 6.5 mg/l to 9.0 mg/l. Highest values were noted in Glacier spring melt from Everest Base Camp (9.0 mg/l) and Ngozumpa glacier (8.7 mg/l) (Table 14). Lobuche khola from side of Pheriche, Lobuche khola near Lobuche, Dudh koshi below Surke, showed the lowest DO. The DO of river water was lower than lake but higher than springs.

Table 14: Dissolved Oxygen (DO) of the Sampling sites of river water bodies in the SNPBZ.

SN	Name of site	DO (mg/l)
A7	Dudh Koshi at Phakding	7.2
A8	Dudh koshi above Jorsalle	7.3
A10	Dudh koshi at Punki Tenga	7.4
A12	Dudh koshi at Pangboche and Deboche	7.4
A13	Dudhkoshi between Pheriche and Pangboche	7.2
A15	Lobuche khola from side of Pheriche	6.5
A16	Imja khola below Denboche village	7.0
A17	Imja just upper Denboche village	7.5
A19	Lobuche near meeting of Chola pass	7.3
A20	Lobuche khola near Lobuche	6.5
A21	Snow melt from EBC	9.0
A32	Ngozumpa glacier	8.7
A36	Dudhkoshi at Phorse Tenga	8.4
A40	Bhotekoshi above Thame	7.9
A43	Bhotekoshi between Thamo and Thame	7.4
A44	Bhotekoshi near Thamo	7.3
A62	Dudh koshi below Surke	6.5

5.1.4 Total Dissolved Solids

Almost all water bodies in SNPBZ had very little dissolved solids. The mean value of lake (0.016 mg/l) was recorded slightly higher than springs (0.013 mg/l) and rivers (0.015 mg/l) (Fig. 10).

Lake: Total dissolved solids (TDS) was generally found between 0.01 and 0.03 mg/l. Generally, lake water had little higher content than rivers and springs. In the year 2008 (May), TDS of lake water ranged between 0.01 and 0.02 mg/l. In the next year, the value was similar (0.00 to 0.02), where as in 2010, Goreskshep lake near to Gorekshep settlement (5100m) altitude showed 0.06 mg/l which was the highest value among all sampled measured (Table 15).

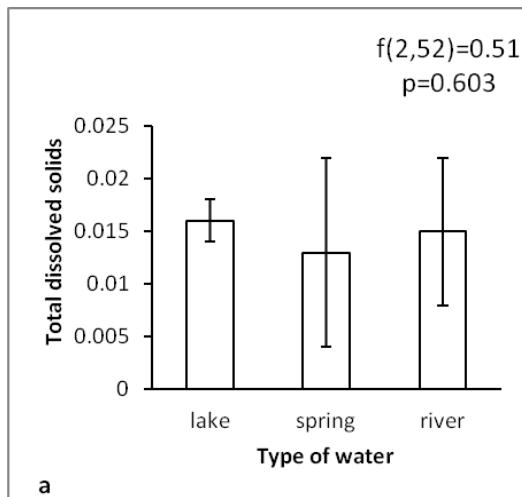


Fig. 10a: Average mean comparison of TDS in different water bodies.

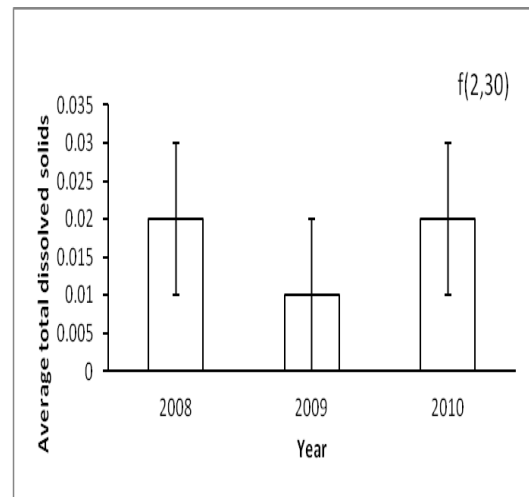


Fig. 10b: Annual mean comparison of TDS in lake in 2008, 2009 and 2010.

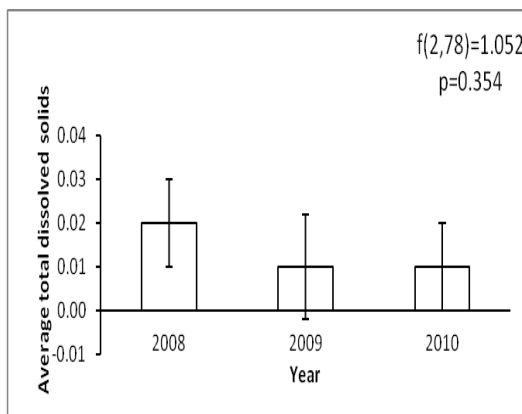


Fig. 10c: Annual mean comparison of TDS in spring in 2008, 2009 and 2010.

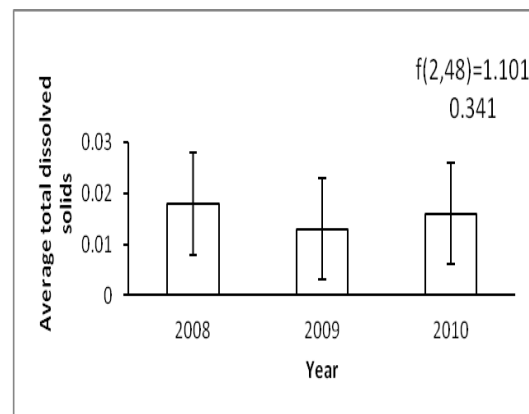


Fig. 10d: Annual mean comparison of TDS in river in lake in 2008, 2009 and 2010.

Table 15: Total dissolved solids (mg/l) recorded in lake waterbodies in SNPBZ.

SN	Name of Site	2008	2009	2010	Average ± SD
A22	Gorekshep lake	0.02	0.02	0.06	0.033 ± 0.023
A23	Small spring near Gorekshep	0.02	0.01	0.02	0.017±0.006
A24	Pyramid lake	0.02	0.01	0.02	0.017±0.006
A26	1 st lake of Gokyo (outlet)	0.02	0.02	0.02	0.020±0.000
A27	2 nd lake of Gokyo (outlet)	0.02	0.02	0.02	0.020±0.000
A28	3 rd lake of Gokyo outlet	0.02	0.01	0.02	0.017±0.006
A29	4 th lake Gokyo (mid)	0.01	0.00	0.00	0.003±0.006
A30	4 th lake Gokyo (outlet)	0.01	0.01	0.01	0.010±0.000
A31	3 rd lake of Gokyo (inlet)	0.02	0.02	0.02	0.020±0.000
A58	Imja lake (near outlet)	0.01	0.00	0.02	0.010±0.010
A59	Imja lake (outlet)	0.01	0.00	0.01	0.007±0.006
Average		0.01±0.005	0.01±0.008	0.02±0.01	0.016±0.008

Springs: Average TDS content in different water samples of springs showed the range between 0.003 to 0.043 mg/l. The low average TDS was recorded in Luza khola, Machharmo khola, Dole khola, etc where as highest TDS was recorded in Tamang springs Lukla (0.043), which showed annually highest TDS, 0.04 mg/l in 2008, 0.04 mg/l in 2009 and 0.05 mg/l in 2010 (Table 16).

Table 16: Total dissolved solids (TDS) recorded in springs in SNPBZ.

SN	Name of Site	2008	2009	2010	Average ± SD
A1	Ghatte khola	0.01	0.00	0.01	0.007 ± 0.006
A2	Hadi khola	0.01	0.00	0.00	0.003 ± 0.006
A3	Muse khola	0.01	0.01	0.01	0.010 ± 0.000
A4	Thado koshi	0.01	0.00	0.01	0.007 ±0.006
A5	Ghatta khola	0.01	0.01	0.00	0.007 ±0.006
A6	Thado khola phakding	0.01	0.04	0.04	0.030 ± 0.017
A9	Monju khola	0.01	0.00	0.01	0.007 ± 0.007
A11	Phunki tenga spring	0.01	0.01	0.02	0.013 ±0.006
A14	Pheriche spring	0.02	0.02	0.02	0.020 ±0.000
A18	Lobuche khola	0.02	0.02	0.04	0.027 ±0.012
A25	Pangboche spring	0.02	0.01	0.03	0.020 ± 0.012
A33	Machhermo khola	0.01	0.00	0.00	0.003 ±0.006
A34	Luza khola	0.00	0.00	0.01	0.003 ±0.006
A35	Dole river	0.01	0.00	0.00	0.003 ±0.006
A37	Namche spring	0.04	0.01	0.01	0.020 ±0.017
A38	Mid of namche spring	0.02	0.01	0.00	0.010 ±0.010
A39	Mouth of Namche spring	0.02	0.02	0.02	0.020 ±0.000

A41	Thame khola (spring)	0.01	0.01	0.00	0.007 ±0.006
A42	Thame khola (KBC)	0.01	0.01	0.01	0.010 ±0.000
A45	Theso khola	0.02	0.00	0.00	0.007 ± 0.012
A46	Mislung (Tap)	0.02	0.01	0.01	0.013 ±0.006
A47	Namche spring	0.02	0.04	0.01	0.023 ±0.015
A48	Mislung spring	0.03	0.01	0.01	0.017 ±0.012
A49	Tok-tok khola	0.01	0.01	0.00	0.007 ± 0.006
A57	Amphulapchacho	0.01	0.01	0.01	0.010 ±0.000
A60	Somare spring	0.02	0.01	0.01	0.013 ±0.006
A61	Lukla Tamang spring	0.04	0.04	0.05	0.043 ±0.006
Average		0.01±0.00	0.01±0.01	0.01±0.01	0.013±0.010

Rivers: The average value of the TDS in river water ranged between 0.007 and 0.03 mg/l with some exception in 2010. Lobuche khola at Lobuche (0.04 mg/l), Lobuche khola meeting at Cho- la pass (0.04 mg/l) etc. Similarly lower values than average range of TDS river water measured in different year by different sampling points. Bhotekoshi near Thamo showed 0.01 mg/l in 2008 and 2010. Bhotekoshi below the bridge between Thame and Thamo, Dudhkoshi at Phakding, Dudhkoshi above Jorsalle, and Dudhkoshi above Phunki Tenga showed 0.01 mg/l. Water samples of Everest Base Camp did not have TDS in detectable amount (Table 17).

Table 17: Total dissolved solids (mg/l) recorded in river water bodies in SNPBZ.

SN	Name of site	2008	2009	2010	Average ± SD
A7	Dudh Koshi at Phakding	0.02	0-00	0.01	0.010 ± 0.01
A8	Dudh koshi above Jorsalle	0.02	0.01	0.01	0.013 ±0.01
A10	Dudh koshi at Punki Tenga	0.02	0.01	0.01	0.013 ±0.01
A12	Dudh koshi at Pangboche and Deboche	0.02	0.04	0.02	0.027 ±0.01
A13	Dudhkoshi between Pheriche and Pangboche	0.02	0.00	0.01	0.010 ±0.01
A15	Lobuche khola (side of pheriche)	0.02	0.02	0.02	0.020 ±0.00
A16	Imja below Denboche village	0.02	0.01	0.01	0.013 ±0.01
A17	Imja just upper Denboche village	0.02	0.01	0.02	0.017 ±0.01
A19	Lobuche near meeting of chola pass	0.01	0.01	0.04	0.020 ±0.02
A20	Lobuche khola near Lobuche	0.03	0.02	0.04	0.030 ±0.01
A21	Everest base camp river	0.00	0.00	0.00	0.000 ±0.00
A32	Ngozumpa glacier	0.02	0.03	0.02	0.023 ±0.01
A36	Dudhkoshi at Phorse Tenga	0.02	0.02	0.02	0.020 ±0.01
A40	Bhotekoshi above thame	0.02	0.01	0.01	0.013 ±0.01
A43	Bhotekoshi betn Thamo and Thame	0.01	0.01	0.01	0.010 ±0.00
A44	Bhotekoshi near thamo	0.01	0.00	0.01	0.007 ±0.01
A62	Dudh koshi below Surke	0.02	0.02	0.02	0.020 ±0.00
Average		0.01±0.00	0.01±0.01	0.01±0.01	0.015±0.007

5.1.5 Conductivity

Conductivity of water in the study area was low. Insignificant differences were found between the water samples from rivers, lakes and springs (Fig. 11).

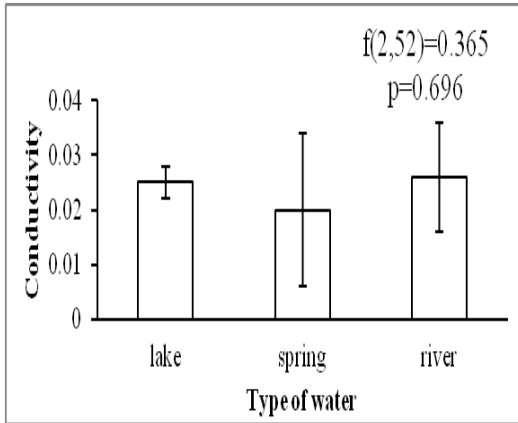


Fig. 11a: Average mean comparison of conductivity in lakes, springs and rivers.

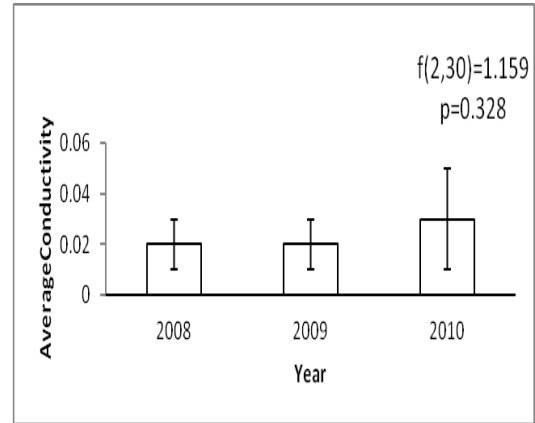


Fig. 11b: Annual mean comparison of conductivity in lakes in 2008, 2009 and 2010.

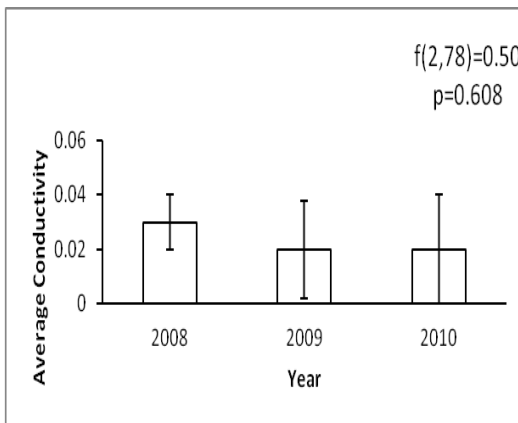


Fig. 11c: Annual mean comparison of conductivity in spring in 2008, 2009 and 2010.

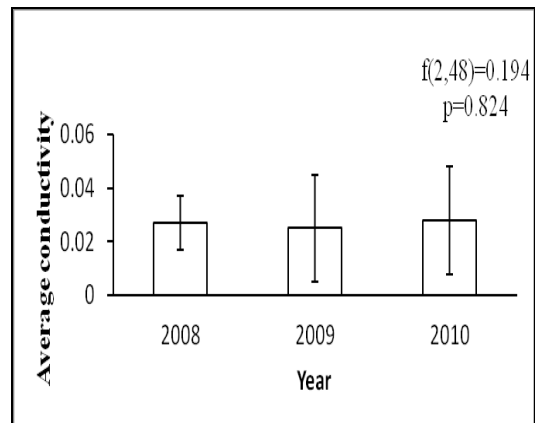


Fig. 11d: Annual mean comparison of conductivity in river in 2008, 2009 and 2010.

Lakes: The average water conductivity was recorded 0.01 to 0.05 mS/sec. Gorekshep lake showed the highest (0.05 mS/sec) conductivity among lake system. Imja lake and 4th Gokyo lake was recorded the lowest. In 2010, (0.09 mS/sec) value was recorded in Gorekshep lake which also showed the highest TDS (Table 18).

Table 18: Conductivity (mS/sec) recorded in lake water in SNPBZ.

SN	Name of Site	2008	2009	2010	Average \pm SD
A22	Gorekshep lake	0.03	0.03	0.09	0.050 \pm 0.035
A23	Small spring near Gorekshep	0.03	0.02	0.03	0.027 \pm 0.006
A24	Pyramid lake	0.03	0.02	0.03	0.027 \pm 0.006
A26	1 st lake of Gokyo (outlet)	0.03	0.03	0.03	0.030 \pm 0.000
A27	2 nd lake of Gokyo (outlet)	0.03	0.03	0.03	0.030 \pm 0.000
A28	3 rd lake of Gokyo outlet	0.03	0.02	0.01	0.020 \pm 0.010
A29	4 th lake Gokyo (mid of lake)	0.02	0.01	0.01	0.013 \pm 0.006
A30	4 th lake Gokyo (outlet)	0.02	0.02	0.02	0.020 \pm 0.000
A31	3 rd lake of Gokyo (inlet)	0.03	0.03	0.03	0.030 \pm 0.000
A58	Imja lake near outlet	0.01	0.01	0.03	0.017 \pm 0.012
A59	Imja lake outlet	0.01	0.01	0.02	0.013 \pm 0.006
Average		0.02\pm0.00	0.01\pm0.00	0.03\pm0.02	0.025\pm0.010

Springs: Generally, lower conductivity of spring water was recorded than of lake water. Average values of conductivity were between 0.01 mS/sec to 0.07 mS/sec. Lukla Tamang spring showed the highest conductivity in all three years (Table 19). Low conductivity was recorded in Tok-Tok (0.007 mS/sec), Dole river (0.007 mS/sec), Luza (0.007 mS/sec), Ghatte khola (0.007 mS/sec) (Table 19).

Table 19: Conductivity (mS/sec) recorded in spring waterbodies in SNPBZ.

SN	Name of Site	2008	2009	2010	Average \pm SD
A1	Ghatte khola	0.02	0.02	0.02	0.020 \pm 0.000
A2	Hadi khola	0.02	0.01	0.01	0.013 \pm 0.006
A3	Muse khola	0.02	0.02	0.02	0.020 \pm 0.000
A4	Thado koshi	0.02	0.00	0.02	0.013 \pm 0.012
A5	Ghatta khola	0.01	0.00	0.01	0.007 \pm 0.006
A6	Thado khola near Phakding	0.02	0.06	0.07	0.050 \pm 0.026
A9	Monju khola	0.02	0.00	0.02	0.013 \pm 0.012
A11	Phunki Tenga spring	0.02	0.03	0.04	0.030 \pm 0.010
A14	Pheriche spring	0.03	0.03	0.03	0.030 \pm 0.000
A18	Lobuche spring (Lower)	0.03	0.04	0.03	0.033 \pm 0.006
A25	Pangboche spring	0.03	0.02	0.04	0.030 \pm 0.010
A33	Machhermo khola	0.02	0.01	0.01	0.013 \pm 0.006
A34	Luza khola	0.01	0.00	0.01	0.007 \pm 0.006

A35	Dole river	0.01	0.01	0.00	0.007 ±0.006
A37	Namche spring	0.06	0.02	0.02	0.033 ±0.023
A38	Namche spring (mid of Namche)	0.04	0.03	0.01	0.027 ±0.015
A39	Mouth of source of spring of Namche	0.03	0.03	0.03	0.030 ±0.000
A41	Thame khola (spring)	0.02	0.02	0.01	0.017 ±0.006
A42	Thame khola (KBC)	0.02	0.02	0.02	0.020 ±0.000
A45	Theso khola	0.02	0.02	0.02	0.020 ±0.000
A46	Mislung Tap water	0.03	0.02	0.02	0.023 ±0.006
A47	Lobuche spring (upper)	0.04	0.05	0.02	0.037 ±0.015
A48	Mislung spring	0.04	0.02	0.03	0.030± 0.010
A49	Tok-Tok khola	0.01	0.01	0.00	0.007± 0.006
A57	Amphulapchacho	0.02	0.02	0.02	0.020± 0.000
A60	Somare	0.03	0.02	0.02	0.023±0.006
A61	Lukla Tamang spring	0.06	0.07	0.08	0.070± 0.010
Average		0.02±0.01	0.02±0.01	0.02±0.01	0.024±0.014

Rivers

The water characteristic of river in term of conductivity was between 0.01 mS/sec to 0.05 mS/sec. Major sampling points showed the value (0.02 mS/sec) in all seasons except few places. Some sampling points had slightly higher conductivity than average e.g. Dudhkoshi between Pangboche and Deboche (0.04 mS/sec), Lobuche near Chola pass (0.04 mS/sec) and Lobuche khola near lobuche settlement (0.04 mS/sec) value were recorded (Table 20) in 2008. In 2009, Dudhkoshi between Pangboche and Deboche (0.07 mS/sec), Lobuche river near Lobuche (0.04 mS/sec) and Dudhkoshi at Phunki Tenga (0.04 mS/sec).

Table 20: Conductivity recorded in river water.

SN	Name of site	2008	2009	2010	Average ± SD
A7	Dudhkoshi at Phakding	0.03	0.01	0.02	0.020 ± 0.010
A8	Dudhkoshi above Jorsalle	0.03	0.02	0.02	0.023 ± 0.006
A10	Dudhkoshi at Punki Tenga	0.03	0.02	0.02	0.023 ± 0.006
A12	Dudhkoshi at Pangboche and Deboche	0.03	0.07	0.03	0.043 ± 0.023
A13	Dudhkoshi between Pheriche and Pangboche	0.03	0.02	0.02	0.023 ± 0.006
A15	Lobuche khola from side of Pheriche	0.03	0.04	0.03	0.033 ± 0.006
A16	Imja khola below Denboche village	0.03	0.02	0.02	0.023 ± 0.006

A17	Imja just upper Dengboche village	0.02	0.02	0.03	0.023 ± 0.006
A19	Lobuche near meeting of Chola pass	0.02	0.02	0.07	0.037 ± 0.029
A20	Lobuche khola near Lobuche	0.04	0.04	0.06	0.047 ± 0.012
A21	Snow melt from Everest Base Camp	0.01	0.00	0.01	0.007 ± 0.006
A32	Ngozumpa glacier	0.03	0.04	0.04	0.037 ± 0.006
A36	Dudhkoshi at Phorse Tenga	0.03	0.04	0.03	0.033 ± 0.006
A40	Bhotekoshi above Thame	0.03	0.02	0.02	0.023 ± 0.006
A43	Bhotekoshi betn Thamo and Thame	0.02	0.01	0.01	0.013 ± 0.006
A44	Bhotekoshi near Thamo	0.02	0.01	0.02	0.017 ± 0.006
A62	Dudh koshi below Surke	0.03	0.03	0.03	0.030 ± 0.000
Average		0.02±0.00	0.02±0.01	0.02±0.01	0.026±0.010

5.1.6 Total nitrogen as nitrate:

Total nitrogen (TN) of spring water was found 1.198 mg/l, 0.922 mg/l in river water and 0.82 mg/l in lake water (Fig. 12).

Lakes: Nitrate- nitrogen content was recorded between 0.20 mg/l and 2.79 mg/l with three years average ranged between 0.20 and 1.3 mg/l. Lowest nitrogen was recorded in Imja lake. Average highest TN 1.3 mg/l was recorded at 3rd Gokyo lake (Table 21). This lake was very near to settlement and garbage pit as well as septic tank of toilet was very close to the Gokyo lake. Some variations were recorded in TN value at different samplings points. 2.79 mg/l in 2010 by 3rd lake and 1.82 mg/l in 2009 1st lake outlets. But, overall, average value of nitrate – nitrogen was increasing (Table 21).

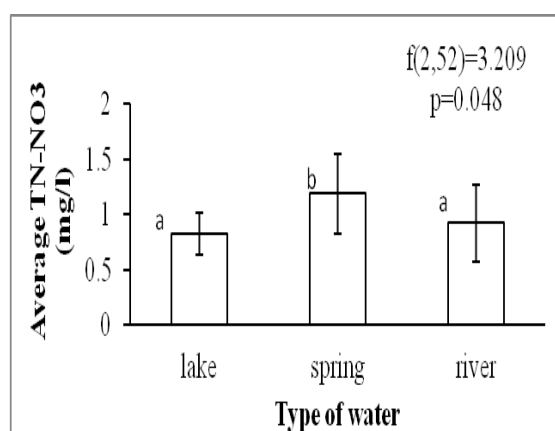


Fig. 12a: Average mean comparison of TN-NO₃ in different water bodies.

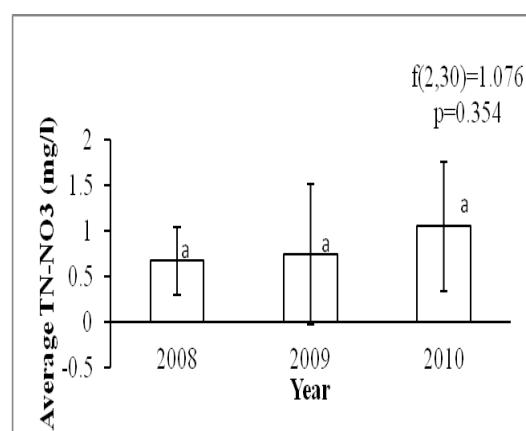


Fig. 12b: Annual mean comparison of nitrogen in lake in 2008, 2009 and 2010.

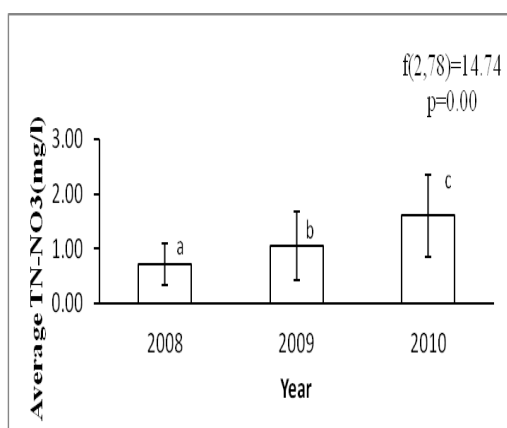


Fig. 12c: Annual mean comparison of nitrogen in spring in 2008, 2009 and 2010.

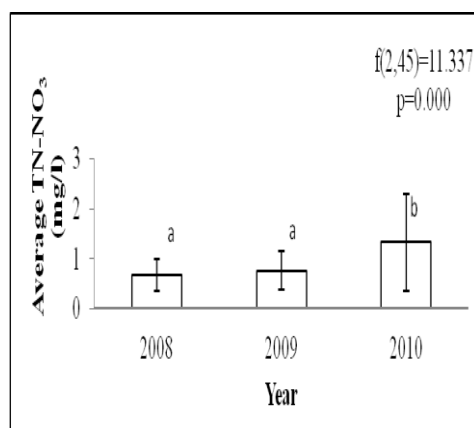


Fig. 12d: Annual mean comparison of nitrogen in rivers in 2008, 2009 and 2010.

Table 21: Nitrate-nitrogen content (mg/l) in lakes in SNPBZ.

SN	Name of Site	2008	2009	2010	Average ± SD
A22	Gorekshep lake	1.25	0.72	1.03	1.00± 0.27
A23	Small spring near Gorekshep	0.86	0.87	1.40	1.04± 0.31
A24	Pyramid lake	1.26	0.11	0.80	0.72± 0.58
A26	1 st lake of Gokyo (outlet)	0.20	0.71	1.82	0.91± 0.83
A27	2 nd lake of Gokyo (outlet)	0.68	1.18	1.03	0.96± 0.26
A28	3 rd lake of Gokyo outlet	0.20	0.41	0.77	0.46± 0.29
A29	4 th lake Gokyo (mid of lake)	0.72	0.81	0.21	0.58± 0.32
A30	4 th lake Gokyo (outlet)	0.65	0.21	0.97	0.61± 0.38
A31	3 rd lake of Gokyo (inlet)	0.20	2.79	0.92	1.30± 1.34
A58	Imja lake near outlet	0.72	0.15	0.01	0.29± 0.38
A59	Imja lake outlet	0.68	0.17	2.60	1.15± 1.28
Average		0.67±0.3	0.73±0.7	1.05±0.7	0.82±0.31

Springs: The TN content was between 0.17 and 2.79 mg/l with three years average between 0.52 and 1.76 mg/l in different springs. The higher value showed by different springs in the 2008, 2009 and 2010 were: Thadokoshi (1.44 mg/l), Pangboche spring (1.74 mg/l), Thadokhola phakding (1.71 mg/l), Namche spring (mid of Namche) 1.43 mg/l, Mislung springs flowing from the mislung tap (1.65 mg/l), Somare spring (1.76 mg/l) but occasionally some samplings in 2010 like origin of the sources of spring of Namche (2.5 mg/l), Theso khola (2.05 mg/l), Tamang spring Lukla (2.60 mg/l) were recorded (Table 22). Generally all springs flow very near to settlement.

Table 22: Nitrate-nitrogen content (mg/l) in spring waterbodies.

SN	Name of Site	2008	2009	2010	Average \pm SD
A1	Ghatte khola	0.93	0.24	0.93	0.70 \pm 0.40
A2	Hadi khola	0.18	0.93	0.85	0.65 \pm 0.41
A3	Muse khola	0.17	0.76	0.77	0.57 \pm 0.34
A4	Thado koshi	0.19	1.74	2.39	1.44 \pm 1.13
A5	Ghatta khola	0.50	0.32	1.30	0.71 \pm 0.52
A6	Thado khola phakding	0.71	1.39	3.02	1.71 \pm 1.19
A9	Monju khola	0.47	0.46	1.03	0.65 \pm 0.33
A11	Phunki tenga spring	0.65	0.31	1.23	0.73 \pm 0.47
A14	Pheriche spring	0.61	0.74	2.60	1.32 \pm 1.11
A18	Lobuche khola	0.90	0.84	1.30	1.01 \pm 0.25
A25	Pangboche spring	0.56	1.87	2.80	1.74 \pm 1.13
A33	Machhermo khola	0.27	0.42	1.50	0.73 \pm 0.67
A34	Luza khola	0.54	1.02	2.13	1.23 \pm 0.82
A35	Dole river	0.61	1.39	1.58	1.19 \pm 0.51
A37	Namche spring	0.77	1.75	1.01	1.18 \pm 0.51
A38	mid of namche spring	1.44	1.44	2.36	1.75 \pm 0.53
A39	Mouth of namche spring	0.54	0.79	2.51	1.28 \pm 1.07
A41	Thame khola (spring)	0.63	0.32	0.99	0.65 \pm 0.34
A42	Thame khola (KBC)	0.77	0.67	0.43	0.62 \pm 0.17
A45	Theso khola	0.51	0.35	2.05	0.97 \pm 0.94
A46	Mislung (Tap)	1.94	2.22	0.78	1.65 \pm 0.76
A47	Namche spring	0.97	1.93	0.76	1.22 \pm 0.62
A48	Mislung spring	0.63	1.77	1.54	1.31 \pm 0.60
A49	Tok-Tok khola	0.94	1.20	1.87	1.34 \pm 0.48
A57	Amphulapchacho	0.86	0.86	0.86	0.86 \pm 0.00
A60	Somare	0.93	2.14	2.20	1.76 \pm 0.72
A61	Lukla Tamang spring	1.18	0.51	2.60	1.43 \pm 1.07
Average		0.71\pm0.3	1.05\pm0.6	1.60\pm0.7	1.19\pm0.36

Rivers: TN content in river water was between 0.00 to 3.6 mg/l with average range 0.46 and 1.57 mg/l in three years. Comparatively, TN in rivers was found higher than the lakes but less than the springs. Higher amount of TN was recorded at different samplings points: Lobuche khola from the side of Pheriche (1.55 mg/l), Imja khola near Dengboche village (1.57 mg/l), Dudhkoshi at Phorse Tenga (1.16 mg/l), Bhotekoshi below a bridge between Thamo and Thame (1.38 mg/l), Bhotekoshi above Thame (1.19 mg/l). Lower TN content was recorded as 0.48 mg/l in Lobuche near meeting of chola pass, 0.46 mg/l in Ngozumpa glacier, 0.51 mg/l in Dudhkoshi at

Pangboche and Deboche, 0.56 mg/l in Dudhkoshi between Pheriche and Pangboche (Table 23).

Similarly, some points showed a little more TN. In 2008, Dudhkoshi at Porse Tenga had 1.21 mg/l and Bhotekoshi above Thame 1.01 mg/l. In 2009, Lobuche Khola near Pheriche had 1.75 mg/l, Lobuche khola near Lobuche 1.5 mg/l total nitrogen. In 2010, some points showed higher value: Imja khola 3.6 mg/l, Lobuche khola near Pheriche 2.2 mg/l, Dudhkoshi at Phunki Tenga 2.17 mg/l, Bhotekoshi below bridge between Thamo and Thame was 2.03 mg/l. The amount of TN in 2010 showed increase in the total nitrogen then 2008 and 2009 (Table 23).

Table 23: Nitrate-nitrogen content (mg/l) in river waterbodies.

SN	Name of site	2008	2009	2010	Average \pm SD
A7	Dudh Koshi at Phakding	0.89	0.77	0.67	0.78 \pm 0.11
A8	Dudh koshi above Jorsalle	0.32	0.37	1.83	0.84 \pm 0.86
A10	Dudh koshi at Punki Tenga	1.21	0.89	0.00	0.70 \pm 0.63
A12	Dudh koshi at Pangboche and Deboche	0.80	0.72	0.00	0.51 \pm 0.44
A13	Dudhkoshi between Pheriche and Pangboche	0.47	0.28	0.93	0.56 \pm 0.33
A15	Lobuche khola at Pheriche	0.71	1.75	2.20	1.55 \pm 0.76
A16	Imja khola below Dengboche village	0.50	0.43	2.20	1.04 \pm 1.00
A17	Imja just upper Dengboche village	0.27	0.84	3.6	1.57 \pm 1.78
A19	Lobuche near meeting of Chola pass	0.12	0.31	1.01	0.48 \pm 0.47
A20	Lobuche khola at Lobuche	0.27	1.53	0.73	0.84 \pm 0.64
A21	EBC River	0.77	0.44	1.60	0.94 \pm 0.60
A32	Ngozumpa glacier	0.68	0.69	0.00	0.46 \pm 0.40
A36	Dudhkoshi at Phorse Tenga	0.63	0.69	2.17	1.16 \pm 0.87
A40	Bhotekoshi above Thame	1.01	0.79	1.78	1.19 \pm 0.52
A43	Bhotekoshi betn Thamo and Thame	1.08	1.03	2.03	1.38 \pm 0.56
A44	Bhotekoshi near Thamo	0.97	0.71	1.07	0.92 \pm 0.19
A62	Dudhkoshi below Surke	0.76	0.76	0.76	0.76 \pm 0.00
Average		0.67\pm0.3	0.76\pm0.3	1.32\pm0.9	0.92\pm0.35

5.1.7 Total Phosphorous as PO₄

Although phosphorous content was found very low than that of standard fixed for different purposes like drinking, irrigation, bathing, domestic purpose increasing was recorded in all waterbodies. Average phosphorous content was 0.46 mg/l recorded in springs, 0.34 mg/l in lakes and 0.335 mg/l in rivers (Fig. 13).

Lakes: Average phosphorous (as phosphate) was found between 0.18 and 1.05 mg/l in different lakes in SNPBZ. Higher content of PO₄ was recorded at 1st Gokyo lake (0.51 mg/l), 2nd Gokyo lake (0.38 mg/l), Imja lake (1.05 mg/l) where as relatively less content was recorded in 4th Gokyo lake (0.18 mg/l) and Pyramid lake (0.26 mg/l). In year 2008, lower value of PO₄ was recorded upto 0.02 mg/l and higher was upto 0.42 mg/l in Imja lake where as in 2009, minimum PO₄ was upto 0.08 mg/l and maximum was 0.97 mg/l in 1st Gokyo lake. In the year 2010, the PO₄ was 0.03 to 2.64 mg/l. Highest PO₄ was found in Imja lake (2.64 mg/l) (Table 24). Hence slight change was noticed from 2008 to 2010 in nearly all the samples in lake water.

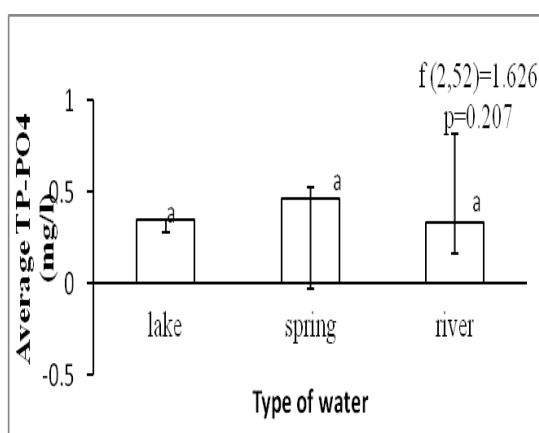


Fig. 13a: Average mean comparison of phosphorous in different water bodies.

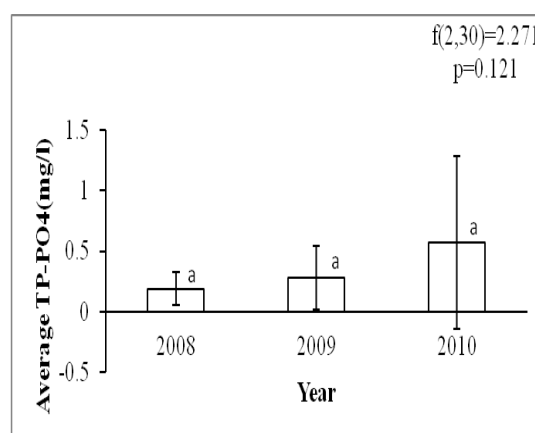


Fig. 13b: Annual mean comparison of phosphorous in lake in 2008, 2009 and 2010.

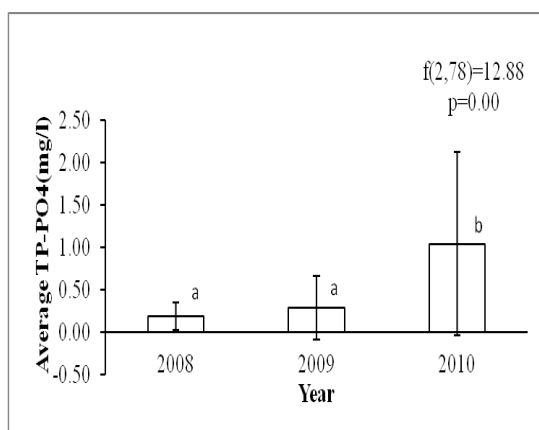


Fig. 13c: Annual mean comparison of phosphorous in spring in 2008, 2009 and 2010.

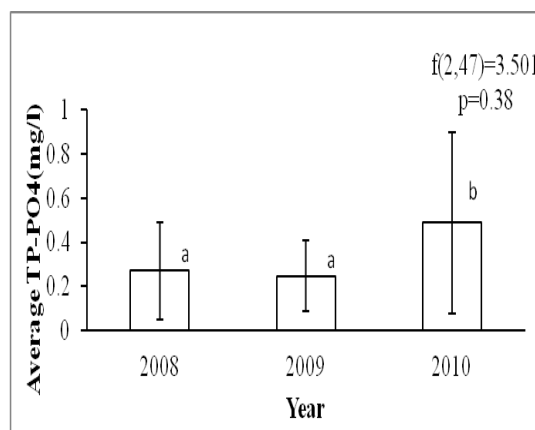


Fig. 13d: Annual mean comparison of phosphorous in river in 2008, 2009 and 2010.

Table 24: Phosphate- phosphorous content (mg/l) in lake water.

SN	Sampling Sites	2008	2009	2010	Average \pm SD
A22	Gorekshep lake	0.09	0.14	0.61	0.28 \pm 0.29
A23	Small spring near Gorekshep	0.28	0.14	0.03	0.15 \pm 0.13
A24	Pyramid lake	0.11	0.26	0.40	0.26 \pm 0.15
A26	1 st lake of Gokyo (outlet)	0.24	0.97	0.33	0.51 \pm 0.40
A27	2 nd lake of Gokyo (outlet)	0.27	0.54	0.32	0.38 \pm 0.14
A28	3 rd lake of Gokyo outlet	0.02	0.17	0.54	0.24 \pm 0.27
A29	4 th lake Gokyo (mid)	0.03	0.22	0.28	0.18 \pm 0.13
A30	4 th lake Gokyo (outlet)	0.08	0.30	0.08	0.15 \pm 0.13
A31	3 rd lake of Gokyo (inlet)	0.11	0.10	0.68	0.30 \pm 0.33
A58	Inja lake (near outlet)	0.39	0.12	0.40	0.30 \pm 0.16
A59	Inja lake (outlet)	0.42	0.08	2.64	1.05 \pm 1.39
Average		0.18\pm0.1	0.27\pm0.2	0.57\pm0.7	0.34\pm0.25

Springs: Averages phosphorous quantity was found between 0.12 and 2.09 mg/l in 2008 to 2010. Minimum PO₄ was recorded in Dole river (0.12 mg/l) where as maximum in Lukla tamang spring (2.09 mg/l). Phosphorous measured in some samples were: 1.38 mg/l in Phunki Tenga spring, Ghatte khola (0.23 mg/l), Muse khola (0.61 mg/l), Lobuche spring (0.52 mg/l), Namche spring (1.06 mg/l), Somare spring (0.62 mg/l), Namche spring (from the mid of namche) was 0.63 mg/l (Table 25).

In 2008, PO₄ content was recorded between 0.08 and 2.0 mg/l. but in 2009 the range was 0.23-3.9 mg/l. Namche spring showed 3.01 mg/l in 2010. Tamang tole spring also showed the highest content of PO₄ i.e. 3.9 mg/l in 2010. In the year 2010, the value ranged between 0.23 and 3.9 mg/l (Table 25).

Table 25: Phosphate- phosphorous content (mg/l) in spring waterbodies in SNPBZ in different year.

SN	Name of Site	2008	2009	2010	Average \pm SD
A1	Ghatte khola	0.15	0.2	1.99	0.78 \pm 1.05
A2	Hadi khola	0.12	0.04	0.37	0.18 \pm 0.17
A3	Muse khola	0.12	0.23	1.49	0.61 \pm 0.76
A4	Thado koshi	0.12	0.08	0.5	0.23 \pm 0.23
A5	Ghatta khola	0.06	0.15	0.48	0.23 \pm 0.22
A6	Thado khola near Phakding	0.15	0.12	2.70	0.99 \pm 1.48
A9	Monju khola	0.05	0.82	0.32	0.40 \pm 0.39
A11	Phunki tenga spring	0.12	0.28	3.73	1.38 \pm 2.04

A14	Pheriche spring	0.14	0.24	1.08	0.49 ± 0.52
A18	Lobuche khola	0.46	0.46	0.65	0.52 ± 0.11
A25	Pangboche spring	0.07	0.28	1.09	0.48 ± 0.54
A33	Machhermo khola	0.07	0.08	0.32	0.16 ± 0.14
A34	Luza khola	0.19	0.28	0.29	0.25± 0.06
A35	Dole river	0.02	0.08	0.25	0.12± 0.12
A37	Namche spring	0.02	0.14	3.01	1.06± 1.69
A38	Namche spring (mid)	0.48	0.34	1.06	0.63± 0.38
A39	Mouth spring of namche	0.14	0.20	0.36	0.23± 0.11
A41	Thame khola (spring)	0.12	0.56	0.27	0.32± 0.22
A42	Thame khola (KBC)	0.28	0.23	0.24	0.25± 0.03
A45	Theso khola	0.11	0.03	0.28	0.14± 0.13
A46	Mislung (Tap)	0.29	0.09	0.62	0.33± 0.27
A47	Namche spring	0.25	0.02	1.03	0.43± 0.53
A48	Mislung spring	0.12	0.12	0.62	0.29± 0.29
A49	Tok-tok khola	0.12	0.16	0.23	0.17± 0.06
A57	Amphulapchacho	0.32	0.32	0.32	0.32± 0.00
A60	Somare	0.69	0.36	0.82	0.62± 0.24
A61	Lukla Tamang spring	0.38	2.00	3.90	2.09± 1.76
Average		0.19±0.1	0.29±0.3	1.03±1.0	0.46±0.48

Rivers: Average PO₄ content was recorded between 0.10 and 0.67 mg/l in the river water. The minimum value was recorded in Dudhkoshi above Jorsalle (0.10 mg/l), Dudhkoshi between Pangboche and Deboche (0.13 mg/l), where as higher PO₄ content in Bhotekoshi near Thamo (0.67 mg/l), Lobuche khola at Lobuche (0.53 mg/l), snow melt river at Base camp (0.54 mg/l) (Table 26).

In the year 2008, PO₄ was recorded between 0.03 and 0.74 mg/l. Minimum PO₄ was recorded in Dudhkoshi above Jorsalle (0.03 mg/l), where as maximum was found in Lobuche khola near Lobuche (0.65 mg/l). But occasionally, in 2009 and 2010, some sampling points had more than 1 mg/l PO₄ in river water. In 2010, snow melt water from EBC was 1.44 mg/l, Lobuche meeting at chola pass had 1.01 mg/l, Bhotekoshi near thamo 1.38 mg/l PO₄. In 2009, all sampling points had the PO₄ between 0.00 and 0.65 mg/l. PO₄ was in negligible quantity in Dudhkoshi at Pangboche and Deboche. PO₄ content was recorded in Imja khola near Denboche village 0.65 mg/l and 0.46 mg/l in Lobuche khola near Lobuche (Table 26).

Table 26: Phosphate- phosphorous content (mg/l) in river waterbodies

SN	Name of site	2008	2009	2010	Average \pm SD
A7	Dudh Koshi at Phakding	0.23	0.18	0.30	0.24 \pm 0.06
A8	Dudh koshi above Jorsalle	0.03	0.14	0.13	0.10 \pm 0.06
A10	Dudh koshi at Punki Tenga	0.15	0.32	0.53	0.33 \pm 0.19
A12	Dudh koshi at Pangboche and Deboche	0.19	0.00	0.19	0.13 \pm 0.11
A13	Dudhkoshi between Pheriche and Pangboche	0.14	0.23	0.34	0.24 \pm 0.10
A15	Lobuche khola at Pheriche	0.09	0.12	0.29	0.17 \pm 0.11
A16	Imja khola below Denboche village	0.14	0.24	0.24	0.21 \pm 0.06
A17	Imja just upper Denboche village	0.65	0.65	0.26	0.52 \pm 0.23
A19	Lobuche near meeting of chola pass	0.09	0.44	1.01	0.51 \pm 0.46
A20	Lobuche khola near Lobuche	0.65	0.46	0.48	0.53 \pm 0.10
A21	Snow melt from Everest Base Camp	0.07	0.12	1.44	0.54 \pm 0.78
A32	Ngozumpa glacier	0.11	0.12	0.22	0.15 \pm 0.06
A36	Dudhkoshi at Phorse Tenga	0.29	0.29	0.49	0.36 \pm 0.12
A40	Bhotekoshi above Thame	0.74	0.11	0.63	0.49 \pm 0.34
A43	Bhotekoshi below betn Thamo n Thame	0.48	0.24	0.12	0.28 \pm 0.18
A44	Bhotekoshi near Thamo	0.32	0.30	1.38	0.67 \pm 0.62
A62	Dudh koshi below Surke	0.24	0.24	0.24	0.24 \pm 0.00
Average		0.27\pm0.2	0.24\pm0.15	0.48\pm0.41	0.33\pm0.17

5.1.8 Metal

5.1.8.1 Iron (Fe)

In 18 sampling points (8 in lakes, 7 in rivers and 3 in springs) in 2008, 2009 and 2010. Iron (Fe) was found higher than the WHO standards for drinking purpose. In lake, average value was recorded in the range 0.83-2.14 mg/l. Fe content (0.02-8.92 mg/l) in lakes, 0.09-2.14 mg/l in springs and 0.1 -1.37 mg/l in river water was recorded in water bodies. In 2010, all the lake water showed Fe higher than the WHO standards for drinking purpose; 8.92 mg/l in 5th Gokyo lake, 1.35 mg/l in 4th lake, 1.20 mg/l in 3rd lake, 1.92 mg/l in 2nd lake and 6.4 mg/l in 1st lake (Table 27).

Table 27: Iron (Fe) content (mg/l) in waterbodies in SNPBZ in 2008, 2009 and 2010.

Type of water bodies	Sites	Altitude (m)	Year				Overall average
			2008	2009	2010	Average	
Lake	5 th Gokyo lake	4950	NA*	NA*	8.92	-	1.97
	4 th Gokyo lake	4860	0.20	1.38	1.35	0.98	
	3 rd Gokyo lake	4740	NA	0.48	1.20	0.84	
	2 nd Gokyo lake	4716	0.04	0.53	1.92	0.83	
	1 st Gokyo lake	4661	0.02	0.02	6.40	2.14	
River	Imja khola	4165	0.70	3.60	3.50	2.60	1.25
	Glacier river	4656	0.10	3.06	1.37	1.51	
	EBC river	5331	0.40	1.05	NA*	0.72	
	Lobuche river	4919	0.20	0.20	0.15	0.18	
Spring	Pheriche spring	4279	0.40	1.58	0.12	0.70	0.45
	Namche spring	3440	0.10	0.05	2.46	0.87	
	Phakding spring	2593	0.10	0.19	0.20	0.16	
	Ghatte khola	2631	0.10	0.06	0.09	0.08	

(NA* = not recorded)

In rivers, some sampling points showed higher Fe content, in glacier river in 2009 Fe was 3.06 mg/l and 1.37 mg/l in 2010, river from Everest base camp had 0.4 mg/l in 2008 and 1.05 mg/l in 2009. The significantly higher value; 0.7 mg/l, 3.6 mg/l and 3.5 mg/l were found in Imja khola in 2008, 2009 and 2010, respectively. Namche and Pheriche springs exhibited slightly higher Fe content than other springs (Table 27, Figs. 14-15).

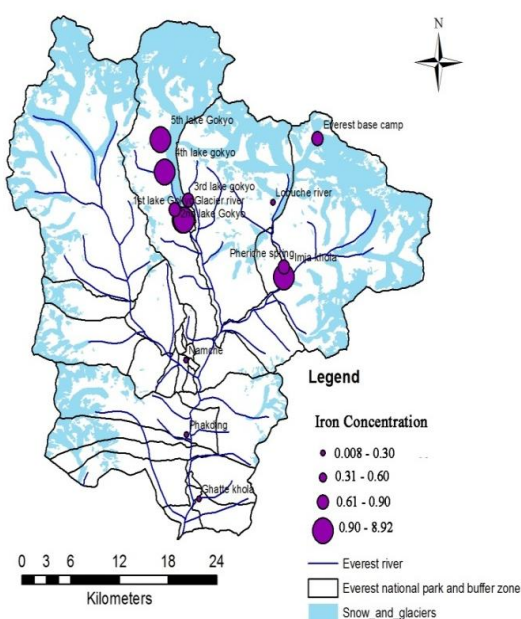


Fig. 14: Average of 2008-2010 iron (Fe) concentration (mg/l) in water bodies in SNPBZ.

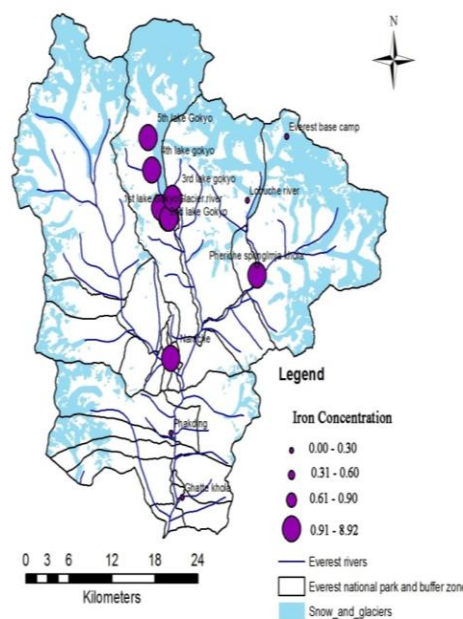


Fig. 15: Iron concentration (mg/l) in the waterbodies of SNPBZ in 2010.

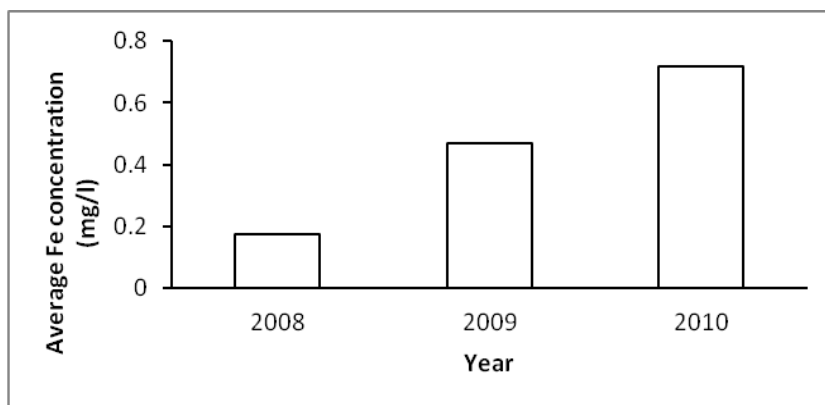


Figure 16: Annual average of Iron (Fe) in springs in 2008, 2009 and 2010.

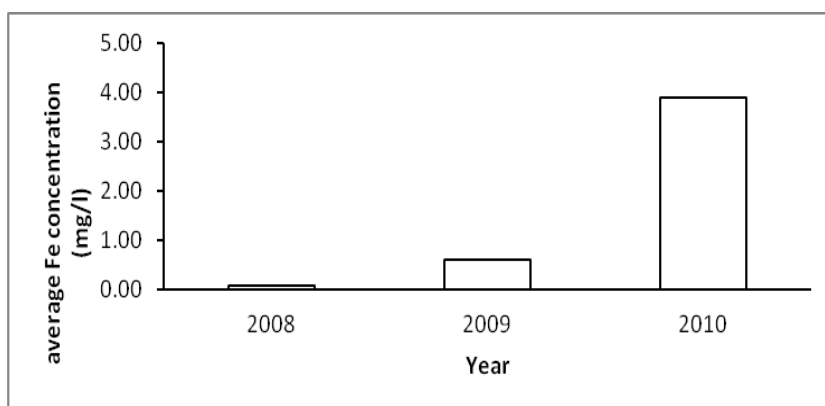


Figure 17: Annual average of Iron (Fe) in lakes in 2008, 2009 and 2010.

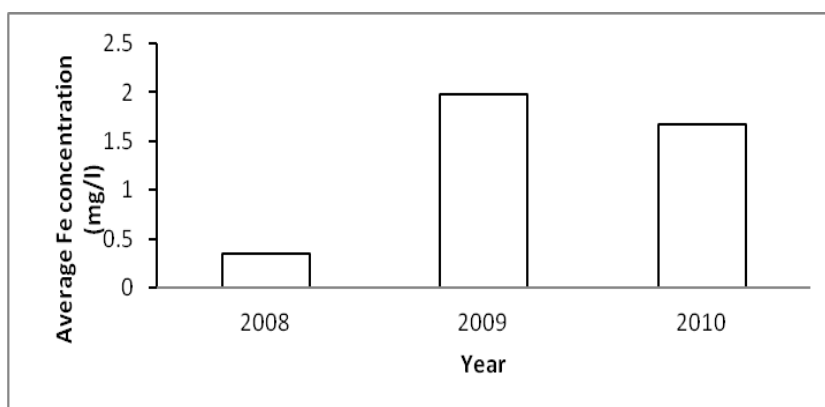


Figure 18: Annual average of Iron (Fe) in rivers in 2008, 2009 and 2010.

5.1.8.2 Sodium (Na)

Sodium (Na) content was found between 0.13 and 6.4 mg/l throughout the sampling years. In rivers, Na content was found between 0.13 and 3.45 mg/l with a three years average 1.23 mg/l. Some of the rivers showed the noticeable values e.g Lobuche River (2.4 mg/l) and Imja river (3.15 mg/l). In case of springs, Na content range was 0.26-3.59 mg/l. Higher than average Na content was recorded in Namche spring (2.80 mg/l) and 3.83 mg/l in 2008 and 2009, respectively (Table 28, Figs. 19-20).

Table 28: Sodium (Na) content (mg/l) in waterbodies of SNPBZ in 2008, 2009 and 2010.

Type of water	Sites	Altitude (m)	Year			Average	Overall analysis
			2008	2009	2010		
Lake	5 th Gokyo lake	4950	NA*	NA*	1.19	-	1.46
	4 th Gokyo lake	4860	0.40	2.78	1.36	1.51	
	3 rd Gokyo lake	4740	NA*	0.70	0.95	0.82	
	2 nd Gokyo lake	4716	6.40	0.70	0.98	2.69	
	1 st Gokyo lake	4661	0.60	0.84	0.99	0.81	
River	Glacier river	4656	0.60	1.20	1.37	1.05	1.23
	EBC river	5331	0.20	0.13	1.15	0.49	
	Lobuche river	4919	1.00	0.31	2.46	1.25	
	Imja khola	4165	0.80	1.21	3.15	1.72	
Spring	Pheriche	4279	1.00	1.14	1.09	1.07	1.47
	Namche spring	3440	2.80	3.83	1.15	2.59	
	Phakding spring	2593	1.00	1.53	1.51	1.34	
	Ghatte khola	2631	1.40	0.26	0.96	0.87	

(NA* = not recorded)

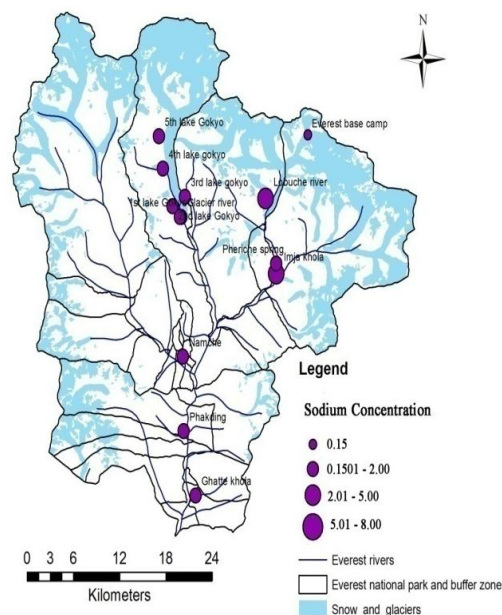
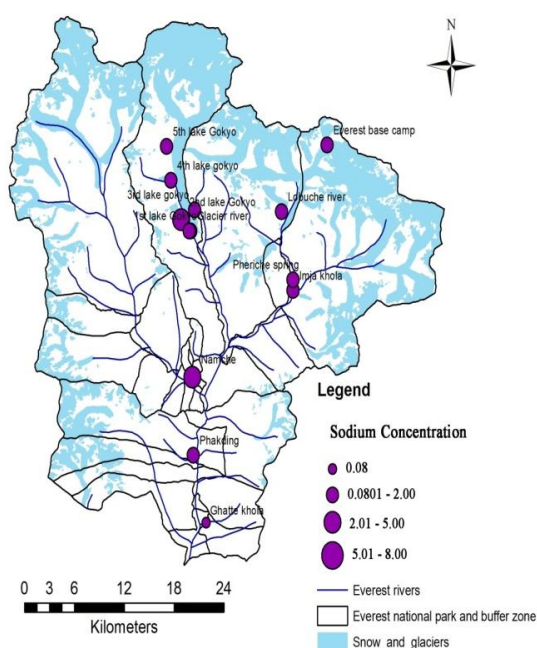


Fig. 19: Average sodium concentration (mg/l) in the water bodies in SNPBZ.

Fig. 20: Sodium concentration (mg/l) in the waterbodies of SNPBZ in 2010.

5.1.8.3 Magnesium (Mg)

Magnesium (Mg) content was recorded between 0.49 mg/l and 8.7 mg/l in all bodies. Fourth Gokyo lake had 3.7 mg/l, 2nd Gokyo lake had 6.2 mg/l and 6.2 mg/l in

2008 and 4.86 mg/l Mg was recorded in 1st Gokyo lake in 2010, which all were higher than the average range (Table 29).

In river, Mg content ranged between 0.97 and 3.70 mg/l. Glacier river (3.7 mg/l) and river from EBC showed higher Mg than average Mg in 2008. In springs, 0.88 mg/l to 3.87 mg/l Mg was recorded during the sampling period (Figs. 21-22). Namche spring recorded 8.7 mg/l in 2008 (Table 29).

Table 29: Magnesium (Mg) content in waterbodies of SNPBZ in 2008, 2009 and 2010.

Type of waterbodies	Sites	Altitude (m)	Year			Average	Overall average
			2008	2009	2010		
Lake	5 th Gokyo lake	4950	NA*	NA*	2.43	-	2.69
	4 th Gokyo lake	4860	3.70	1.94	4.86	3.50	
	3 rd Gokyo lake	4740	NA*	1.46	0.97	1.21	
	2 nd Gokyo lake	4716	6.20	1.46	2.43	3.36	
	1 st Gokyo lake	4661	6.20	0.97	0.97	2.71	
River	Glacier river	4656	3.70	2.92	0.97	2.53	2.33
	EBC river	5331	3.70	1.46	NA*	2.58	
	Lobuche river	4919	1.20	0.97	2.43	1.53	
	Imja khola	4165	3.70	2.92	1.46	2.69	
Spring	Pheriche	4279	3.70	1.94	0.49	2.04	2.17
	Namche spring	3440	8.70	1.94	0.97	3.87	
	Phakding spring	2593	3.70	0.97	0.97	1.88	
	Ghatte khola	2631	0.60	0.49	1.56	0.88	

(NA* = not recorded)

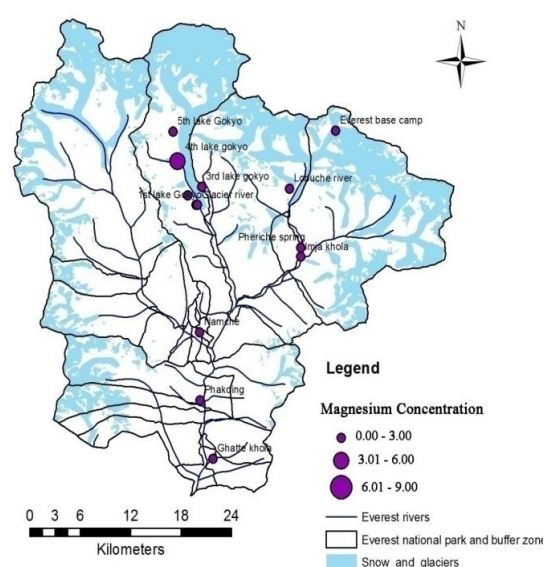
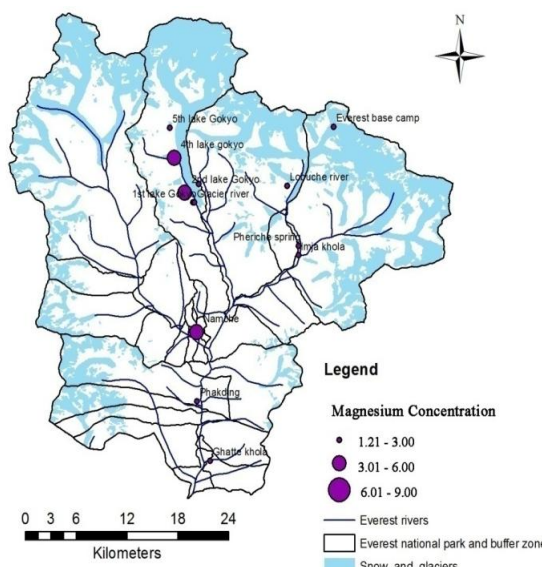


Fig. 21: Average magnesium (Mg) concentration (mg/l) in water bodies.

Fig. 22: Magnesium (Mg) concentration (mg/l) in water bodies in SNPBZ in 2010.

5.1.8.4 Manganese (Mn)

Generally, Manganese (Mn) was recorded <0.05 mg/l but some points exhibited the detectable amount. In lakes, Mn was recorded 0.01 to 0.22 mg/l; 0.22 mg/l value was found in 5th Gokyo lake in 2010. River showed the Mn range between 0.01 and 0.10 mg/l. Amount of Mn (0.1 mg/l) was recorded in Imja khola in 2009. In springs, Mn was recorded between 0.01 -0.11 mg/l. Namche spring showed 0.11 mg/l Mn in 2010 and Pheriche spring 0.06 mg/l in 2009 (Table 30).

Table 30: Manganese (Mn) content in waterbodies of SNPBZ in 2008, 2009 and 2010.

Waterbodies	Sites	Altitude (m)	Year				Overall average
			2008	2009	2010	Average	
Lake	5 th Gokyo lake	4950	0.01	NA	0.22	0.11	0.048
	4 th Gokyo lake	4860	0.01	0.05	0.05	0.03	
	3 rd Gokyo lake	4740	0.01	0.05	0.05	0.03	
	2 nd Gokyo lake	4716	0.01	0.05	0.07	0.04	
	1 st Gokyo lake	4661	0.01	0.05	0.05	0.03	
River	Glacier river	4656	0.01	0.10	0.05	0.05	0.042
	EBC river	5331	0.01	0.06	0.05	0.04	
	Lobuche river	4919	0.01	0.05	0.05	0.03	
	Imja khola	4165	0.01	0.10	0.05	0.05	
Spring	Pheriche	4279	0.01	0.06	0.05	0.04	0.037
	Namche spring	3440	0.01	0.05	0.11	0.05	
	Phakding spring	2593	0.01	0.05	0.05	0.03	
	Ghatte khola	2631	0.01	0.05	0.05	0.03	

(NA* = not recorded)

5.1.8.5 Zinc (Zn)

Zinc (Zn) content was recorded between 0.01 and 0.20 mg/l in all studied years in all water bodies. Zn was 0.12 mg/l in 1st Gokyo lake in 2009, 0.08 mg/l in Pheriche spring in 2009 and 0.20 mg/l in Namche spring in 2010 (Table 31).

Table 31: Zinc (Zn) content in waterbodies of SNPBZ in 2008, 2009 and 2010.

Waterbodies	Sites	Altitude (m)	Year			Average	Overall average
			2008	2009	2010		
Lake	5 th Gokyo lake	4950	NA	NA	0.05	-	0.04
	4 th Gokyo lake	4860	0.01	0.05	0.05	0.03	
	3 rd Gokyo lake	4740	0.01	0.05	0.05	0.03	
	2 nd Gokyo lake	4716	0.01	0.05	0.06	0.04	
	1 st Gokyo lake	4661	0.01	0.12	0.06	0.06	
River	Glacier river	4656	0.01	0.07	0.06	0.05	0.04
	EBC river	5331	0.01	0.07	NA*	0.04	
	Lobuche river	4919	0.01	0.07	NA*	0.04	
	Imja khola	4165	0.01	0.07	0.05	0.04	
Spring	Pheriche	4279	0.01	0.08	0.06	0.05	0.05
	Namche spring	3440	0.01	0.05	0.20	0.08	
	Phakding spring	2593	0.01	0.06	0.05	0.04	
	Ghatte khola	2631	0.01	0.05	0.05	0.04	

(NA* = not recorded)

5.1.8.6 Copper

Copper (Cu) content was found below the detection level <0.02 mg/l in all sampled water bodies (lake, spring and river) in the studied year (Table 32).

Table 32: Copper (Cu) content (mg/l) in water bodies of SNPBZ in 2008, 2009 and 2010.

Waterbodies	Sites	Altitude (m)	Year			Average	Overall average
			2008	2009	2010		
Lake	5 th Gokyo lake	4950	<0.02	<0.02	<0.02		<0.02
	4 th Gokyo lake	4860	<0.02	<0.02	<0.02		
	3 rd Gokyo lake	4740	<0.02	<0.02	<0.02		
	2 nd Gokyo lake	4716	<0.02	<0.02	<0.02		
	1 st Gokyo lake	4661	<0.02	<0.02	<0.02		
River	Glacier river	4656	<0.02	<0.02	<0.02		<0.02
	EBC river	5331	<0.02	<0.02	<0.02		
	Lobuche river	4919	<0.02	0.04	<0.02		
	Imja khola	4165	<0.02	0.08	<0.02		
Springs	Pheriche spring	4279	<0.02	0.10	<0.02		<0.02
	Namche spring	3440	<0.02	<0.02	<0.02		
	Phakding spring	2593	<0.02	<0.02	<0.02		
	Ghatte khola	2631	<0.02	<0.02	<0.02		

5.1.8.7 Lead (Pb)

Lead (Pb) was found below the detection level <0.02 mg/l in all samplings of water bodies (lake, spring and river) in 2008 to 2010 (Table 33).

Table 33: Lead (Pb) content (mg/l) in waterbodies in SNPBZ in 2008, 2009 and 2010.

Waterbodies	Sites	Altitude (m)	Year				Overall average
			2008	2009	2010	Average	
Lake	5 th Gokyo lake	4950	<0.02	<0.02	<0.02	<0.02	<0.02
	4 th Gokyo lake	4860	<0.02	<0.02	<0.02	<0.02	
	3 rd Gokyo lake	4740	<0.02	<0.02	<0.02	<0.02	
	2 nd Gokyo lake	4716	<0.02	<0.02	<0.02	<0.02	
	1 st Gokyo lake	4661	<0.02	<0.02	<0.02	<0.02	
River	Glacier river	4656	<0.02	<0.02	<0.02	<0.02	<0.02
	EBC river	5331	<0.02	<0.02	<0.02	<0.02	
	Lobuche river	4919	<0.02	<0.02	<0.02	<0.02	
	Imja khola	4165	<0.02	<0.02	<0.02	<0.02	
Spring	Pheriche	4279	<0.02	<0.02	<0.02	<0.02	<0.02
	Namche spring	3440	<0.02	<0.02	<0.02	<0.02	
	Phakding spring	2593	<0.02	<0.02	<0.02	<0.02	
	Ghatte khola	2631	<0.02	<0.02	<0.02	<0.02	

5.2 Aquatic Biota

5.2.1 Algae

Fifty nine species of algae belonging to four families (Chlorophyceae, Bacillariophyceae, Cyanophyceae and Xanthophyceae) were recorded during the present study. Twenty seven species belonging to family Chlorophyceae, 22 species to Bacillariophyceae, 9 species to Cyanophyceae and one species to family Xanthophyceae were enumerated (Table 34). In Total 46% of algal species belonged to family Chlorophyceae, followed by 37% to Bacillariophyceae and 15% to Cyanophyceae and 2% to Xanthophyceae. Chlorophycean genera were: *Actinotaenium*, *Bulbochaete*, *Chlorella*, *Closterium*, *Cosmarium*, *Cylindrocapsa*, *Cylindrocystis*, *Euastrum*, *Hyalotheca*, *Mougeotia*, *Netrium*, *Oedogonium*, *Pediasium*, *Penium*, *Phacus*, *Scenedesmus*, *Sphaerocystis*, *Spirogyra*, *Staurastrum* and *Zygnema*.

Among Bacillariophyceae, genus *Eunotia* consisted of three species, *Fragilaria* two species, *Cymbella* two species and *Gomphonema* one species. Other recorded genera were: two species of *Pinnularia*, two species each of *Ceratoneis*, *Cocconeis*, *Denticula*, *Diatoma*, *Frustulia*, *Meridion*, *Navicula*, *Stauroneis*, *Surirella*, *Synedra* and *Tabellaria*. Locality wise, Gokyo 1st lake, Gokyo 3rd lake, Pheriche had high number of algal species (Table 34).

Table 34: Enumeration of algal species from Sagarmatha National Park and Buffer Zone.

SN	Name of species	Class	Locality	Altitudinal range (m)	Habitat
1.	<i>Actinotaenium cf. subglobosum</i>	Chlorophyceae	Larcha dovan	2700	Stagnant water at edge of Dudh kosi river
2.	<i>Anabaena</i> sp.	Cyanophyceae	Namche, beteen 1 st and 2 nd lake	3400-4700	Running water
3.	<i>Botryococcus cf. braunii</i>	Xanthophyceae	between Pheriche and Lobuche	4300	Stagnant water
4.	<i>Bulbochaete</i> sp.	Chlorophyceae	1 st Lake gokyo	4660	From outlet of 1 st lake Gokyo
5.	<i>Ceratoneis arcus</i>	Bacillariophyceae	Lobuche khola, 1 st lake, bet. 1 st and 2 nd lake, Thamo, bet. 2 nd and 3 rd Lake	3600-4700	Slow running water
6.	<i>Chlorella vulgeria</i>	Chlorophyceae	Between 1 st and 2 nd lake	4650	Slow running water
7.	<i>Closterium acerosum</i>	Chlorophyceae	Between 1 st and 2 nd lake, Namche, Pheriche, Thamo, 2 nd and 3 rd lake	3400-4700	Running water
8.	<i>Cocconeis placentula var. euglypta</i>	Bacillariophyceae	Thamo	3700	Small pond edge of Bhotekoshi
9.	<i>Cosmarium subspeciosum</i>	Chlorophyceae	Luza, Pheriche	4300	Stagnant as well as running
10.	<i>Cosmarium awadhense</i>	Chlorophyceae	Thame, 1 st lake	3700-4660	Stagnant water
11.	<i>Cosmarium cf. sublateriundatum</i>	Chlorophyceae	Larcha dovan	2700	Stagnant water with rocky habitat
12.	<i>Cosmarium nudum</i>	Chlorophyceae	Just below to 1 st lake	4600	Moist sloppy rocks
13.	<i>Cylindrocapsa</i> sp.	Chlorophyceae	Namche spring	3400	Running water
14.	<i>Cylindrocystis brebissonii</i>	Chlorophyceae	Luza khola	4300	Running water
15.	<i>Cymbella cymbiformis</i>	Bacillariophyceae	Between 1 st and 2 nd lake, 1 st lake, Pheriche	4300-4700	Stagnant as well as running water
16.	<i>Cymbella lanceolata</i>	Bacillariophyceae	Lobuche, Pheriche, Thamo	3700-4600	Running water
17.	<i>Denticula</i> sp.	Bacillariophyceae	Between 1 st and 2 nd lake	4700	Running water
18.	<i>Diatoma hiemale var. mesodon</i>	Bacillariophyceae	Larcha dovan, Pheriche, Thamo, 2 nd and 3 rd , Thame, between 1 st and 2 nd lake,	2700-4770	Running water
19.	<i>Euastrum coralloidae var. trigibberum</i>	Chlorophyceae	Luza khola	4300	Running water
20.	<i>Euastrum oblongum</i>	Chlorophyceae	Pheriche	4300	Stagnant water
21.	<i>Eunotia alpina</i>	Bacillariophyceae	Luza	4300	Running water
22.	<i>Eunotia lunaris</i>	Bacillariophyceae	Pheriche	4300	Stagnant water at edge of lobuche khola
23.	<i>Eunotoia coralloides</i>	Bacillariophyceae	Just below 1 st lake	4600	Sloppy moist rocky habitat like lichen
24.	<i>Fragilaria capucina var. vaucheriae</i>	Bacillariophyceae	Between Pheriche and Lobuche, between 1 st and 2 nd lake, Larcha dovan	2700-4700	Running water

25.	<i>Fragilaria crotonensis</i>	Bacillariophyceae	Lobuche, Pheriche, Thamo	3700-4600	Running water
26.	<i>Frustulia rhomboids</i>	Bacillariophyceae	Luza khola	4300	Running water
27.	<i>Gloeocapsa aeruginosa</i>	Cyanophyceae	Between Pheriche and Lobuche	4300	Stagnant water
28.	<i>Gomphonema geminatum</i>	Bacillariophyceae	Between pheriche and lobuche, Namche	3400-4300	Running water
29.	<i>Gomphonema sphaerophorum</i>	Bacillariophyceae	Thame, between 1 st and 2 nd lake, Thamo	3700-4700	Running water
30.	<i>Hyalotheca dissiliens</i>	Chlorophyceae	Pheriche	4300	Stagnant water
31.	<i>Meridion circulare</i>	Bacillariophyceae	Pheriche	4300	Stagnant water at edge of lobuche khola
32.	<i>Merismopedia glauca</i>	Cyanophyceae	Thamo, Lobuche khola, just below 1 st lake, between Pheriche and Lobuche	3700-4300	Stagnant as well as running water
33.	<i>Mougeotia</i> sp.	Chlorophyceae	Below 1 st lake, between 1 st and 2 nd lake, Luza, Pheriche	4300-4700	Moist steep rocks, stagnant as well as running water
34.	<i>Navicula perrotetti</i>	Bacillariophyceae	Thame, Thamo, Luza, Pheriche	3700-4300	Running as well as stagnant water
35.	<i>Netrium digitus</i>	Chlorophyceae	Luza	4300	Running water
36.	<i>Oedogonium</i> sp.	Chlorophyceae	Between Pheriche and Lobuche, 1 st lake	4300-4660	Stagnant water
37.	<i>Oscillatoria subbrevis</i>	Cyanophyceae	Just below 1 st lake	4600	Moist rocks in sloppy region
38.	<i>Oscillatoria agardhii</i>	Cyanophyceae	Larcha dovan, Lobuche	2700-4900	Stagnant water
39.	<i>Oscillatoria brevis</i>	Cyanophyceae	Lobuche	4900	Stagnant water
40.	<i>Oscillatoria cf. Insignis</i>	Cyanophyceae	Between 2 nd and 3 rd lake	4700	Running water
41.	<i>Pediastum duplex</i>	Chlorophyceae	Between Pheriche and Lobuche	4300	Stagnant water
42.	<i>Penium cylindrus</i>	Chlorophyceae	Pheriche	4300	Stagnant water
43.	<i>Phacus</i> sp.	Chlorophyceae	Namche	3400	Running water
44.	<i>Phormidium</i> sp.	Cyanophyceae	1 st lake	4660	Outlet of 1 st gokyo lake
45.	<i>Pinnularia viridis</i>	Bacillariophyceae	Thame, Namche, Lobuche khola, Pheriche	3400-4900	Running as well as stagnant water
46.	<i>Pinnularia braunii</i>	Bacillariophyceae	Namche	3400	Running water
47.	<i>Scenedesmus bijugatus</i>	Chlorophyceae	Pheriche, Namche	3400-4300	Running water
48.	<i>Scenedesmus quadricauda</i>	Chlorophyceae	Just below 1 st lake, Pheriche	4300-4600	Sloppy moist rocky region and running water
49.	<i>Scenedesmus bijuga</i>	Chlorophyceae	Below Pheriche and Lobuche	4300	Stagnant water
50.	<i>Scenedesmus cf. obliquus</i>	Chlorophyceae	Namche	3400	Running water
51.	<i>Sphaerocystis schroeteri</i>	Chlorophyceae	Between Pheriche and Lobuche	4300	Stagnant water
52.	<i>Spirogyra cf. amplectens</i>	Chlorophyceae	Below 1 st lake, 1 st lake, Namche, Larcha dovan,	2700-4660	Rocky sloppy region, running water, stagnant water
53.	<i>Staurastrum</i> sp.	Chlorophyceae	Larcha dovan, Luza, Namche, Between 1 st and 2 nd lake, Between Pheriche and Lobuche,	2700-4700	Running as well as stagnant water
54.	<i>Stauroneis phoenicenteron</i>	Bacillariophyceae	Thame	3700	Running water
55.	<i>Stigonema mamillosum</i>	Cyanophyceae	Imja lake	5000	Out let of Imja lake
56.	<i>Surirella didyma</i>	Bacillariophyceae	Between Pheriche and Lobuche, Larcha dovan	2700-4300	Stagnant water
57.	<i>Synedra ulna</i>	Bacillariophyceae	Between 1 st and 2 nd lake, between Pheriche and Lobuche, 2 nd and 3 rd lake	4300-4700	Stagnant as well as running water
58.	<i>Tabellaria flocculosa</i>	Bacillariophyceae	Luza, Pheriche, Thamo	3700-4300	Running water
59.	<i>Zygnema</i> sp.	Chlorophyceae	Lobuche khola, Just below 1 st lake, between 2 nd and 3 rd lake.	4700-4900	Moist Rocky habitat as well as running water

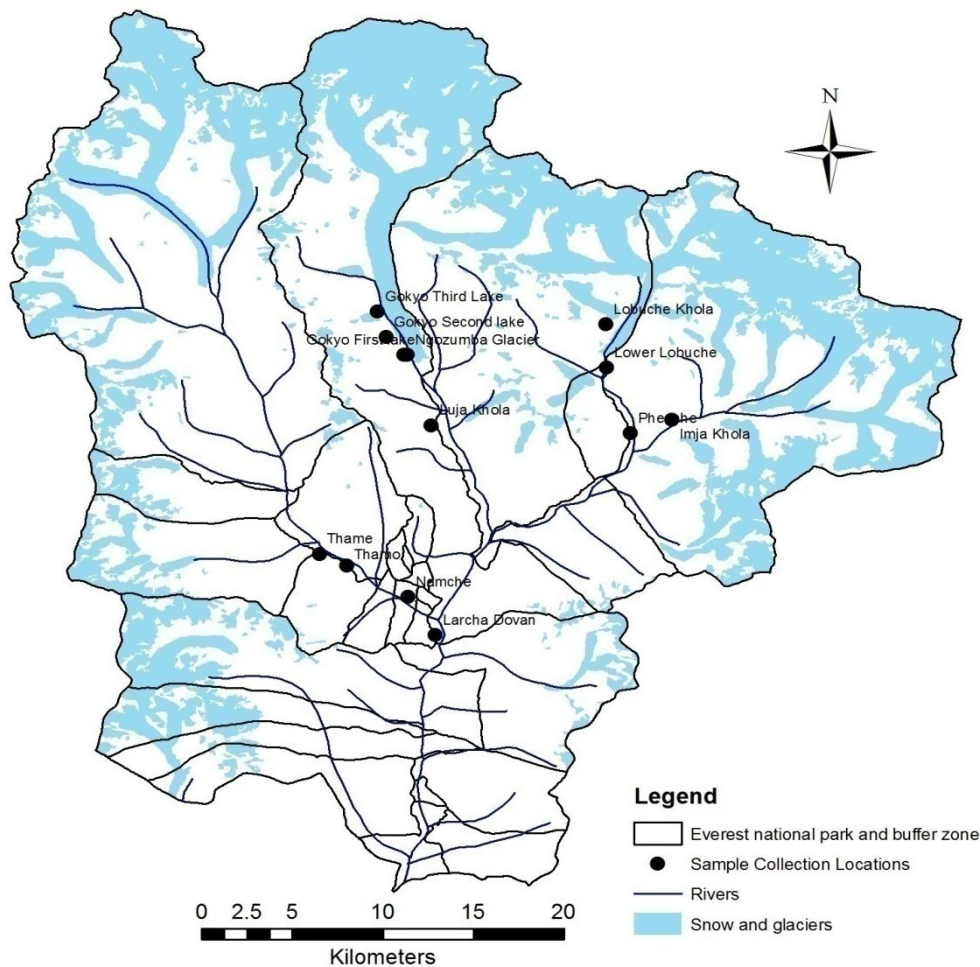


Figure 23: Map showing sampling stations and algal occurrence in Sagarmatha National Park.

Relationship between environmental variables and algal diversity (multivariate analysis)

Quite high gradient length (>6 SD units), exceptionally high species heterogeneity with fair dispersion of species along the first and second DCA axes was found. First DCA axis explained about 63.2% variance in the species data, and the second axis explains about 43.7% of the variance (Fig. 24). Eigen values for the succeeding axes were much lower showing a redundant secondary gradient. Cumulative percentage variance of species data shows that the first and second DCA axes altogether represent more than 70% of the variation in the data. It means the first two axes (mainly the DCA1) are the most important to explain the algal species diversity.

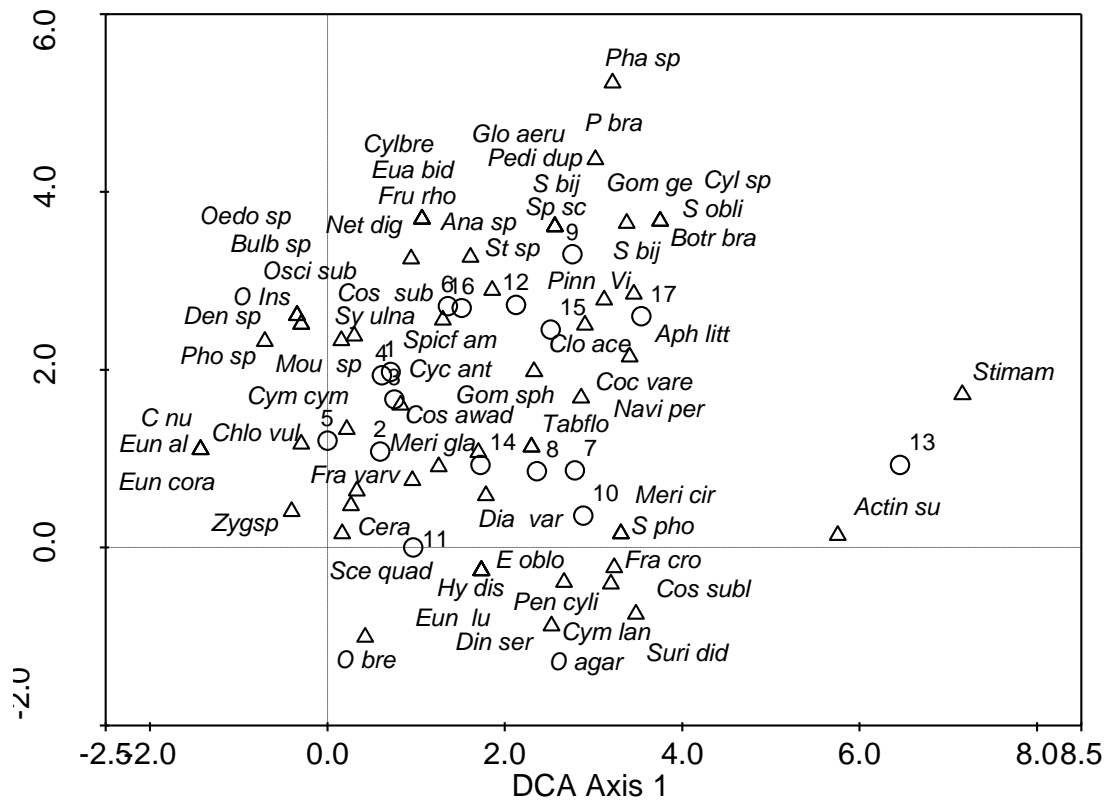


Figure 24: DCA diagram (showing the relationship between sampling plot and species composition).

Species description: (Actinsub, *Actinotaenium cf. subglobosum*; Ana sp, *Anabaena* sp.; Aph litto, *Aphanocapsa littoralis*; Botr bra, *Botryococcus cf. braunii*; Bulb sp, *Bulbochaete* sp.; Cera, *Ceratoneis arcus*; Chlo vul, *Chlorella vulgaris*; Clo ace, *Closterium acerosum*; Coc vareu, *Cocconeis placentula var. euglypta*; Cos subs, *Cosmarium subspeciosum*; Cos awad, *Cosmarium awadhense*; Cos subl, *Cosmarium cf. sublateriundatum*; C nu, *Cosmarium nudum*; Cyc ant, *Cyclotella antique*; Cyl sp, *Cylindrocapsa* sp.; Cylbre, *Cylindrocystis brebissonii*; Cym cym, *Cymbella cymbiformis*; Cym lan, *Cymbella lanceolata*; Den sp, *Denticula* sp.; Dia varm, *Diatoma hiemale var. mesodon*; Din ser, *Dinobryon cf. sertularis*; Eua bid, *Euastrum cf. bidentatum*; E oblo, *Euastrum oblongum*; Eun al, *Eunotia alpine*, Eun lu, *Eunotoia lunaris*; Eun cora, *Eunotoia coralloides*; Fra yarv, *Fragilaria capucina var. vaucheriae*, Fra cro, *Fragilaria crotonensis*; Fru rho, *Frustulia rhomboids*; Glo aeru, *Gloeocapsa aeruginosa*; Gom ge, *Gomphonema geminatum*; Gom sph, *Gomphonema sphaerophorum*; Hy dis, *Hyalotheca dissiliens*; Meri cir, *Meridion circulare*, Meri gla, *Merismopedia glauca*; Mou sp, *Mougeotia* sp.; Navi perro, *Navicula perrotetti*; Net dig, *Netrium digitus*; Oedo sp, *Oedogonium* sp.; Osci sub, *Oscillatoria subbrevis*; O agar, *Oscillatoria agardhii*; O bre, *Oscillatoria brevis*; O Ins, *Oscillatoria cf. Insignis*; Pedi dup, *Pediastrum duplex*; Pen cyli, *Penium cylindrus*; Pha sp, *Phacus* sp.; Pho sp, *Phormidium* sp.; Pinn Vir, *Pinnularia viridis*; P bra, *Pinnularia braunii*; S bij, *Scenedesmus bijugatus*; Sce quad, *Scenedesmus quadricauda*; S bij, *Scenedesmus bijuga*; S obli, *Scenedesmus cf. obliquus*; Sp sc, *Sphaerocystis schroeteri*; Spicf am, *Spirogyra cf. amplexans*; St sp, *Staurastrum* sp.; S pho, *Stauroneis phoenicenteron*; Stimam, *Stigonema mamillosum*; Suri did, *Surirella didyma*; Sy ulna, *Synedra ulna*; Tabflo, *Tabellaria flocculosa*; Zygsp, *Zygnema* sp.)

Heterogeneity was found between sampling points and species composition. Sampling point 6 (luza khola), sampling point 16 (Macharmmo khola), sampling point 12 (Lobuche khola) showed more or less similar species composition. Similarly sampling point 15 (Phakding springs), sampling point 17 (Lukla springs) showed more closeness in species composition (Fig. 24).

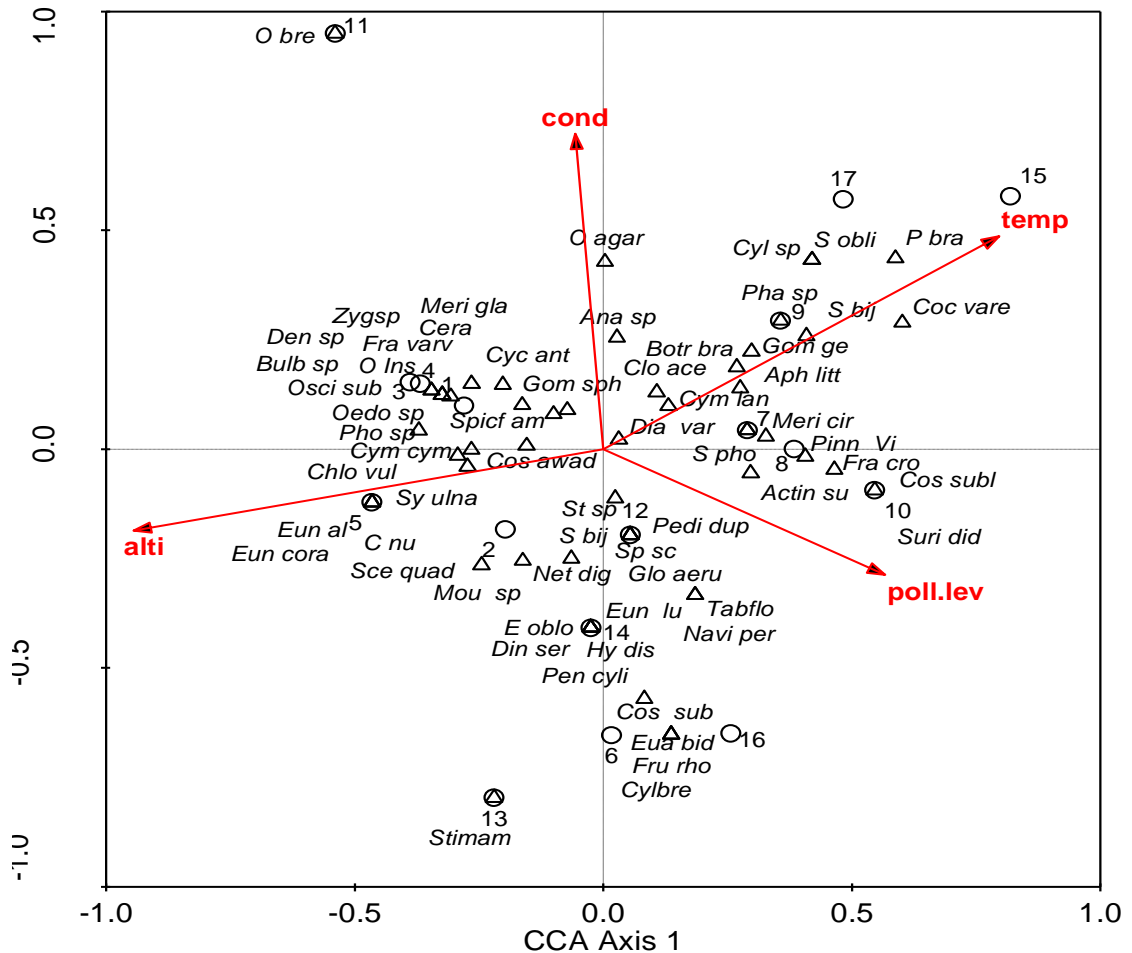


Figure 25: CCA diagram (showing the relationship between significant environmental variables with algal species).

Pinnularia braunii, *Scenedesmus cf. obliquus*, *Cylindrocapsa* sp., *Phacus* sp., *Scenedesmus bijuga*, *Cocconeis placentula var.euglypta* and *Aphanocapsa littoralis* showed positive significant relationship with temperature. Generally higher temperature favours occurrence of these species. Sampling point 15 (Phakding spring), sampling point 17 (Lukla spring) and sampling point 9 (Namche spring) were in lower altitude having higher temperature (Fig. 25).

Actinotaenium cf. subglobosum, *Surirella didyma*, *Cosmarium cf. sublateriundatum*, *Fragilaria crotonensis*, showed strong positive co-relation with pollution level. More

diatom species showed strong positive correlation with altitude and negative with temperature. These were found in very high altitude (above 4500m altitude sampling point 2 (Gokyo 3rd lake) and sampling point 5 (glacier near 1st Gokyo lake). These species are *Eunotia alpine*, *Eunotoia coralloides*, *Synedra ulna*, *Cosmarium nudum*, *Scenedesmus quadricauda*, *Mougeotia* sp.. These are cold tolerant species. Similarly, *Cylindrocystis brebissonii*, *Frustulia rhomboids*, *Euastrum cf. bidentatum*, *Cosmarium subspeciosum*, and *Penium cylindrus* had negative correlation with conductivity (Fig. 25).

Bulbochaete sp, *Oscillatoria subbrevis*, *Oedogonium* sp., *Phormidium* sp., *Denticula* sp, *Fragilaria crotonensis*, *Spirogyra cf amplexens*, *Zygnema* sp. had negative relationship with pollution level in the sampling point 1 (4th Gokyo lake), sampling point 3 (Gokyo 2nd lake), and sampling point 4 (Gokyo 1st lake) (Fig. 25).

5.2.2 New record of Algal species for Nepal

Six species of algae (*Euastrum coralloides*, *Euastrum oblongum*, *Penium cylindrus*, *Spirogyra amplexens*, *Cymbella lanceolata* and *Oscillatoria insignis*) were recorded as new to Nepal. Taxonomic descriptions of these species are as follows.

Chlorophyceae

1. *Euastrum coralloides* Josh. var. *trigibberum* Lagerheim

Class- Zygnematophyceae

Order- Desmidiiales

Family- Desmidiaceae

Genus- *Euastrum*

Species- *coralloides*

Locality: Luza Khola

Altitude: 4300 m

Habitat: Running water

Cell 40 µm long, 30 µm broad; semicell has five facial swellings; isthmus 13 µm wide; thickness 19 µm. (Plate 4)

2. *Euastrum oblongum* (Grev.) Ralfs ex Ralfs

Class- Zygnematophyceae

Order- Desmidiiales

Family- Desmidiaceae

Genus- *Euastrum*

Species- *oblongum*

Locality: Pheriche

Altitude: 4300m

Habitat: stagnant water

Cell 148 μm long, 74 μm broad; a deep, close median apical invagination, lateral invaginations many. (Plate 4)

3. *Penium cylindrus* (Ehr.) ex Bréb

Class- Zygnematoophyceae

Order- Zygnematales

Family- Peniaceae

Genus- *Penium*

Species- *cylindrus*

Locality: Pheriche

Altitude: 4300m

Habitat: Stagnant water

Cell 41 μm long, 11.5 μm broad, cylindrical with truncately rounded ends; cell wall dotted, bands present (Plate 4).

4. *Spirogyra amplexans* Skuja

Class- Zygnematophyceae

Order- Zygnematales

Family- Zygnemataceae

Genus- *Spirogyra*

Species- *amplexans*

Locality: Below Gokyo 1st lake, below than 1st lake, Namche, Larcha Dovan

Altitude: 2700-4660 m

Habitat: Rocky sloppy region, running water, stagnant water

Vegetative cell 143 μm long, 18 μm broad; chloroplast single; conjugation lateral; zygospore 61 μm long, 36 μm broad, ellipsoid (Plate 4).

Bacillariophyceae

One species belonging to class Bacillariophyceae was recorded for Nepal from the study area Sagarmatha National park. Taxonomical description of new recorded species is as follows

5. *Cymbella lanceolata* Kirchner

Class- Bacillariophyceae

Order- Cymbellales

Family-Cymbellaceae

Genus- Cymbella

Species- *lanceolata*

Locality: Lobuche, Pheriche, Thamo

Altitude: 3700-4600m

Habitat: Running water

This species was perviously reported from Europe (Spain) by Alvarer cobelas and Estever Garcia (1982) and South East Asia (Singapur) Pham *et al.* (2011) (Plate 4).

Cyanophyceae

Oscillatoria insignis Skuja collected from Gokyo lakes at an elevation of 4700 m was new record for Nepal.

6. *Oscillatoria insignis* Skuja. (Plate 4)

Class- Cyanophyceae

Order- Oscillatoriales

Family-Oscillatoriaceae

Genus- *Oscillatoria*

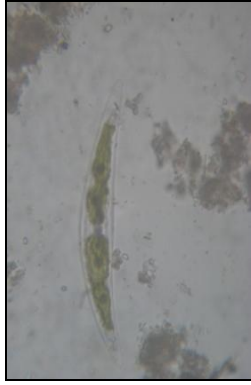
Species- *insignis*

Synonym: *Phormidium insigne* (Skuja) Anagnostidis

Locality: Between 2nd and 3rd lake Gokyo

Altitude: 4700 m

Habitat: Running water



Pseudolunga borge



Cosmarium cf portianum



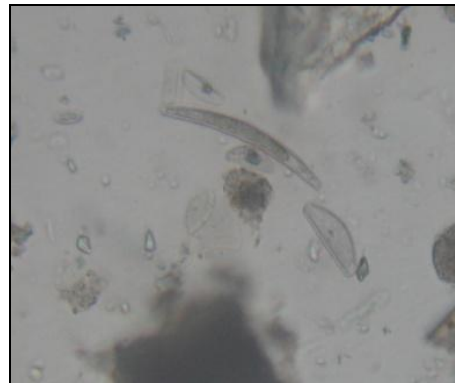
Closterium acerosum



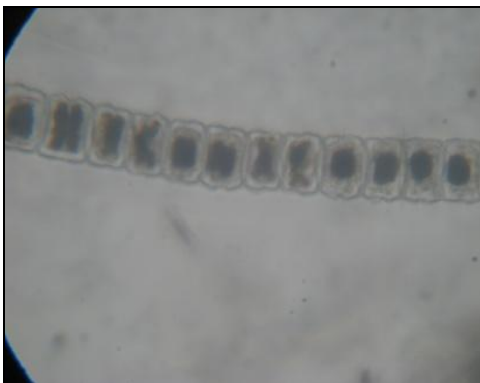
Cosmarium granatum



Cosmarium obsoletum



Hennae arcus

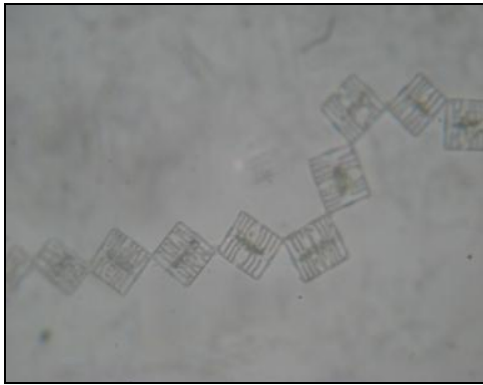


Hyalotheca dissilens



Gom. Geminatum

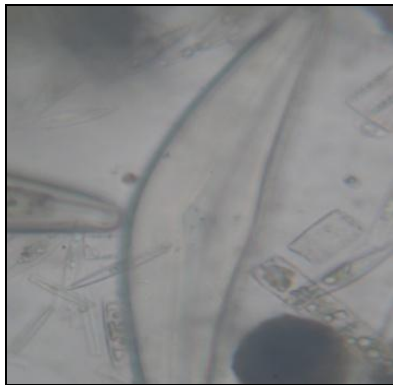
Plate 3: Algal species recorded in SNPBZ.



Tabellaria flcocuulosa



Cl (1). ochthodes v. amoebum



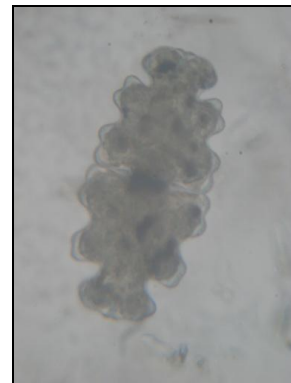
Cymbella cf lanceolata



Spirogyra amplexens



Oscillatoria insignis



Euastratum oblongum



E. corallides v. trigibberum



Penium cylindrus

Plate 4: Algal species recorded in SNPBZ.

5.2.3 Bacteria

Bacterial presence (*Escherichia coli* and *Streptococcus faecolies*) was recorded in the water samples collected from spring at Phakding, Namche Bazaar (near garbage pit), Pheriche, Thado Khola at Phakding, Everest Base Camp, Machhermo Khola, Bhote Koshi below Thame (Fig. 26 and Tables 35-37).

Table 35. Bacterial presence in lakes water of SNPBZ. (- absent, + presence)

Sites	2008				2009				2010			
	Total coli.	E. coli	S. fae.	P. aer.	Total coli	E. coli	S. fae	P. aer	Total coli	E. coli	S. fae.	P. aer
Gorekshep lake	-	-										
Small lake near Gorekshep	-	-	-	-	-	-	-	-	-	-	-	-
Pyramid lake	-	-	-	-	-	-	-	-	-	-	-	-
1st lake of Gokyo	-	-	-	-	-	-	-	-	-	-	-	-
2nd lake of Gokyo (outlet)	-	-	-	-	-	-	-	-	-	-	-	-
3rd lake of Gokyo outlet	-	-	-	-	-	-	-	-	-	-	-	-
4th lake Gokyo	-	-	-	-	-	-	-	-	-	-	-	-
4th lake Gokyo	-	-	-	-	-	-	-	-	-	-	-	-
3rd lake of Gokyo	-	-	-	-	-	-	-	-	-	-	-	-
Imja lake near outlet	-	-	-	-	-	-	-	-	-	-	-	-
Imja lake outlet	-	-	-	-	-	-	-	-	-	-	-	-

Table 36. Bacterial presence in springs water of SNPBZ.

Sampling points	2008				2009				2010			
	Total coli.	E. coli	S. fae.	P. aer.	Total coli	E. coli	S. fae.	P. aer.	Total coli	E. coli	S. fae.	P. aer.
Ghatte khola	-	-	-	-	-	-	-	-	-	-	-	-
Hadi khola	-	-	-	-	-	-	-	-	-	-	-	-
Muse khola	-	-	-	-	-	-	-	-	-	-	-	-
Thado koshi	-	-	-	-	-	-	-	-	-	-	-	-
Ghatta khola	-	-	-	-	-	-	-	-	-	-	-	-
Thado khola near phakding	+	-	+	-	+	-	+	-	+	-	+	-
Monju khola	-	-	-	-	-	-	-	-	-	-	-	-
Phunki tenga spring	-	-	-	-	-	-	-	-	-	-	-	-
Pheriche spring	+	-	+	-	+	-	+	-	+	-	+	-
Lobuche khola	+	-	-	-	+	-	-	-	+	-	-	-
Pangboche spring	-	-	-	-	-	-	-	-	-	-	-	-
Machhermo khola	+	+	-	-	+	+	-	-	+	+	-	-

Luza khola	-	-	-	-	-	-	-	-	-	-	-	-
Dole river	-	-	-	-	-	-	-	-	-	-	-	-
Namche spring	-	-	-	-	-	-	-	-	-	-	-	-
Namche spring (mid of namche)	+	+	-	-	+	+	-	-	+	+	-	-
Mouth of source of spring of namche	-	-	-	-	-	-	-	-	-	-	-	-
Thame khola (spring)	+	+	-	-	+	+	-	-	+	+	-	-
Thame khola (KBC)	-	-	-	-	-	-	-	-	-	-	-	-
Theso khola	-	-	-	-	-	-	-	-	-	-	-	-
Mislung (Tap)	-	-	-	-	-	-	-	-	-	-	-	-
Namche spring	-	-	-	-	-	-	-	-	-	-	-	-
Mislung spring	-	-	-	-	-	-	-	-	-	-	-	-
Tok-tok khola	-	-	-	-	-	-	-	-	-	-	-	-
Amphulapchacho	-	-	-	-	-	-	-	-	-	-	-	-
Somera	+	-	-	-	+	-	-	-	+	-	-	-
Tamang spring	+	-	-	-	+	-	-	-	+	-	-	-

Table 37. Bacterial presence in rivers water of SNPBZ.

Name of sampling point	2008				2009				2010			
	Total coli	E. coli	S. fae.	P. aer.	Total coli	E. coli	S. fae.	P. aer.	Total coli	E. coli	S. fae.	P. aer.
Dudh Koshi at Phakding	-	-	-	-	-	-	-	-	-	-	-	-
Dudh koshi above Jorsalle	-	-	-	-	-	-	-	-	-	-	-	-
Dudh koshi at Punki Tenga	-	-	-	-	-	-	-	-	-	-	-	-
Dudh koshi at Pangboche and Deboche	-	-	-	-	-	-	-	-	-	-	-	-
Dudhkoshi between pheriche and Pangboche	-	-	-	-	-	-	-	-	-	-	-	-
Lobuche khola from side of Pheriche	-	-	-	-	-	-	-	-	-	-	-	-
Imja khola below Dengboche village	-	-	-	-	-	-	-	-	-	-	-	-
Imja just upper Dengboche village	-	-	-	-	-	-	-	-	-	-	-	-
Lobuche near meeting of Chola pass	-	-	-	-	-	-	-	-	-	-	-	-
Lobuche khola near Lobuche	-	-	-	-	-	-	-	-	-	-	-	-
Snow melt from Everest base camp	+	-	+	-	+	-	+	-	+	-	+	-
Ngozumpa glacier	-	-	-	-	-	-	-	-	-	-	-	-
Dudhkoshi at Phorse Tenga	-	-	-	-	-	-	-	-	-	-	-	-
Bhotekoshi above Thame	-	-	-	-	-	-	-	-	-	-	-	-
Bhotekoshi below a bride betn Thamo n Thame	-	-	-	-	-	-	-	-	-	-	-	-
Bhotekoshi near Thamo	-	-	-	-	-	-	-	-	-	-	-	-
Dudh koshi below Surke	-	-	-	-	-	-	-	-	-	-	-	-

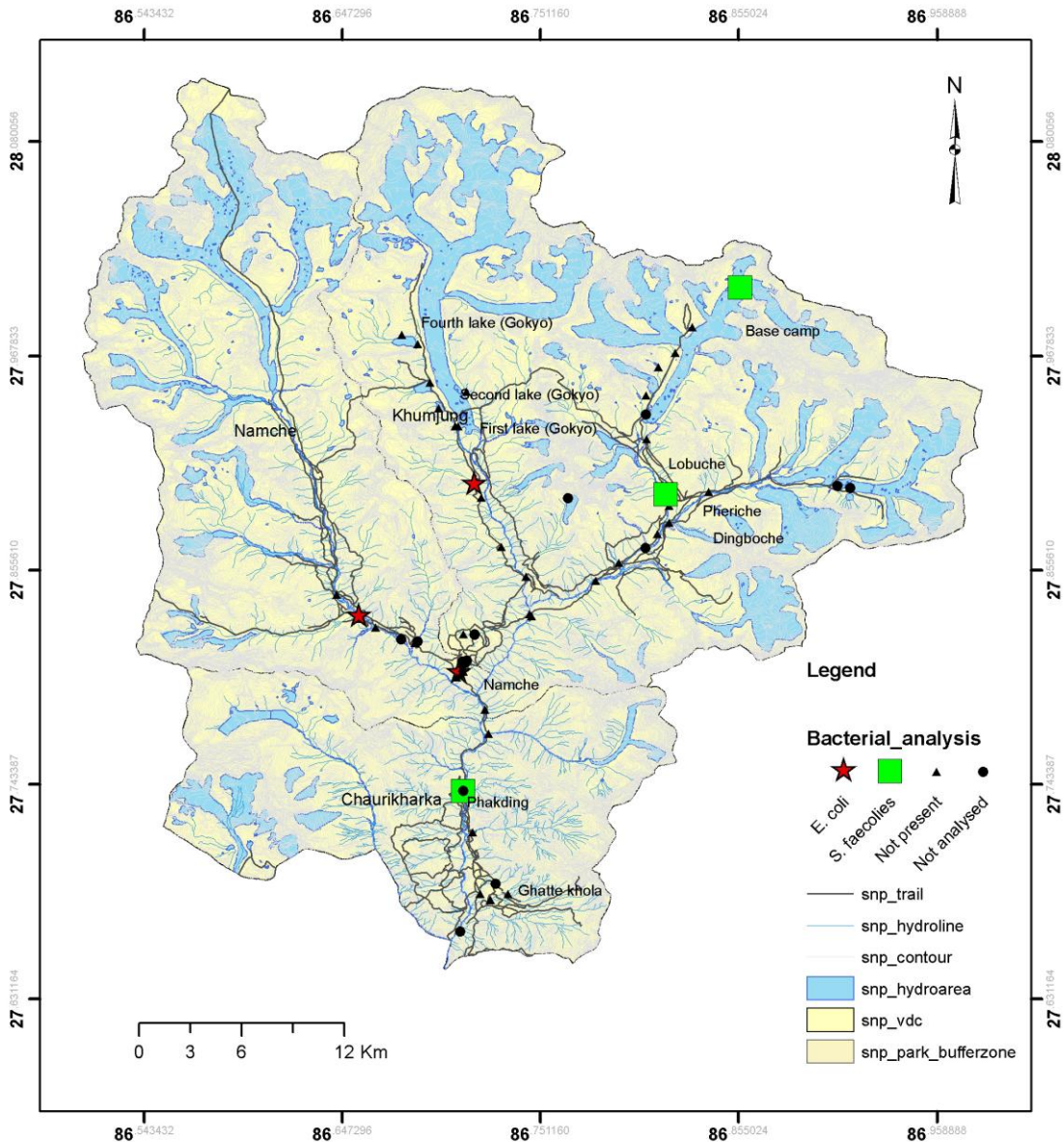


Figure 26: Bacterial contamination in river water in SNPBZ.

5.2.4 Micro-invertebrate

Total five orders of invertebrate (Ephemeroptera, Plecoptera, Tricoptera, Trichedida and Diptera) representing fourteen families (Baetidae, Heptageniidae, Amelidae, Nemouriidae, Capniidae, Perlidae, Leuctridae, Leptoceridae, Rhyacophilidae, Glossosomatidae, Planariidae, Chironomidae, Simuliidae, Tripulidae) were recorded during the present study in different waterbodies of the SNPBZ from Lukla to Everest base Camp, Gokyo lake series and towards Imja lake (Table 38). Baetidae was found as the dominant family in SNPBZ region. Gerentially it occurred at all localities and types of water. More families of invertebrates were present in running water than in stagnant water.

Table 38: Enumeration of aquatic micro-invertbrate from SNPBZ.

SN	Order	Family	Locality
1	Ephemeroptera	Baetidae	Monju khola, Phorse tenga, Gokyo lake, Dudhkoshi, Pangboche, Imja khola, Glacier below 1 st lake, Dole river, Lake above pyramid
		Heptageniidae	Monju khola, Gokyo lake, Dudhkoshi, Pangboche, Dole river
		Amelidae	Pheriche
2	Plecoptera	Nemouriidae	Monjo khola, Phorse Tenga, Pheriche, Lobuche khola, Imja khola, Glacier below 1 st lake, Dole river
		Capniidae	Phorse Tenga, Dole river
		Perlidae	Pangboche
		Leuctridae	Lukla khola,
3	Trichoptera	Leptoceridae	Monju khola, Gokyo lake
		Rhyacophilidae	Phorse Tenga, Dudhkoshi
		Glossosomatidae	Dole river
4	Tricladida	Planariidae	Phorse Tenga, Lobuche khola, Glacier below 1 st lake, Dole river
5	Diptera	Chironomidae	Lobuche khola, Glacier near Gorekshep, Glacier below 1 st lake, Lake above pyramid, Lukla khola
		Simulidae	Gokyo lake
		Tripulidae	Lukla khola

Family Baetidae was found most dominating covering 80% of the samples taken from different localities as well as water bodies (Fig. 27).

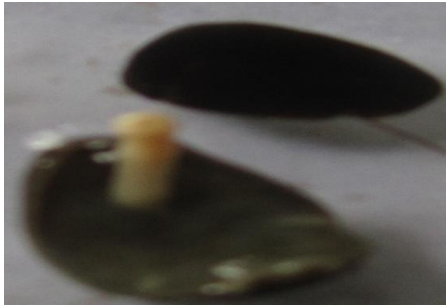
Amelidae, Perlidae, Tripulidae and Simulidae were found in very few samples (Fig. 27). Family Simulidae of order Diptera was found only in the water of Gokyo lake. Similarly, Tripulidae family was found only in the Lukla khola at comparatively low altitude in the SNPBZ. Very less representing families were: Perlidae, Leuctridae of the Plecoptera order from the samples collected from Pangboche spring and Lukla spring (Ghatte khola), respectively.



Glossosomatidae



Heptageniidae



Planaridae



Baetidae larva



Baetidae adult



Tipulidae



Leuctridae



Heptageniidae



Rhyseophilidae



Simulidae

Plate 5: Aquatic micro-invertebrate from SNPBZ.

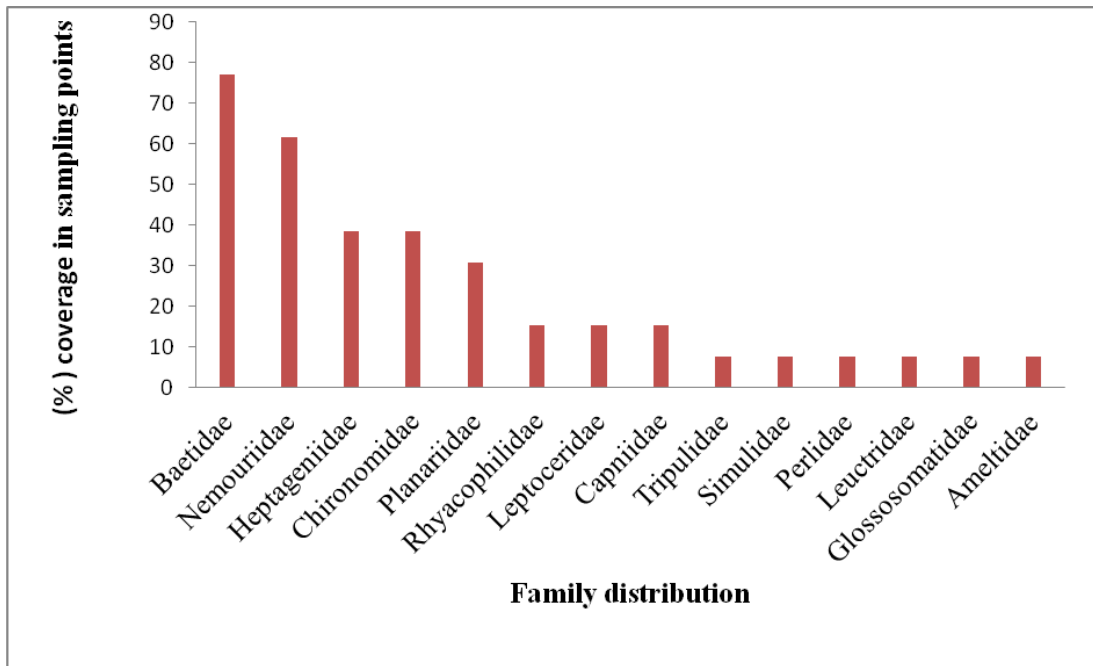


Figure 27: Familywise distribution of microinvertebrates in SNPBZ.

5.3 Water Pollution Sources

5.3.1 Toilet and Septic Tank

Nearly 20% of surveyed houses were without toilet. Generally these houses were along the trekking route. Most of the septic tanks had stone wall (without cement work) having impermeability between 50-60% especially in lodges due to inadequate space, high costing of cement, and very poor cementing to stone due to low temperature at high altitude but in agricultural sides litter toilets were found common. Impermeability of cemented wall septic tank was over 90%, stone wall around 50-60% and litter toilet around 20-30% were estimated. In very rare case, hotel lodges had cemented septic tank. In many cases, lodges with cemented toilet directly discharged human waste into Dudhkoshi river at Phakding and Jorsalle. It was observed that toilets were drained into springs in Lukla tamang tole (Table 39). Most of the houses at Phakdings, Jorsalle, etc, especially lodges had stone wall septic tank (non-cemented). There were a few septic tanks with cemented wall having 90% impermeability.

Litter toilet was the most common in settlements like Chaurikharka, Kunde, Khumjung, Phortse, and Thame. These settlements have been less benefited from mainstream tourism in Khumbu, and therefore agriculture still is a common practice. Organic fertilizer prepared from litter used toilets was most preferred for potato fields.

Table 39: Details of toilet / septic tank that is the source of pollution in SNPBZ. (Septic tanks: A) with cement wall, B) with stone wall (non-cemented), and (C) simple pit (including litter toilet).

Settlements	Total Households (HH)	Total HH surveyed	No. of toilets in surveyed HH	No. of septic tanks in survey HH	Number (percentage) of different types of septic tanks**			No of households having no toilet
					A	B	C	
Lukla	153	22	97	36	7 (19.4)	20 (55.6)	9 (25.0)	2
Chaurikharka	45	14	21	17	1 (5.9)	2 (11.8)	14 (82.4)	0
Phakding	24	7	46	5	0 (0)	4 (80.0)	1 (20.0)	4
Dhadokoshi	7	3	2	2	0 (0)	0 (0)	2 (100)	1
Jorsella	22	7	29	11	0 (0)	6 (54.4)	5 (45.5)	1
Namche	141	13	77	19	3 (15.8)	9 (47.4)	7 (36.8)	3
Kunde	69	8	11	11	0 (0)	1 (9.1)	10 (90.1)	1
Khumjung	163	6	17	8	0 (0)	2 (25.0)	6 (75.0)	0
Tangboche	6	7	20	16	0 (0)	5 (31.3)	11 (68.8)	1
Pangboche	105	10	23	17	0 (0)	7 (41.2)	10 (58.8)	1
Pheriche	18	8	19	11	0 (0)	7 (63.6)	4 (36.4)	2
Dingboche	80	8	25	18	0 (0)	15 (83.3)	3 (16.70)	1
Lobuche	7	4	9	3	0 (0)	3 (100)	0 (0)	3
Gorekshep	6	4	12	5	0 (0)	5 (100)	0 (0)	1
Porste	82	6	12	10	0 (0)	3 (30.0)	7 (70.0)	0
Dole	10	7	14	12	0 (0)	4 (33.3)	8 (66.7)	2
Gokyo	9	4	22	7	0 (0)	5 (71.5)	2 (28.6)	1
Phurste	12	12	19	11	0 (0)	5 (45.5)	6 (54.5)	5
Thame	60	6	14	8	0 (0)	5 (62.5)	3 (37.5)	1
Thamo	45	6	13	9	0 (0)	5 (55.6)	4 (44.4)	2

Only 4.66% toilets had septic tanks with cement wall, whereas 47.45% toilets had simple pit and 47.88% with stone wall (Fig. 28).

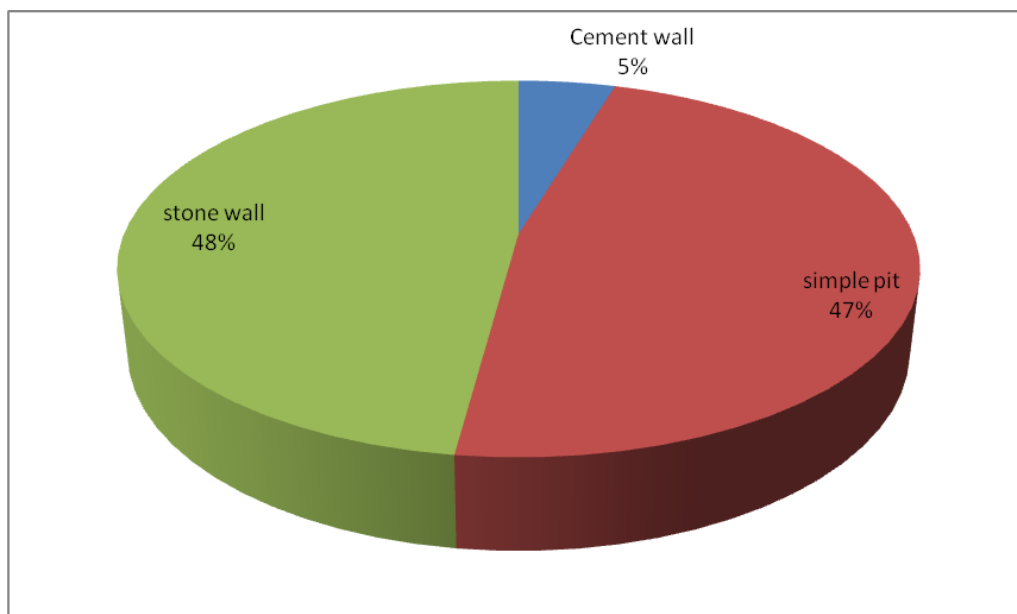


Figure 28: Percentage of different type of toilets.

5.3.2 Organic fertilizer production and utilization

Nitrogen in soils of Chaurikharka was found 2.1%, but less in Thamo (1.5%) and Phorste (1.15%) (Table 41). Major agricultural sites were Chaurikharka, Phorste, Dinboche, and Khumjung. The species used for litter in Chaurikharka were *Rhododendron* sp., *Liyonia* sp., where as *Betula* sp. and *Rhododendron* sp. were used as litter at other sites in high altitude.

Table 40: Amount of organic fertilizer production and used in different settlements in SNPBZ.

Settlements	HH surveyed	Organic fertilizer production (kg)	Organic fertilizer used in settlements (kg/sqm)
Lukla	22	22,475	0.82
Chaurikharka	14	29,510	0.49
Phakding	70	27,375	0.40
Thado Koshi	3	9,100	0.70
Jorsalle	7	29,650	0.21
Namche	13	6,950	1.37
Kunde	8	8,750	0.87
Khumjung	6	11,875	---
Pangboche	10	7,750	0.89
Pheriche	8	5,500	0.37
Dingboche	8	6,500	1.06
Portse	6	10,750	1.09
Dole	7	5,000	0.59
Phurte	12	5,750	0.09
Thame	6	14,500	1.44
Thamo	6	4,825	0.91
Total		2197000	
Average		1.7 t/HH	0.82

Total annual production of organic fertilizer in SNPBZ was about 2197 t. A household produced an average of 1.7 t, and it was used at the rate of 0.82 kg/sq m in the farm lands (Table 40).

Table 41: N, P and K (%) in different types of organic fertilizer in SNPBZ.

SN	Type of fertilizer	N (%)	P (%)	K (%)
1.	Fresh litter	1.50	0.91	3.35
2.	Decomposed litter	0.95	0.63	1.06
3.	Litter + Cow dung	2.10	0.59	2.35
4.	Litter + pig dung	1.56	0.57	1.72
5.	Litter + Toilet waste	0.78	0.68	1.39
Average		1.15	0.68	1.71
Contribution (kg/ha)		94.3	53.76	140.22

Different types of organic fertilizers were used in farmlands of SNPBZ; these were: decomposed litter, litter + cow dung, litter + pig dung, and litter + human waste in toilets. Nitrogen, phosphorous and potassium content varied among the different types of organic fertilizers (Table 40). Potassium was found higher in fresh litter (3.35%) followed by litter + cow dung (2.35%). Similarly, Phosphorous was 0.91% in fresh litter (Table 41).

Nitrogen content ranged from 0.78 to 2.1% (average 1.15%); phosphorous content ranged from 0.57 to 0.91% (average 0.68%); and potassium ranged from 1.06 to 3.35% (average 1.71%) in different types of fertilizer. Only two households in the Namche Bazaar revealed the use of chemical fertilizer in their farm. Thus the contribution of N, P and K in soil was 94.3 kg/ha, 53.76 kg/ha and 140.22 kg/ha, respectively (Table 41). The chemical fertilizer is not sold in the market in SNP BZ.

5.3.3 Tourism and solid waste generation

Since the opening of Khumbu region for tourists, around half a million tourists (national and international) visited the SNP. The number of tourists in the Khumbu region slided down after 1999 because of insurgency in Nepal, but an accelerated trend was seen from 2007 (as a result of peace in the country) and reached to 26511 in 2007, 31201 in 2008 and 29036 in 2009.

Table 42: Solid waste data generated in SNPBZ (Source: SPCC report 2001-2010, Khanal *et al.* 2010)

Fiscal year	Burnable All (kg)	Non - burnable (kg)	Expedition team			
			Burnable (kg)	Bottle/tin (kg)	Used up batteries (pcs)	Used up O2 cylinder (pcs)
2001-02	71561	30128	3866	2187	3397	632
03-04	148886	55639	6160	1711	3669	773
4-5/5-6	458051	124398	19412	4700	8389	833
2006-07	160935	24141	10901	14193	4359	1174
2007-08	175718	45868	5003	45683	3617	1540
2008-09	251121	26761	NA	NA	7480	1182
2009-010	263723	28004	NA	NA	NA	NA

Tourist number was recorded 32084 in 2010 and 36518 in 2012. In addition to the international tourists, a large number of people as porter and guide accompany tourists and national researchers.

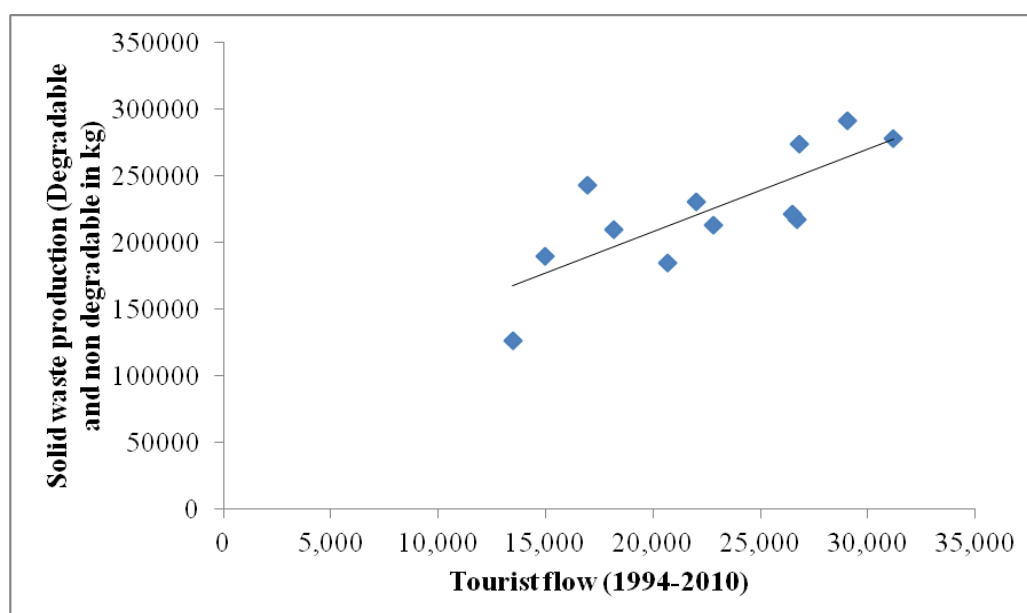


Figure 29: Corelation between tourist flow and solid waste generation in SNPBZ.

Large number of tourists and trekkers leave a huge quantity of garbage and human excreta in the SNP. In 1994, the total garbage (waste) altogether burnable as well as non burnable was recorded 126,373 kg; at that time international tourist flow was 13461. This amount increased with increase of tourist flow; 213,112 kg of waste in 1999 with tourist number 26788. In 2007, 221586 kg of waste, at that time the tourist number was 26511. 7.95 kg/ tourist waste generated was calculated in 1966, where as in 8.36 kg/tourist waste generated in 2007 (Table 42). Similarly 277,883 kg generated waste was recorded by SPCC in 2008 which reached 291,727 kg total waste (degradable and non degradable) was recorded in 2009 (SPCC, 2011). From this, it was concluded that solid waste generation rapidly increased with increase in tourist number (Fig. 29).



a) Garbage pit on the bank of Machhermo. The distance between pit and water is less than 5 m.



b) Garbage pit of Thame near Thame river.

Plate 6: Sources of water pollution.



a) Toilet on the bank of Lobuche river of Pheriche.



b) Garbage disposed on the bank of Dudhkoshi at Phakding.

Plate 7: Sources of water pollution.



a) Constructing of garbage pit near the water course.



b) A temporary toilet at Everest Base Camp. Waste outside the tank can be seen.

Plate 8: Sources of water pollution.



a) Everest Base Camp: one of the world's most crowded tourist destination.



b) Public toilet at Chukkung. Toilet waste flows out on the surface near the water course.

Plate 9: Sources of water pollution.

5.4 Fluvial Function Level (INDEX) of water bodies

Fluvial Function Index (FFI) of water bodies was recorded. Water bodies (rivers and springs as well as out and inlet of lakes) were classified into different types on the basis of their threats and disturbance. From the conversion Table from the FFI, excellent, good, poor and very poor status of the water bodies of different sampling points were calculated. It is a useful tool to assess the most important ecological aspects of the whole course of a river such as riparian areas, morphological characteristics and biological features.

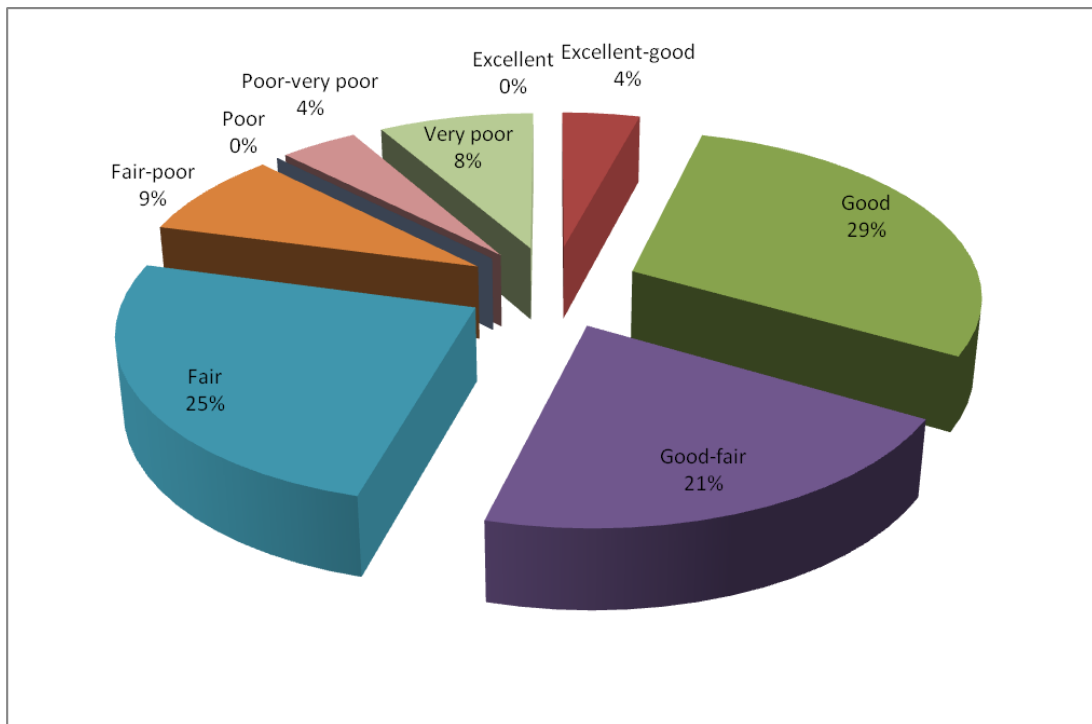


Figure 30: FFI category of water bodies in SNPBZ.

More sites of springs and rivers showed good fluvial functional level (29%), which is followed by fair (25%) and Good-fair (21%), very poor (8%), poor to very poor (4%) (Fig. 30). Muse khola was categorized into good to excellent in condition (Fig. 31). Very dense vegetation in left and right of the river, good extension of primary as well as secondary perfluval zone, well developed riparian vegetation which all combined affect the good hydrological ecosystem as well as sustainable developed model ecosystem than the other streams system.

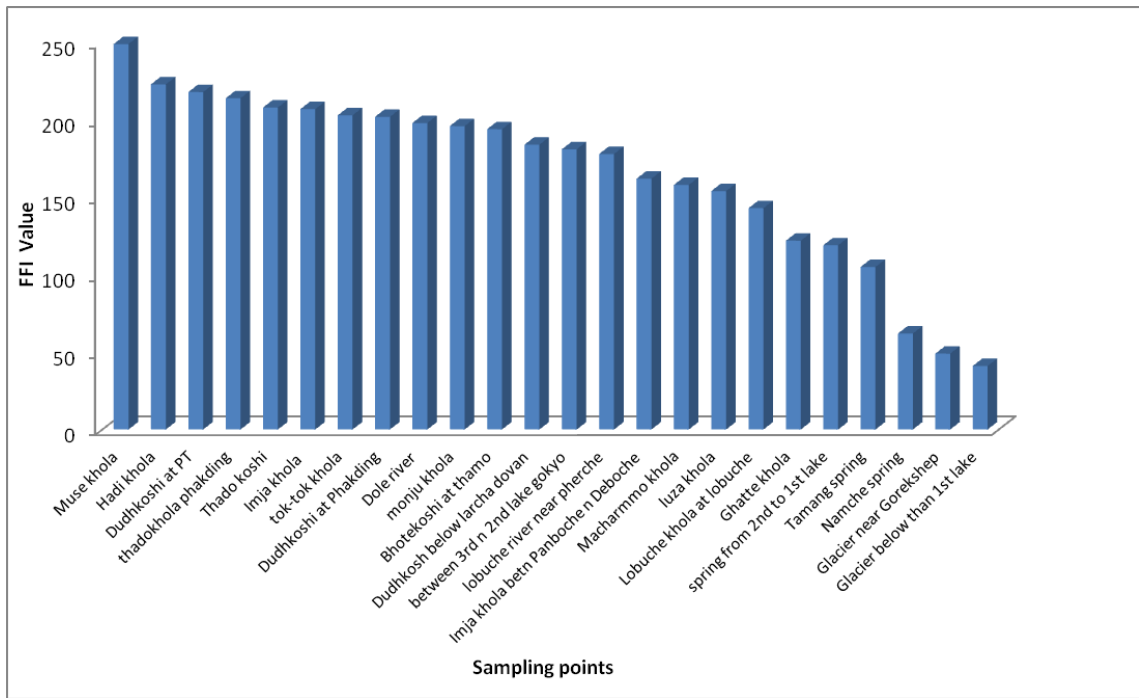


Figure 31: FFI value of different sampling stations of water bodies in SNPBZ.

CHAPTER 6: DISCUSSION

Physical, chemical and biological parameters were studied to record the status of water quality in different waterbodies (springs, rivers and lakes) in Sagarmatha National Park and Buffer zone (SNPBZ). Important features, trend and new information have been found under the present study.

6.1 Physico-chemical characters

6.1.1 Temperature, pH, TDS and Conductivity

Water temperature at high altitude is generally low between 4.1°C and 15°C. Water temperature changes with season and time, hence can not be compared with other reports easily. However, water temperature can give some insight to biological features.

Water temperature of Gokyo 3rd lake was recorded 6°C, 7.5 ° C of Gokyo 2nd lake and of Pyramid lake 3.7-5.5°C (Tartari *et al.* 1998). The water temperature of 3rd Gokyo lake was 10.4°C where as 6°C previous by Tartari *et al.* (1998). Similarly 2nd lake Tartari *et al.* reported 7.5°C where as the mean value was found 10.2°C. Sharma *et al.* (2010) also recorded the temperature of surface water of Gokyo 3rd lake as 8°C and 2nd lake had 7°C for the surface water. Glacier retreat in the Everest region was found very rapidly (5.5-8.7 m / annum) which accelerated (5.56-9.1 m/annum) during the 1997-2001 (Ren *et al.* 2004) which may be due to climate change (Ives 2005). So, there was increasing trend of temperature of the water bodies of SNPBZ. The average temperature was found in the order; spring>river> lake (Fig. 7). It is altitude dependent. River and lakes origin from glacier. So, average temperature of spring shows higher than river and lakes.

The pH of an aquatic system is determined by a number of factors such as, CO₂ concentration in water, geology and soils of watershed, drainage from mine sites, pollution, etc. CO₂ enters in water bodies from the variety of sources including atmosphere, runoff from land, release from bacteria in water and respiration by aquatic organisms. CO₂ from the respiration of aquatic organisms and from the atmosphere reacts with water to form a weak acid. Human activities also influence pH. Water flowing through mine tailings (waste rock from mining operations) can

become acidic because of the presence of minerals. Drainage from these areas into soft-water streams or streams with little buffering minerals lower the pH.

pH of water in lakes, springs and river was found within the range between 6.0 to 8.0 (Tables 9-11). Lami *et al.* (2007) recorded the pH range between 6.2 to 8.2 in the high altitude lakes of Khumbu valley. Antoninetti *et al.* (1998) also recorded the range between 7.4 to 8.2 in the lake water of Khumbu Himal area. Renold *et al.* (1998) found 6.5 to 8.7 in the surface water of upper Khumbu region. Present study shows similar trend in all types of waterbodies. Previous studies in the lakes, springs and rivers showed similar range. pH value of 3rd Gokyo lake in 1998 was 7.2, 2nd Gokyo lake was 7.3, the lake above the Pyramid had pH between 7.2 to 7.9 (Tartari *et al.* 1998), where as the present study reveals pH 7.8 in Gokyo 3rd lake, 7.4 pH in Gokyo 2nd lake and 7.9 in Gokyo 1st lake (Table 9). In case of springs, different streams showed almost same range when compared with the previous reports. Lobuche khola at Pheriche had pH 7.5 (Tartari *et al.* 1998) where as it was measured 7.2 in the present study. From pH point of view, all water bodies are still good for drinking as well as other purposes.

Average pH of lake water was found significantly higher than springs and rivers (Fig. 8a). All springs run near to settlements. Garbage pit, organic waste, agricultural waste are very near to spring water bodies. So, due to high rate of decomposition of waste spring water shows acidic in nature. pH trend in water bodies were in the following order: Lake > river > spring (Fig. 8a). From pH point of view, lake and river experienced less anthropogenic disturbance than spring. Namche springs, Phakding spring, Lobuche spring, Pangboche springs got more waste from the settlements.

Although all water samples from lakes, springs and rivers (except very few place) had pH within the standard limits but lakes and rivers showed increasing (alkalinity) pH during 2008, 2009 and 2010 (Tables 9-11). Though, water pH was found fluctuating year to year, but in general, mean comparison between the springs, lakes and rivers, lake exhibited higher water pH than springs and river.

Conductivity and total dissolved solids (TDS) were found very low and did not show any significant change through out the study period. Similarly no significant difference in conductivity and TDS were found between lakes, springs and lake water

(Tables 15-17 and Tables 18-20). TDS and conductivity data reveal that water bodies of SNPBZ are still unpolluted. Previous reports also concluded the similar result. Lobuche khola (0.01 to 0.04 S/cm) at different point of lobuche, 0.015 S/cm by Imja khola, 0.01 to 0.004 S/cm by Gokyo lake series by Tartari *et al.* (1998), where as between 0.01 and 0.04 were found in the Gokyo lake series in the present study (Table 15).

Lami *et al.* (2007) recorded 0.008-0.067 S/cm for high altitude lakes of Khumbu valley, 0.011 to 0.51 S/cm by Antoninetti *et al.* (1998) for Khumbu lake water. 0.019 to 0.057 s/cm in the streams of upper Khumbu valley by Renold *et al.* (1998). Tiberti *et al.* (2010) recorded 0.01 to 0.17s/cm in the alpine lakes in Italy.

6.1.2 TN-NO₃ and TP-PO₄

Very high amount of nitrogenous compounds are contained in domestic sewage. Runoffs from agricultural field also contain nitrate. Although high concentration of nitrate are useful in irrigation but their entry into water causes eutrophication. The most important sources of nitrogen are the biological oxidation of organic nitrogenous substances produced from sewage and industrial waste mixing in the water.

General comparison between lakes, springs and rivers showed that spring water had more total nitrogen (1.198 mg/l) than rivers (0.922 mg/l) and lakes (0.82 mg/l). Although all data were found within the national standard set for drinking water, WHO, USEPA. During the present study, TN-NO₃ was found significantly increased in 2008, 2009 and 2010 in SNPBZ. In all the cases, trend of TN was found in the order: 2010>2009>2008> previous studies (Figs. 12 a-d).

Total nitrogen as nitrate in the lake was recorded between 0.4 mg/l and 1.03 mg /l (Table 20). Imja Lake (outlet) and 4th Gokyo lake showed higher quantity of TN-NO₃. Nitrate in Gokyo 3rd lake was 0.056 mg/l where as the total nitrogen was 0.21 mg/l (Table 21). Similarly, 2nd Gokyo lake 0.065 mg/l as nitrate and TN 0.31 mg/l was recorded by Tartari *et al.* (1998), Antoninetti *et al.* (1998) found 0.18 to 0.75 mg/l nitrate- nitrogen for lake water but the present study showed 0.86 mg/l average Nitrogen as nitrate. Present result showed a little increase in nitrogen than the earlier reports. Pyramid lake showed 0.86 mg/l average nitrogen as nitrate where as 0.11 mg/l – 0.301 mg/l total nitrogen was recorded between 1990-1997 by Tartari *et al.* (1998).

Lami *et al.* (2007) found TN between 0.12 mg/l and 0.75 mg/l with mean value 0.29 mg/l for high altitude lakes but present study revealed that the average value of TN as nitrate was found 0.82 mg/l which is higher than the maximum value for the quantity reported earlier. The average total nitrogen in lakes was recorded 1.05 mg/l in 2010, which indicates that there is increase of nitrogen in all types of waterbodies.

Ngozumpa glacier showed 0.37 mg/l TN as nitrate where as in present study it was 1.05 mg/l (0.71 mg/l in 2008, 2.17 mg/l in 2010). Lobuche khola at lobuche as well as Pheriche also exhibited significantly higher TN than the earlier report (Tartari *et al.* 1998). It was recorded 0.17 to 0.237 mg/l earlier but 1.41 mg/l in Lobuche khola at Pheriche and 0.75 mg/l at Lobuche which is 4-5 folds greater than the previous record. Springs were found running through or nearby agricultural land, settlement, garbage pit, septic tank (toilet) and direct discharge waste was found towards nearby springs (i.e. Phakding, Lobuche, Pheriche, Tamang Spring Lukla, Namche spring, etc) (Table 23). Reynolds *et al.* (1998) reported the range on NO₃-N in Khumbu region, 0.01 to 0.69 mg/l for surface water and 0.15 to 0.17 mg/l for spring's water, 0.03 to 0.21 mg/l for glacier melt water of Khumbu region and 0.04 to 0.29 mg/l for stream of Upper khumbu valley. Earlier report (Reynolds *et al.* 1998) revealed NO₃-N between 0.15 to 0.17 mg/l in the upper Khumbu valley melt water streams where as in the present study, it was found between 0.1 and 1.94 mg/l. The anthropogenic impacts on waterbodies through organic waste, disposal of human excreta, construction of garbage pit near to water course etc are non point sources that appear to enhance TN-NO₃ in waterbodies of Khumbu.

Lami *et al.* (2007) analyzed the lake water chemistry and concluded that phosphorous content was lower than 0.005 mg/l in more than 50% samples from Khumbu valley, where as the present average phosphorous as phosphate value was found 0.345 mg/l (Table 24). Antoninetti *et al.* (1998) recorded between 0.002 to 0.011 mg/l phosphate in lake water of Khumbu Himal which was less than that obtained in 2007 by Lami *et al.* An increasing trend of phosphorous in waterbodies in SNPBZ has been recorded during present study.

Average phosphorus values were found more in springs (0.46 mg/l) than lakes (0.345 mg/l) and rivers (0.335 mg/l) (Fig. 13a). The trend was found similar to TN-NO₃ and

pH. The annual variation also showed an increasing trend of total phosphate in water bodies in SNPBZ.

6.1.3 Metals

Iron (Fe) content in eighteen out of thirty nine water samples from thirteen sampling sites was found higher than the WHO and Nepalese standard for drinking purpose. Fe was found between <0.02 and 8.92 mg/l (Table 27), the highest at Gokyo 5th Lake at 4950 m. In the year 2008, three samples showed higher quantity of Fe than standards; these were 0.4 mg/l at Everest Base Camp, Lobuche river at Pheriche 0.4 mg/l and 0.7 mg/l at Imja khola just below Dengboche village. Quantity of Fe was found increased in year 2009, seven samples showed higher Fe content than standard: at 4th Gokyo lake (1.38 mg/l), 3rd Gokyo lake (0.48 mg/l), 2nd Gokyo lake (0.53 mg/l), Glacier river below 1st lake (3.06 mg/l), Everest base camp (1.05 mg/l), Lobuche river near Pheriche (1.58 mg/l) and Imja khola near Denboche village (3.6 mg/l). The 4th Gokyo lake had highest average iron concentration (0.98 mg/l) compared to 1st and 2nd Gokyo lakes during all sampling period. Similar trend was recorded by Sharma *et al.* (2012); 1.6 mg/l in 4th Gokyo lake, 0.85 mg/l in Gokyo 3rd lake and 0.73 mg/l in 2nd lake (Table 27).

Sharma *et al.* (2010) have also recorded almost similar result in the Gokyo lakes: 1.0 - 1.5 mg/l Fe in 2008 and 0.6-1.5 mg/l in 2009. During present study, eight samples showed higher quantity of iron in 2010 than that of WHO and Nepalese standards for drinking purpose: 5th Gokyo lake (8.92 mg/l), 4th Gokyo lake (1.35 mg/l), 3rd Gokyo lake (1.2 mg/l), 2nd Gokyo lake (1.92 mg/l), 1st Gokyo lake (1.92 mg/l), Glacier river below 1st lake (1.37 mg/l), Imja khola below Dengboche village (3.5 mg/l), Namche spring (2.46 mg/l) (Fig. 15). But all the data for Fe in springs, lakes and rivers were found higher than the earlier reports (Renold *et al.*, 1998, Tartari *et al.*, 1998). Fe / organic matter ratio increase due to change in the amount of anoxic ground water rich in Fe, feeding into these river system (Kritzberg and Ekstrom, 2011) and also mining of enriched ores, intensified forestry, peat presence and agricultural draining have increased the load of iron in the river ecosystem. Hence from these data, it is concluded that the quantity of iron in waterbodies has increasing trend in most of the waterbodies in SNPBZ. The increased Fe may affect the bio-chemical cycling of arganic matter, phosphorous and nitrogen. Increasing concentration of Fe can have direct and indirect toxic effect on aquatic biota (Kritzberg and Ekstrom, 2012).

Sodium (Na) and Magnesium (Mg) were at the lower level than the standard threshold (Tables 28 and 29). However, an increasing trend in Na and Mg when compared with the earlier reports were observed. Reynolds *et al.* (1998) had reported 1.61 mg/l (0.71-1.61 mg/l) content of Na, where as in present investigation, it was 0.2-6.4 mg/l (Figs. 19, 20), 6.4 mg/l in 2nd Gokyo lake in 2008, 3.83 mg/l in Namche spring in 2009, 3.15 mg/l at Imja khola near Denboche village in 2010, 2.8 mg/l at Namche spring and 2.78 in 2nd Gokyo lake in 2009. Sodium (Na) content recorded in the present study was almost higher than the quantity reported by Sharma *et al.* (2010). They found 0.9-1.1 mg/l in Gokyo lake series in 2008 and 1.0-1.2 mg/l in 2009 which was lower than the value recorded here. Sharma *et al.* (2012) reported 0.92 mg/l in 2nd lake, 1.19 mg/l in 3rd lake, 0.26 mg/l Sodium in 4th lake. There are a number of anthropogenic sources of sodium that can contribute significant quantity of sodium to surface water, including trail salt, water treatment chemicals, domestic water softeners and sewage effluents (WHO, 1979).

Magnesium (Mg) was earlier reported between 0.11 and 0.52 mg/l (Reynolds *et al.* 1998), but in present investigation, it was found between 0.49 at Pheriche and 8.7 mg/l at Namche spring (Figs. 21-22). At some places, Mg content was high, such as: 2nd Gokyo lake 6.2 mg/l, 6.2 mg/l at 1st Gokyo lake, 6 mg/l at Lukla (Ghatte khola), 4.86 mg/l at 4th Gokyo lake, 3.7 mg/l at four spots (Glacier river, Lobuche river at Pheriche, Imja khola at Dengboche, Phakding springs) (Table 29). These values indicate that Mg concentration in the Khumbu region is increasing.

Manganese (Mn) was found between 0.01 at many sites to 0.22 mg/l. 0.22 mg/l at 5th Gokyo lake, 0.11 mg/l in Namche spring, 0.1 mg/l in Imja near Dengboche village and 0.1 mg/l in Glacier river (Table 30).

The average concentration of zinc (Zn) was well below the limit of WHO (3 mg/l) and Nepalese standard for safe drinking water at all the sampling points. Zinc was found between 0.01 mg/l -0.2 mg/l, however four samples had an increase of Zn in 2009 and 2010 compared to 2008 samplings. Zn content 0.2 mg/l was recorded at Namche spring where as 0.12 mg/l at 1st Gokyo lake (Table 31).

Copper (Cu) content was found in detectable quantity in three water samples collected from Lobuche river (0.04 mg/l), Lobuche river before mixing Imja (0.1

mg/l), Imja khola near to Dengboche village (0.08 mg/l) (Table 32). Increase in copper contamination is observed, however it is less than the prescribed standard level.

The concentration of lead (Pb) was also very low in all samplings (Table 33).

Based upon the present study, it can be said that, the concentrations of metals were found gradually increased (2010>2009>2008>previous report), particularly Na and Mg.

6.2 Biological characteristics

6.2.1 Algae

A total 59 taxa of algae were recorded between altitudes 2777-5007 m. A total 27 chlorophycean algae under 20 genera have been reported from SNPBZ. Twenty two species of Bacillariophyceae under 16 genera, nine species of Cyanophyceae under 6 genera and one species of Xanthophyceae were identified (Table 34).

Out of 27 chlorophycean algae, 20 algae were identified up to species level where as seven were identified only up to genus level. Twenty genera were *Actinotaenium* (1 sp.), *Bulbochaete* (1sp.), *Chlorella* (1sp.), *Closterium* (1 sp.), *Cosmarium* (4 spp.), *Cylindrocapsa* (1sp.), *Cylindrocystis* (1 sp.), *Euastrum* (2 spp.), *Hyalotheca* (1sp.), *Mougeotia* (1 sp.), *Netrium* (1 sp.), *Oedogonium* (1 sp.), *Pediasium* (1sp.), *Penium* (1 sp.), *Phacus* (1 sp.), *Scenedesmus* (4 spp.), *Sphaerocystis* (1 sp.), *Spirogyra* (1sp.), *Staurastrum* (1sp.) and *Zygnema* (1 sp.). In the present study, four chlorophycean algal taxa viz., *Euastrum coralloides* Josh. var. *trigibberum* Lagerheim, *Euastrum oblongum* (Grev.) Ralfs ex Ralfs, *Penium cylindrus* (Ehr.) ex Bréb. and *Spirogyra amplexans* Skuja were reported for the first time from Nepal. These species were collected from running water, stagnant water, rocky and sloppy moist habitats at Pheriche, Luza khola, below 1st lake, in 1st lake, Namche and Larcha dovan between 2700-4600 m elevation.

Green algae (Chlorophyceae) common to this area like *Closterium*, *Scenedesmus*, *Cosmerium*, *Spirogyra* genera have also been reported from Sikkim Himalaya range, 3000-5,500 m elevation (Kumar and Rai, 2005). Yoshimura *et al.* (1997) also reported five species of algae from Yala glacier, central Nepal (Langtang region). Among them

one species *Cylindrocystis brebissonii* is also found in Khumbu region. Takeuchi *et al.* (1998) also reported *Cylindrocystis brebissonii* from Himalayan glacier (Shorong region of East Nepal) altitude between 4950-5380 m.

Generally unicellular, colonial algae and desmids are found to be dominant in stagnant water where as filamentous green algae are common in both running and stagnant water bodies. Due to chilling temperature, chlorophycean algae were not as much dominant as in warm climate of Tarai of the country.

Total 22 species of 17 genera belonging to class Bacillariophyceae were recorded. Among them, genera *Eunotia* consisted of three species, *Fragilaria* two species, *Cymbella* two species, *Gomphonema* one species. Other recorded genera were: two species of *Pinnularia* two species, each of *Ceratoneis*, *Cocconeis*, *Denticula*, *Diatoma*, *Frustulia*, *Meridion*, *Navicula*, *Staurastrum*, *Stauroneis*, *Surirella*, *Synedra* and *Tabellaria*.

Juttner *et al.* (2004, 2007) also reported eight new species of *Gomphonema* and one species of *Navicula* from Himalayan stream. Li *et al.* (2007, 2008) studied *Gomphonema* and *Cymbelloid* (diatoms) from Mount Everest region. Juttner *et al.* (2004, 2007) also reported eight new species *Gomphonema* and one species of *Navicula* from Himalayan stream. One species *Cymbella lanceolata* was found new to Nepal. This species was collected from running water bodies at Lobuche, Pheriche and Thamo between 3700-4600 m altitudes.

Total nine cyanophyceae algae under six genera were recorded (Table 34). Among them, genera *Oscillatoria* consisted of four species, *Anabaena*, *Merismopedia*, *Gloeocapsa*, *Phormidium* and *Stigonema* genera having single species. *Anabaena* cf. *laxa* was previously reported from Phakding, 2700 m north east of Chhukung, 4770 m and a shallow lake near Kongma La, 5300 m, Sagarmatha National Park, Solukhumbu (Watanabe and Komarek, 1994). *Merismopedia glauca* was also reported from a stream between Chhukung and Amphu, 4770 m in Sagarmatha National Park (Watanabe and Komarek, 1994). *Oscillatoria agardhii* from a small stream near Langtang Base Camp, 3800 m, Rasuwa (Hirano, 1969). *Oscillatoria brevis* previously reported from Langtang river near Langtang Base Camp, 3800 m (Hirano, 1969). Among them, one species *Oscillatoria insignis* Skuja was found new to Nepal. This

species was collected from running water bodies between 2nd Gokyo and 3rd lake at an altitude of 4700 msl.

Some species like *Chroococcus minutes* reported by Subba Raju and Suxena (1979), *Chroococcus varius*, *Eucapsis himalayensis* by Watanabe and Komarek (1994), *Gleocopsa* species, *Cyanobacteria epiphyticum* by Komarek and Watanabe (1998) were reported from the waterbodies of Khumbu valley but these species were not found in the present study. *Chorogloea simplex* is another endemic algae found in Pakdingma lake (Solukhumbu) at 2700m by Watanabe and Komarek (1994). *Schizothrix radius-salis* endemic algae was found by Watanabe and Komarek in 1994 at 4450m in Panboche pond. Similarly, *Woronichinia kuseiae* endemic algae at 5300m in Kongma lake (Watanabe and Komarek, 1994). *Coleodesmium sagarmathae* is an endemic algae found at 4770m in Imja river by Komarek and Watanabe (1990). *Spirogyra nepalensis* endemic algae reported by Muller (1966) from khumbu Himal.

6.2.2 Bacterial analysis

Bacterial presence (*Escherichia coli* and *Streptococcus faecolies*) was recorded in the water samples collected from springs at Phakding, between Jorsalle and Dudhkoshi bridge, Namche Bazaar (near garbage pit), Pheriche, Phunki Tenga Dudh Koshi, Thado Khola at Phakding, Everest Base Camp, Machhermo Khola, Bhote Koshi below Thame (Fig. 26).

Microbiologically most contaminated water body was found near the hotels, which is due to anthropogenic activities (Sharma *et al.*, 2010). In residential areas, forest litter is used in toilets instead of water. Therefore, the so called “septic tank” is the site for composting manure used in agriculture lands. Direct leaching of pollutants from such septic tank and subsequent contamination of water bodies could be negligible. However along the trekking routes, a significant number of tea shops and a few hotels did not have septic tanks. For example, at Jorsalle hotels/tea shops lying towards the river bank did not have septic tank and effluent from the toilets (which used water) opened to the cliff on the bank of Dudhkoshi. It is well known that the coliform bacteria are present in very high numbers in fecal contaminated waters (WHO 2008).

The solid waste generated from the hotels and open toilet sites at Gokyo and its deposition is ultimately leaching to Gokyo lake (Dudh Kunda). During Janai Purnima

(July/August) festival, over 500 pilgrims take sacred bath in the lake. In the tourist seasons, sometimes camps haphazardly established nearby the lake and contribute to pollution, especially from their abandoned items, adding the amount of waste (Karki, 2010).

The drinking water used by hotels show high level of total coliform indicating high fecal contamination from other animals and aquatic birds. In some cases, lodges had cemented toilets, but had no septic tanks and discharged the waste directly to water bodies (e.g. Phakding, Jorsalle). Therefore, the sites were contaminated with bacteria. About 80% of the garbage pits constructed by Sagarmatha Pollution Control Committee (SPCC) and local community lied near the water courses; a few of them were within the distance of five meters from water surface. At some places (e.g. Phakding) wastes were disposed on the bank of river and stream. It appears that pits near the water courses have been flooded during rainy season and contaminated river water.

6.2.3 Micro-invertebrate

Five orders of micro-invertebrate (Ephemeroptera, Plecoptera, Tricoptera, Trichedida, Diptera) belonging to fourteen families (Baetidae, Heptageniidae, Amelidae, Nemouridae, Capniidae, Perlidae, Leuctridae, Leptoceridae, Rhyacophilidae, Glossosomatidae, Planariidae, Chironomidae, Simuliidae, Tripulidae) were recorded during the present study in different waterbodies (lakes, springs and rivers) of the SNPBZ from Lukla to Everest base Camp, Gokyo lake series and towards Imja lake (Table 38). Baetidae family was found as the dominant family in SNPBZ region (Fig. 27).

Hutchinson (1937) reported abundant and varied benthic fauna (Turbicididae, Chironomidae, Amphipods and Molluscs) in high altitude lake water from Indian Tibet. Chironomidae were also reported in high altitude Himalayan water by Roback and Coffman (1987), Riess (1968) and Kiffer (1911). Loffer (1969) concluded the presence of Enchytraeidae in the Khumbu valley. Entonostrea also reported from Ngozumpa glacier of the Khumbu valley by Dumont and Van de velde (1977). In the present study, no any species from Enchytraeidae was recorded from Khumbu valley.

Very little study exists on the micro invertebrates at high altitude water bodies in Himalaya region. The only few studies were done from lake sediments of Gokyo and

Imja (Manca *et al.* 1998). Low diversity of macro invertebrates in high altitude waterbodies occur, due to low level of nutrients in water and the sediments.

Sharma *et al.* (2010) studied the ecology of water of Gokyo lake and found that Plecoptera (stonefly), Ephemeroptera, Trichoptera, Diptera were the most dominating groups of micro-invertebrate of Gokyo lakes. Lakes and streams in Gokyo wetlands had differences in richness and assemblage composition of microinvertebrates. In the present study, Ephemeroptera (family Baetidae) was found most dominating order covering 80% of the samples taken from different localities.

Diptera, Chironomidae and few Oligochaeta (Lumbriculidae) were also reported as bottom fauna from the study sites by Ruggia *et al.* (1998) who collected different groups of fauna from the waterbodies of Khumbu valley.

6.3 Water pollution sources

6.3.1 Septic tank/toilet

The condition of toilets and septic tanks in the Khumbu region was not satisfactory. The situation of public toilets and their septic tanks (at Namche, Chukung) was the worst. No construction of septic tanks (e.g. at Somare, Pheriche), leakage from septic tanks (e.g. at Gorakhshep), no construction of toilets (e.g. at Thamo), and high permeability of the septic tanks were common problems. Improvement in the condition of toilets and septic tanks can prevent the pollutants from sources to the waterbodies. In residential areas, forest litter is used in toilets instead of water.

At Somare, a tea shop area next to Pangboche, at least two toilets had no septic tanks and effluent directly contaminate a small spring passing from the area. At Pheriche, at least four hotels had toilets on the river side of the route and all they have no wall towards the river side, allowing whole content to flow out. This could directly contaminate Lobuche river when water surface rises during rainy season. At Gorakhshep, semi-solid human excreta were seen on the surface that leached out from septic tank.

Twenty percent of the households didn't have toilets. Generally, these households were along the trekking routes (Table 39). Most of the households, especially lodges,

had stone wall septic tank (non-cemented) having 40-50% permeability (estimated). The cement cost at high altitude is high and cementing is poor due to cold condition. There were a few septic tanks with cemented wall having more than 90% impermeability (estimated). In some cases, lodges had cemented toilets, but had no septic tanks and discharged the waste directly to waterbodies (e.g. Phakding, Jorsalle).

Management of toilets and septic tank is not within responsibility of SPCC (except at Everest base camp), and the resources available is not sufficient (SPCC coordinator, Mr. Kapindra Rai, personal communication, 2009). Park authority has noticed the problem of poor situation of septic tanks but they have no plan to improve this problem because the buffer zone management committees have never proposed any activities towards this problem. Therefore management of toilets and septic tank appeared to be the most neglected sanitary/environmental issue in Sagarmatha National Park.

6.3.2 Tourist and solid waste problem

Sagarmatha National Park is a popular eco-touristic destination for international community. Number of trekkers increases every year in this park. A large number of tourists accompanied with porters and guides produce impacts on environment and society. In 2010, 32084 international trekkers visited the area, each trekker staying for 14 to 15 days in average in the SNPBZ. More than 36,000 tourists visited the park in 2012. These visitors are concentrated and overcrowded in spring and autumn seasons creating a pressure on resources. This large number of tourists and trekkers leave a large amount of garbage and human excreta in the SNP.

Increase in non-biodegradable solid waste such as batteries, bottles and other results in environmental pollution. Unmanaged solid waste and open defecation may contaminate drinking water. About 80% of the garbage pits constructed by SPCC and local community lied near the water courses; a few of them were within the distance of five meters from water surface. At some places (e.g. Phakding) wastes were disposed on the bank of rivers and streams. Pits near the water courses have been flooded during rainy season and contaminate river water. Trails, campsites and other infra structures are vulnerable to landslide and erosion due to fragile geology

Tabei (2001) reported that a trekker leave around 51 kg of garbage in the route to Mt. Everest But human waste had not been taken seriously as source of pollution.

However the accumulated solid excretes in the glaciers and base camp are so unmanaged that it started polluting the environment. The amount of urine per person per day at high altitude was estimated to be 2.16 liter. Tabei (2001) calculated and reported that 615,520 liter urine was left on the Khumbu glaciers up till 1999 by trekkers and 92,780 liter by Sherpa. Using the same formulae, urine excretion was 78879 liter in 2012 only.

In 2002, there were 380 lodges in SNP (up from 240 in 1996). Infact, almost all the local Sherpa houses are converted into lodges/houses for visitors (DNPWC, 2003) but this number is increasing year to year due to increasing number of visitors in the SNP which also can further affect the carrying capacity of fragile ecosystem.

6.3.3 Fertilizer production and utilization

Total annual production of organic fertilizer in SNPBZ was about 2197 t. A household produced an average of 1.7 t organic fertilizer in a year, and it was used at the rate of 0.82 kg/sq m in the farm lands (Table 40). Different types of organic fertilizers were used in farmlands of SNPBZ; they were: decomposed litter, litter with cow dung, litter with pig dung, and litter with human waste in toilets. Nitrogen, phosphorous and potassium content varied among the different types of organic fertilizers.

Nitrogen content ranged from 0.78 to 1.5% (average 1.15%); phosphorous content ranged from 0.57 to 0.91% (average 0.68%); and potassium ranged from 0.72 to 3.35% (average 1.71%) (Table 40). The average rate of use of organic fertilizer is 8 t/ha (i.e. 0.8kg/sqm), that is lower than the recommended dose (30 t/ha for potato crop). At this rate, the nitrogen, phosphorous and potassium content to the agricultural field comes around 94.3, 53.76 and 140.22 kg/ha. Recommended dose of inorganic fertilizer in potato crop is: 70 kg/ha N, 50 kg/ha P and 40 kg/ha K (Salerno *et al.* 2009). Nutrient content is higher than the recommended dose and thus leachate quantity may also be high.

6.4 Fluvial Functioning Index (FFI)

Fluvial Functioning Index (FFI) was published by the Provincial Agency for Environmental Protection of Italy (Siligardi *et al.* 2000) underlying principle of the

EC water framework Directive (European Commission 2003). Now it is widely applied in Italy. In fact, it is a tool to approach to present and future management of rivers. To understand the entire riverine environment, it is one of the unique tools for evaluation. It is an integrated strategy for river protection, management and restoration.

FFI method can be a useful tool to assess the most important ecological aspects of the whole course of a river such as riparian areas, morphological characteristics and biological features. It is also useful in order to support an appropriate river basin management. The output of the FFI is a river stretch map indicating the functionality level of the river because this method can be easily implemented into GIS system.

Many points like Thadokoshi phakding, Dudhkoshi at Phakding, Dudhkoshi at Phunki Tenga, Imja khola have the good fluvial function level due to good perfluvial vegetation as well as large stable boulders at the river bottom. Similarly Dudhkoshi below Larcha dovan, Monju khola, Dole khola, Bhotekoshi below Thamo showed fair to poor FFI condition.

Lobuche spring at lobuche settlement, Ghatte khola, Macharmmo khola, spring between 2nd and 3rd lake, Luza khola, Lobuche spring near pheriche, these all sites showed between ranged 121-182 which indicated fair in condition and need to conserve the aquatic ecosystem (Table 5).

Likewise Gokyo spring between Gokyo 2nd lake and 1st lake, spring near Tamang tole categorized to Fair to poor in condition. Namche spring categorized to poor to very poor condition due to very less vegetation on the left and right of the spring as well as no aquatic species inside the spring. Glacier below 1st lake and Glacier near Gorekshep recorded the very least FFI value which indicated the very poor condition due to no vegetation in primary as well as secondary perfluvial zone, which indicated that proper attention should be given for further degradation as well as sustainable development of water ecosystem.

Proposed Water pollution management strategies and models

- Park authority and buffer zone management committee should work together to ensure that every hotels/tea shops would have toilets and septic tanks. As far as practicable the toilets and septic tanks should be at least 100 m away from water bodies and water courses.

- Traditional practice of using forest litter in toilets for composting organic manure should not be discouraged. According to the medical in-charge of Khunde Hospital, use of this kind of manure did not have direct health hazards to farmers. This traditional practice has helped to sustain agriculture productivity in the area where a major fraction of animal dung goes to furnace for space heating.
- Septic tank with stone wall is the most viable option for all kind of hotels and tea shops. This kind of septic tank has two advantages; firstly, due to low construction cost all economic classes can afford it, and secondly, it takes several years to be filled completely by the waste. Environmental safety of this kind of septic tank depends on the depth of the tanks, soil texture (high if soil texture is fine), slope of the location, and the distance from the water sources. Environmental safety of cemented septic tank is higher than of stone wall, but the former type is filled in a few years and currently there is no proper mechanism to dispose this waste safely. Due to very high transportation cost, cemented septic tank with high impermeability is not viable economically for small hotels and tea shops above 4000 m.
- Some of the septic tanks constructed at slope were not completely within the soil surface. Due to high permeability of stone wall, semi-solid waste materials were found to flow out from the septic tanks (e.g. septic tanks of first hotel at Gorakshep). Therefore all septic tanks should be well below the soil surface.
- Impermeability of the stone wall septic tanks could be improved by having concrete on the vertical wall with soil alone or pebbles at the bottom. This will minimize the possible contamination of surface runoff water from stone wall septic tank during rainy season. Having two septic tanks of this kind could be economically viable and environmentally safe. When one septic tank is filled, another can be used. If the filled septic tank is not used for few months, the materials inside become dry and practically easy to evacuate.
- Dependency of people on dung as a source of energy is so high that some hotels and Gumba hired laborers only to collect dung from public places. Use of dung in dining for space heating has negative impact on both agriculture productivity

and wild vegetation. Therefore, use of dung as source of energy should be discouraged. There could be two alternative solutions; firstly, for space heating biomass briquettes (e.g. bee hive briquettes) can be supplied at subsidized rate, and secondly development of micro-hydroelectricity projects to improve access to electricity. With these approaches, the amount of dung that is being used in dining hall can be reduced, thereby increasing the proportion of dung in organic manure. This will ultimately prevent the people from using chemical fertilizers in their farmlands. For this approach, community awareness is also vital.

- Amount of organic manure can also be increased by encouraging people to use biodegradable waste from kitchen and other sources for composting. It can be assumed that if organic manure is available locally in sufficient amount, people will not use chemical fertilizers which are available at very high cost.

Linkage models and linkage attributes focusing on water quality (+/- represent the positive and negative relationship)

The designing of model was developed by using C map tool software to manage the issues related to environmental problems (Solid waste problem, human health problem caused by water quality). The sub- models provide hypothetical or proposed changes to view, analyze and compare the experimental value.

Tourists and local inhabitants generate solid waste, consuming energy which ultimately affect the forestry sector. So all these sub models are interlinked with each other. Management of single problem is not possible without considering other problems. Hence, a detail model is developed to manage issues related to environmental problems by a team of researcher of HKKH project including myself and stakeholders (<http://hkkhpartnership.org>, Manfredi *et al.* 2010).

By implementing all sub- models, we can simulate scenarios identifying and evaluating possible management solutions and intervention in the SNPBZ. This model reveals insight into general dynamics that supports the solution of different management problems (solid waste, water quality) in other protected area and mountain landscape.

Water quality model with its attributes

Water quality model evaluates the nutrient concentration in water bodies by considering the civil load of nutrient, releasing from anthropogenic sources like organic human waste (feces and urine), solid waste generation from hotel, lodge and litter solid waste (<http://hkkhpartnership.org>).

The anthropogenic production of nutrient influenced by number of inhabitants, number of tourists, disposed waste and litter waste. By considering these attributes, per-capita nutrient load is estimated. The total nutrient from anthropogenic load, natural load (rocks, forests, rainfall) and agricultural load (from fertilizer) defines the potential load of nutrients in the park.

Location of sampling points was chosen with the aim of calibrating. On the one hand, the nutrient sources and on the other hand impacts on water quality in different section of main course can be calculated by the model. Comparison between the nutrient content by model and field experiment helps to calibrate the model. By comparison the nutrients content in water bodies of different section, the ecological status can be assessed. By acting on the management levers that allow the change of agriculture and anthropogenic nutrient load, different sustainable or unsustainable water pollution scenarios can be obtained and evaluated (Manfredi *et al.* 2010).

Linkages among models

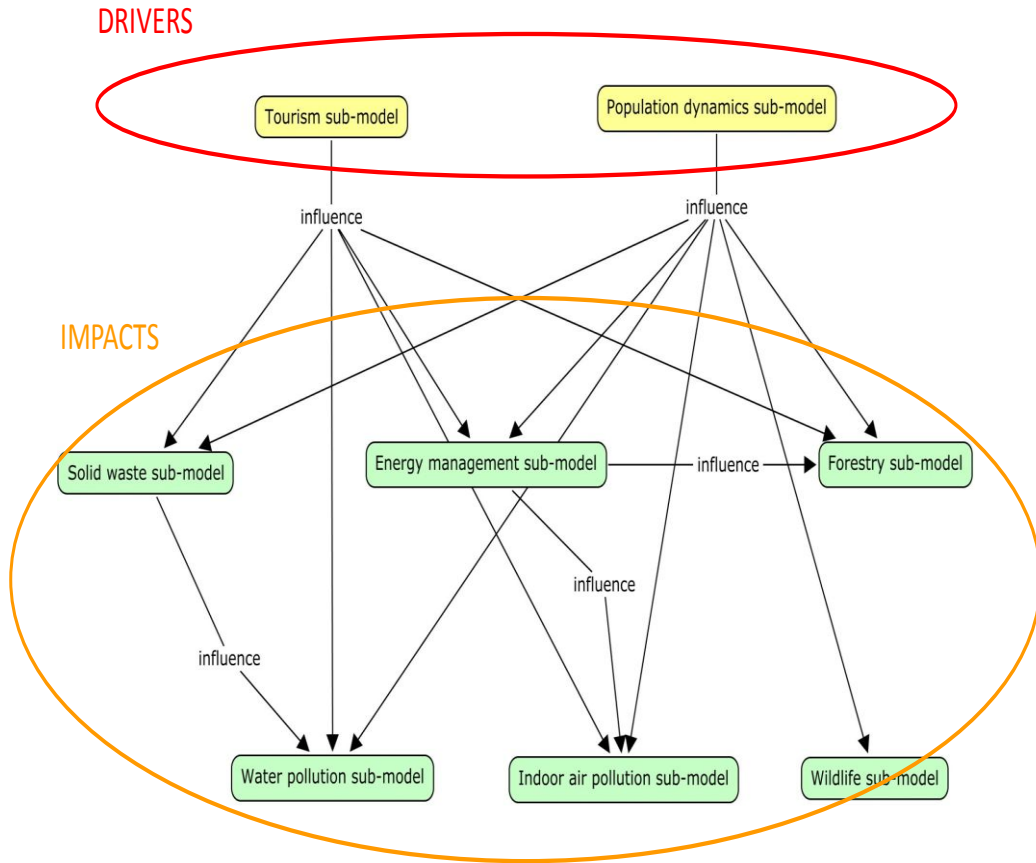


Figure 32: Co-relation of water pollution with other sub-model.

CHAPTER 7: CONCLUSION AND RECOMMENDATION

7.1 Conclusion

River water quality in general in Sagarmatha National Park and Buffer Zone (SNPBZ) still stands good in terms of standard for drinking water (WHO, Nepal Standard) however initiation of degradation process has been noticed. Certain changes in water quality parameters in waterbodies on the major tourist treks have been recorded mainly effected due to anthropogenic activities, particularly waste disposal. Sources of pollution were: Human waste (toilet) disposed to the water bodies, solid waste mainly by tourists, whereas nitrogen and phosphorous come from agricultural field.

Changes in pH, increase of TN-NO₃, TP-PO₄ was noted. Iron (Fe) concentration also increased when compared with earlier report. The present findings revealed that trend is going to deteriorate the quality of water bodies of the Khumbu region. The trend in heavy metal content in waterbodies in Sagarmatha National Park and Buffer Zone was in the following order: Pb>Cu>Zn >Mn>Mg>Fe>Na. Sodium (Na), Magnesium (Mg), Lead (Pb), Manganese (Mn), Copper (Cu) and Zinc (Zn) were found within the limit set for drinking purpose. Results reveal that quantity of these heavy metals has increased in the last few years.

During the present investigation, a total 59 species of algae have been reported from Sagarmatha National Park and Buffer Zone, Nepal. Among them Chlorophyceae, Bacillariophyceae, Cyanophyceae are found the most dominating families. One species belonging to family Xanthophyceae is also enumerated from this region. Gokyo lake (1st and 3rd) located at more than 4600m altitude had more algal species. Generally unicellular, colonial algae and desmids were found to be dominant in stagnant where as filamentous green algae were common in both running and stagnant waterbodies. Six species (*Euastrum oblongum*, *Penium cylindrus*, *Scenedesmus quadricauda*, *Spirogyra amplexens*, *Cymbella lanceolata* and *Oscillatoria insignis*) were found new record for Nepal.

Five orders of micro-invertebrate (Ephemeroptera, Plecoptera, Tricoptera, Trichedida, Diptera) belonging to fourteen families (Baetidae, Heptageniidae, Amelidae,

Nemouridae, Capniidae, Perlidae, Leuctridae, Leptoceridae, Rhyacophilidae, Glossosomatidae, Planariidae, Chironomidae, Simuliidae, Tripulidae) were recorded during the present study in different waterbodies (lakes, springs and rivers) of the SNPBZ from Lukla to Everest base Camp, Gokyo lake series and towards Imja lake. Baetidae family was found as the dominant family in SNPBZ region.

Contamination of most waterbodies in the SNPBZ area with fecal coliform was low. *Escherichia coli* and *Streptococcus faecolies* bacteria were recorded in 13% samples in the Sagarmatha National Park and Buffer Zone (SNPBZ), due to the activities of visitors and increase in human waste especially human excreta. Many of the toilets in SNPBZ were not maintained, completely full and have effluent leaking nearby portable water sources.

The best part of the agriculture here is its organic form. Average rate of use of organic fertilizer is 8 t/ha (i.e. 0.8 kg/sqm), that is less than the recommended dose. At this rate, the nitrogen, phosphorous and potassium to the agricultural field comes around 97, 54.4 and 136.8 kg/ha. To meet the high demand of potato in hotels and tea shops people might have used organic fertilizer at the rate higher than recommended dose for potato crop to maximize the yield.

Non-scientific solid waste management, open defecation and poor condition of septic tanks, and direct disposal of toilet waste to water courses or on the exposed surface, are major sources of surface water pollution. High solid waste generation due to high tourism flow, no proper management practice of solid waste, open defecation, construction of garbage pit near to the water coarse were found the root causes for water pollution.

7.2 Recommendations

Based upon the present study, a few points are suggested here to manage the water bodies in the SNPBZ.

- The carrying capacity of tourists to SNP should be determined.
- Organic farming should be continued and sell of inorganic fertilizer in SNPBZ should not be introduced.

- Micro-hydro should be encouraged to meet energy needs and discouraged burning of dung cake.
- There should be separation of solid waste into degradable and non –degradable wastes. Non degradable (plastics, can, bottle) should be brought down and recycled as well as reused.
- Improve condition of septic tanks of toilet. Drainage from toilet into water bodies should be strictly banned.
- The garbage pit should be constructed far from water bodies.
- Porters, guides, hotel owners and farmers should be educated about sanitation.
- Water quality should be regularly monitored.

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APPENDIX 1

List of Publications

1. Manfredi, E.C., B. Flury, G. Viviano, S. Thakuri, S.N. Khanal, P.K. Jha, R.K. Maskey, R.B. Kayastha, K.R. Kafle, S. Bhochhibhoya, **N.P. Ghimire**, B.B. Shrestha, G. Chaudhary, F. Giannino, F. Carteni, S. Mazzoleni and F. Salerno. 2010 “*Solid Waste and Water Quality Management Models for Sagarmatha National Park and Buffer Zone, Nepal*” Mountain Research and Development 30 (2):127-142. doi: 10.1659/MRD-JOURNAL-D-10-00028.1
2. **Ghimire, N.P.**, B.B. Shrestha, G.U. Caravello and P.K. Jha. 2010. Sources of water pollution in Sagarmatha National Park and Buffer Zone, Nepal. In: *Contemporary Research in Sagarmatha (Mt.Everest) Region, Nepal: An Anthology*. Eds. P.K. Jha and I. Khanal, Publ. Nepal Academy of Science and Technology, Kathmandu, pp. 103-109.
3. **Ghimire, N.P.**, S.K. Rai, P.K. Jha and G.U. Caravello. 2012. Some Bacillariophyceae from Nepal, including a new record. *Indian Hydrobiology*, 15 (2):189-193.
4. **Ghimire, N.P.**, S.K. Rai and P.K. Jha. 2012. Cyanobacteria from khumbu region (mt.Everest) including a new record for Nepal. *Indian Hydrobiology*, 15 (2): 223-226.
5. **Ghimire, N.P.**, P.K. Jha and G.U. Caravello. 2013. Water Quality of High-Altitude Lakes in the Sagarmatha (Everest) National Park, Nepal. *Journal of Environmental Protection* 4 (7A), pp. 22-28. doi: 10.4236/jep.2013.47A003.
6. **Ghimire, N.P.**, P.K. Jha and G.U. Caravello. 2013. Physico-chemical parameters of high-altitude rivers in the Sagarmatha (Everest) National Park, Nepal, *Journal of Water Resource and Protection*, 5: 761-767.
7. **Ghimire, N.P.**, B.B. Shrestha and P.K. Jha. 2013. Bacterial contamination in the surface waterbodies in Sagarmatha National Park and Buffer Zone, Nepal. *Scientific World*.11: 94-96.

8. **Ghimire, N.P.**, S.K. Rai and P.K. Jha. 2013. Chlorophycean algae in Khumbu Himalaya region of Nepal, including four new records. *World Journal of Science and Technology Research (WJST)* 1 (7): 144-150.
9. **Ghimire, N.P.**, B.B. Shrestha, P.K. Jha and G.U. Caravello. 2014. Metal assessments in the Water Bodies of Sagarmatha National Park and Buffer Zone Nepal, *Journal of Water Resource and Protection*, 6: 68-74.

APPENDIX 2

Conversion table and FFI form for the fluvial functioning levels.

LEVEL	SCORE	JUDGEMENT	COLOUR
I	261-300	excellent	
I-II	251-260	excellent-good	
II	201-250	good	
II-III	181-200	good-fair	
III	121-180	fair	
III-IV	101-120	fair-poor	
IV	61-100	poor	
IV-V	51-60	poor-very poor	
V	14-50	very poor	

FFI FORM

Basin.....Stream name.....
 Location.....
 Stretch (metres)..... width (metres)..... altitude.....
 daterecord no..... photo no.....
 code.....

Tab 1a: The FFI form, question 1 to 6

	Bank	Left	Right
1) Land use pattern of the surrounding area			
Undisturbed forests, woods and/or natural wetlands		25	25
Meadows, pasture, woods, a few areas of arable and uncultivated land		20	20
Mainly seasonal cultivation and/or mixed arable and/or permanent cultivation		5	5
Urbanised area		1	1
2) Vegetation of primary perfluvial zone (fluvial zone around watercourse)			
Arboreal riparian formations		30	30
Shrub riparian formations (shrubby willow thicket) and/or reeds		25	25
Non-riparian arboreal formations		10	10
Made up of non-riparian or herbaceous or absent shrub species		1	1
2b) Vegetation of secondary perfluvial zone			
Arboreal riparian formations		20	20
Shrub riparian formations (shrubby willow thicket) and/or reeds		15	15
Non-riparian arboreal formations		5	5
Made up of non-riparian or herbaceous or absent shrub species		1	1
3) .Extention of the perfluvial vegetation zone			
Perfluvial vegetation zone >30 m		20	20
Perfluvial vegetation zone 5-30 m		10	10
Perfluvial vegetation zone 1-5 m		5	5
Perfluvial vegetation zone absent		1	1
4) Continuity of the perfluvial vegetation zone			
Continuous perfluvial vegetation without gap		20	20
Perfluvial vegetation zone with gap in vegetation		10	10
Frequent gaps or only continuous and consolidated herbaceous vegetation		5	5
Soil without or with thin herbaceous vegetation		1	1
5) Water conditions of the river bed			
Width of the annual peak flow bed less than three times than the wet river bed		20	
Annual peak flow bed more than three times than the wet river bed with discharge fluctuations with seasonal variation		15	
Annual peak flow bed more than three times that of the wet river bed with discharge fluctuations with frequent variation		5	
Wet river bed non-existent or almost non-existent or presence of impermeabilisation of the river bed		1	
6) Stream bank structure			
Bank with arboreal vegetation and/or stones		25	25
Bank with grass and shrubs		15	15
Bank with a fine grassy layer		5	5
Bare banks		1	1

Tab 1b: The FFI form, question 7 to 14

7) Retention structures of trophic matter			
River bed with large boulders and/or old trunks firmly embanked or presence of reeds or hydrophyte strips	25		25
Boulders, cobbles and/or branches present with depositing of sediment or scarce and not extensive reeds or hydrophyte	15		15
Retention structures free and mobile during flooding or absence of reeds	5		5
River bed with sandy sediment without algae or smooth artificial profile with uniform current	1		1
8) Erosion			
Little evident and not important	20		20
Only at bends and/or narrow passages	15		15
Frequent with cutting of the banks and of roots	5		5
Very evident with undercutting of banks and landslips or presence of artificial intervention	1		1
9) Cross-section			
Natural		15	
Natural with some artificial intervention		10	
Artificial with some natural elements		5	
Artificial		1	
10) Stream bottom			
Diversified and stable		25	
Movable in stretches		15	
Easily moveable		5	
Cemented		1	
11) Riffles, pools or meanders			
Clearly distinguished and recurrent		25	
Present at different distances and at irregular intervals		20	
Long pools which separate short riffles or vice versa, few meanders		5	
Meanders, riffles and pools absent, straightened path		1	
12) Vegetation in the wet river bed			
Periphyton only noticeable on touching and/or low covering of macrophytes		15	
Periphyton visible and/or small covering of macrophytes		10	
Periphyton fair, presence of filamentous algae and/or monotonous macrophytes		5	
Periphyton thick and/or macrophytes relatively unvaried		1	
13) Detritus			
Presence of leaves and woods, vegetable fragments recognisable and fibrous		15	
Leaves and woods scarce, vegetable fragments fibrous and pulpy		10	
Pulpy fragments		5	
Anaerobic detritus		1	
14) Macrobenthonic community			
Well structured and diversified, appropriate to the fluvial type		20	
Sufficiently diversified but with altered structure as compared to that expected		10	
Poorly balance and diversified with a prevalence of taxa tolerant of pollution		5	
Absence of a structured community, presence of a few taxa all relatively tolerant of pollution		1	
Total Score			
Fluvial Functioning Level			

Appendix 3

Enumeration of algae species in the water bodies of khumbu region

SN	Name of species	Class	Remarks	Name of species	Class	Remarks
1.	<i>Actinotaenium cf.subglobosum</i>	Chlorophyceae	<i>Actin sub</i>	<i>Gomphonema sphaerophorum</i>	Bacillariophyceae	<i>Gom sph</i>
2.	<i>Anabaena</i> sp.	Cyanophyceae	<i>Ana sp</i>	<i>Hyalotheca dissiliens</i>	Chlorophyceae	<i>Hy dis</i>
3.	<i>Aphanocapsa littoralis</i>	Chlorophyceae	<i>Aph litto</i>	<i>Meridion circulare</i>	Bacillariophyceae	<i>Meri cir</i>
4.	<i>Botryococcus cf. braunii</i>	Xanthophyceae	<i>Botr bra</i>	<i>Merismopedia glauca</i>	Cyanophyceae	<i>Meri gla</i>
5.	<i>Bulbochaete</i> sp.	Chlorophyceae	<i>Bulb sp</i>	<i>Mougeotia</i> sp.	Chlorophyceae	<i>Mou sp</i>
6.	<i>Ceratoneis arcus</i>	Bacillariophyceae	<i>Cera</i>	<i>Navicula perrotetti</i>	Bacillariophyceae	<i>Navi perro</i>
7.	<i>Chlorella vulgaris</i>	Chlorophyceae	<i>Chlo vul</i>	<i>Netrium digitus</i>	Chlorophyceae	<i>Net dig</i>
8.	<i>Closterium acerosum</i>	Chlorophyceae	<i>Clo ace</i>	<i>Oedogonium</i> sp.	Chlorophyceae	<i>Oedo sp</i>
9.	<i>Cocconeis placentula var.euglypta</i>	Bacillariophyceae	<i>Coc vareu</i>	<i>Oscillatoria subbrevis</i>	Cyanophyceae	<i>Osci sub</i>
10.	<i>Cosmarium subspeciosum</i>	Chlorophyceae	<i>Cos subs</i>	<i>Oscillatoria agardhii</i>	Cyanophyceae	<i>O agar</i>
11.	<i>Cosmarium awadhense</i>	Chlorophyceae	<i>Cos awad</i>	<i>Oscillatoria brevis</i>	Cyanophyceae	<i>O bre</i>
12.	<i>Cosmarium cf.sublateriundatum</i>	Chlorophyceae	<i>Cos subl</i>	<i>Oscillatoria cf.Insignis</i>	Cyanophyceae	<i>O Ins</i>
13.	<i>Cosmarium nudum</i>	Chlorophyceae	<i>C nu</i>	<i>Pediastrum duplex</i>	Chlorophyceae	<i>Pedi dup</i>
14.	<i>Cyclotella antiqua</i>	Chlorophyceae	<i>Cyc ant</i>	<i>Penium cylindrus</i>	Chlorophyceae	<i>Pen cyli</i>
15.	<i>Cylindrocapsa</i> sp.	Chlorophyceae	<i>Cyl sp</i>	<i>Phacus</i> sp.	Chlorophyceae	<i>Pha sp</i>
16.	<i>Cylindrocystis brebissonii</i>	Chlorophyceae	<i>Cylbre</i>	<i>Phormidium</i> sp.	Cyanophyceae	<i>Pho sp</i>
17.	<i>Cymbella cymbiformis</i>	Bacillariophyceae	<i>Cym cym</i>	<i>Pinnularia viridis</i>	Bacillariophyceae	<i>Pinn Vir</i>
18.	<i>Cymbella lanceolata</i>	Bacillariophyceae	<i>Cym lan</i>	<i>Pinnularia braunii</i>	Bacillariophyceae	<i>P bra</i>
19.	<i>Denticula</i> sp.	Bacillariophyceae	<i>Den sp</i>	<i>Scenedesmus bijugatus</i>	Chlorophyceae	<i>S bij</i>
20.	<i>Diatoma hiemale var.mesodon</i>	Bacillariophyceae	<i>Dia varm</i>	<i>Scenedesmus quadricauda</i>	Chlorophyceae	<i>Sce quad</i>
21.	<i>Dinobryon cf.sertularis</i>	Chrysophyceae	<i>Din ser</i>	<i>Scenedesmus bijuga</i>	Chlorophyceae	<i>S bij</i>
22.	<i>Euastrum cf. bidentatum</i>	Chlorophyceae	<i>Eua bid</i>	<i>Scenedesmus cf. obliquus</i>	Chlorophyceae	<i>S obli</i>
23.	<i>Euastrum oblongum</i>	Chlorophyceae	<i>E oblo</i>	<i>Sphaerocystis schroeteri</i>	Chlorophyceae	<i>Sp sc</i>
24.	<i>Eunotia alpine</i>	Bacillariophyceae	<i>Eun al</i>	<i>Spirogyra cf amplexens</i>	Chlorophyceae	<i>Spicf am</i>
25.	<i>Eunotoia lunaris</i>	Bacillariophyceae	<i>Eun lu</i>	<i>Staurastrum</i> sp.	Chlorophyceae	<i>St sp</i>
26.	<i>Eunotoia coralloides</i>	Bacillariophyceae	<i>Eun cora</i>	<i>Stauroneis phoenicenteron</i>	Bacillariophyceae	<i>S pho</i>
27.	<i>Fragilaria capucina var.vaucheriae</i>	Bacillariophyceae	<i>Fra varv</i>	<i>Stigonema mamillosum</i>	Cyanophyceae	<i>Stimam</i>
28.	<i>Fragilaria crotonensis</i>	Bacillariophyceae	<i>Fra cro</i>	<i>Surirella didyma</i>	Bacillariophyceae	<i>Suri did</i>
29.	<i>Frustulia rhomboids</i>	Bacillariophyceae	<i>Fru rho</i>	<i>Synedra ulna</i>	Bacillariophyceae	<i>Sy ulna</i>
30.	<i>Gloeocapsa aeruginosa</i>	Cyanophyceae	<i>Glo aeru</i>	<i>Tabellaria flocculosa</i>	Bacillariophyceae	<i>Tabflo</i>
31.	<i>Gomphonema geminatum</i>	Bacillariophyceae	<i>Gom ge</i>	<i>Zygnema</i> sp.	Chlorophyceae	<i>Zygsp</i>

APPENDIX 4
Distribution of algae species

SN	Locality	Lat./Lon.	Alt. (m)	Chlorophyceae	Bacillariophyceae	Cyanophyceae	Xanthophyceae
1	Gokyo 3rd lake	27.9488 86.7125	4720	<i>Chlorella vulgaris</i> <i>Closterium acerosum</i> <i>Diatoma hiemale</i> <i>var.mesodon</i> <i>Fragilaria capucina</i> <i>var.vaucheriae</i> <i>Zygnema</i> sp.	<i>Ceratoneis arcus</i> <i>Synedra ulna</i>		
2	Gokyo 2 nd lake	27.9403 86.6978	4716	<i>Chlorella vulgaris</i> <i>Closterium acerosum</i> <i>Cyclotella antique</i> <i>Diatoma hiemale</i> <i>var.mesodon</i> <i>Fragilaria capucina</i> <i>var.vaucheriae</i> <i>Mougeotia</i> sp. <i>Staurastrum</i> sp. <i>Zygnema</i> sp.	<i>Ceratoneis arcus</i> <i>Cymbella cymbiformis</i> <i>Denticula</i> sp. <i>Synedra ulna</i>	<i>Anabaena</i> sp. <i>Gomphonema sphaerophorum</i> <i>Oscillatoria brevis</i> <i>O. cf.Insignis</i>	
3	Gokyo 1 st lake	27.9308 86.7066	4661	<i>Bulbochaete</i> sp. <i>Closterium acerosum</i> <i>Cosmarium awadhense</i> <i>Cyclotella antique</i> <i>Diatoma hiemale</i> <i>var.mesodon</i> <i>Mougeotia</i> sp. <i>Netrium digitus</i> <i>Oedogonium</i> sp <i>Spirogyra cf amplectens</i> <i>Staurastrum</i> sp. <i>Zygnema</i> sp.	<i>Ceratoneis arcus</i> <i>Cymbella cymbiformis</i> <i>Denticula</i> sp. <i>Synedra ulna</i>	<i>Anabaena</i> sp. <i>Gomphonema sphaerophorum</i> <i>Oscillatoria subbrevis</i> <i>O. brevis</i> <i>O. cf.Insignis</i> <i>Phormidium</i> sp.	
4	Ngozumpa glacier	27.9308 86.7082	4650	<i>Cosmarium nudum</i> <i>Eunotia alpine</i> <i>E. coralloides</i> <i>Mougeotia</i> sp. <i>Scenedesmus quadricauda</i> <i>Spirogyra cf amplectens</i> <i>Zygnema</i> sp.	<i>Synedra ulna</i>	<i>Merismopedia glauca</i>	
5	Luza khola	27.8935 86.7201	4325	<i>Cosmarium subspeciosum</i> <i>Cylindrocystis brebissonii</i> <i>Euastrum cf. bidentatum</i> <i>Frustulia rhomboids</i> <i>Mougeotia</i> sp. <i>Netrium digitus</i> <i>Staurastrum</i> sp.	<i>Navicula perrotetti</i> <i>Tabellaria flocculosa</i>		

6	Thame	27.8254 86.6647	3692	<i>Aphanocapsa littoralis</i> <i>Cosmarium awadhense</i> <i>Diatoma hiemale</i> <i>var.mesodon</i>	<i>Meridion circulare</i> <i>Navicula perrotetti</i> <i>Pinnularia viridis</i> <i>Stauroneis</i> <i>phoenicenteron</i>	<i>Gomphonema</i> <i>sphaerophorum</i>	
7	Thamo	27.8193 86.6781	3410	<i>Closterium acerosum</i> <i>Cyclotella antique</i> <i>Diatoma hiemale</i> <i>var.mesodon</i> <i>Fragilaria crotonensis</i>	<i>Ceratoneis arcus</i> <i>Cocconeis placentula</i> <i>var.euglypta</i> <i>Cymbella lanceolata</i> <i>Navicula perrotetti</i> <i>Tabellaria flocculosa</i>	<i>Gomphonema</i> <i>sphaerophorum</i> <i>Merismopedia</i> <i>glauca</i>	
8	Namche	27.8041 86.7103	3417	<i>Closterium acerosum</i> <i>Cylindrocapsa</i> sp. <i>Phacus</i> sp. <i>Scenedesmus bijugatus</i> <i>Scenedesmus cf. obliquus</i> <i>Spirogyra cf amplectens</i> <i>Staurastrum</i> sp.	<i>Gomphonema</i> <i>geminatum</i> <i>Pinnularia viridis</i> <i>P. braunii</i>	<i>Anabaena</i> sp.	
9	Dudhkoshi	27.7825 86.7221	2777	<i>Actinotaenium</i> <i>cf.subglobosum</i> <i>Cosmarium</i> <i>cf.sublateriundatum</i> <i>Diatoma hiemale</i> <i>var.mesodon</i> <i>Spirogyra cf amplectens</i>	<i>Surirella didyma</i>	<i>Oscillatoria</i> <i>agardhii</i>	
10	Lobuche khola	27.9470 86.8065	4919	<i>Fragilaria capucina</i> <i>var.vaucheriae</i> <i>Scenedesmus bijuga</i> <i>Sphaerocystis schroeteri</i>	<i>Ceratoneis arcus</i> <i>Cymbella lanceolata</i>	<i>Merismopedia</i> <i>glauca</i> <i>Oscillatoria</i> <i>agardhii</i>	
11	lower lobuche	27.9470 86.8065	4219	<i>Aphanocapsa littoralis</i> <i>Fragilaria capucina</i> <i>var.vaucheriae</i> <i>Gloeocapsa aeruginosa</i> <i>Netrium digitus</i> <i>Staurastrum</i> sp.	<i>Gomphonema</i> <i>geminatum</i> <i>Pinnularia viridis</i> <i>Synedra ulna</i>	<i>Merismopedia</i> <i>glauca</i> <i>Pediastrum duplex</i>	<i>Botryococcus cf.</i> <i>braunii</i>
12	Imja khola	27.8802 86.8187	5007	-	-	<i>Stigonema</i> <i>mamillosum</i>	
13	Pheriche	27.8893 86.8188	4279	<i>Closterium acerosum</i> <i>Cosmarium</i> <i>subspeciosum</i> <i>C. awadhense</i> <i>Diatoma hiemale</i> <i>var.mesodon</i> <i>Euastrum oblongum</i> <i>Eunotoia lunaris</i> <i>Hyalotheca dissiliens</i> <i>Mougeotia</i> sp. <i>Penium cylindrus</i> <i>Scenedesmus bijugatus</i> <i>S. quadricauda</i> <i>Zygnema</i> sp.	<i>Cymbella cymbiformis</i> <i>C. lanceolata</i> <i>Navicula perrotetti</i> <i>Pinnularia viridis</i> <i>Tabellaria flocculosa</i>		

Appendix 5

Format of Questionnaire

- House number
- Site District
- Latitude Ward number
- VDC
- Tole
1. How many members in your family
 2. Highest level of education
 3. Which type of toilet you used:
 - (a) Pure septic (cemented)
 - (b) Septic (stone wall inside tank)
 - (c) Only litter box + collection in pit
 - (d) Only hole but not a collection pit.
 - (e) Open (in a field, no toilets)
 4. Number of toilets in your buildings
 5. Percentage of impermeability of toilet.
 - a) 0-20%
 - b) 20-40%
 - c) Above then 40%
 6. What type of fertilizer you used.
 - a) No
 - b) Chemical
 - c) Organic
 7. How much is your agriculture area

8. Quality of fertilizer you used in field
9. How much amount of dung use is field
10. If chemical fertilizer is used, what in the name of fertilizer
(Local name may be used)
11. Patterns of the fertilizer used.
 - a) Annul
 - b) semi-Annual
 - c) Monthly
12. Type of fertilizer used in your area.
 - a) Pure dung
 - b) Litter + dung
 - c) Litter d) No
13. No. of cattle
14. What is the name of river near by your house
15. Average distance from your house to river
16. What is the name of species used specially for litter
17. Name of site of the solid waste product
18. Damping site:
 - a) Yes
 - b) No
- Separation of garbage
 - a) Yes
 - b) No
- a) Biodegradable
 - b) Plastic
 - c) Metal and glass
19. Capacity of hotel
20. Total Estimated tourist No. in year
21. Number of opening month

The End



a) Working in Gokyo 5th lake.



b) Working in Gokyo 2nd lake.

Plate 10: Field work.



a) Working in Laboratory of Central Department of Botany, Kirtipur, Kathmandu.

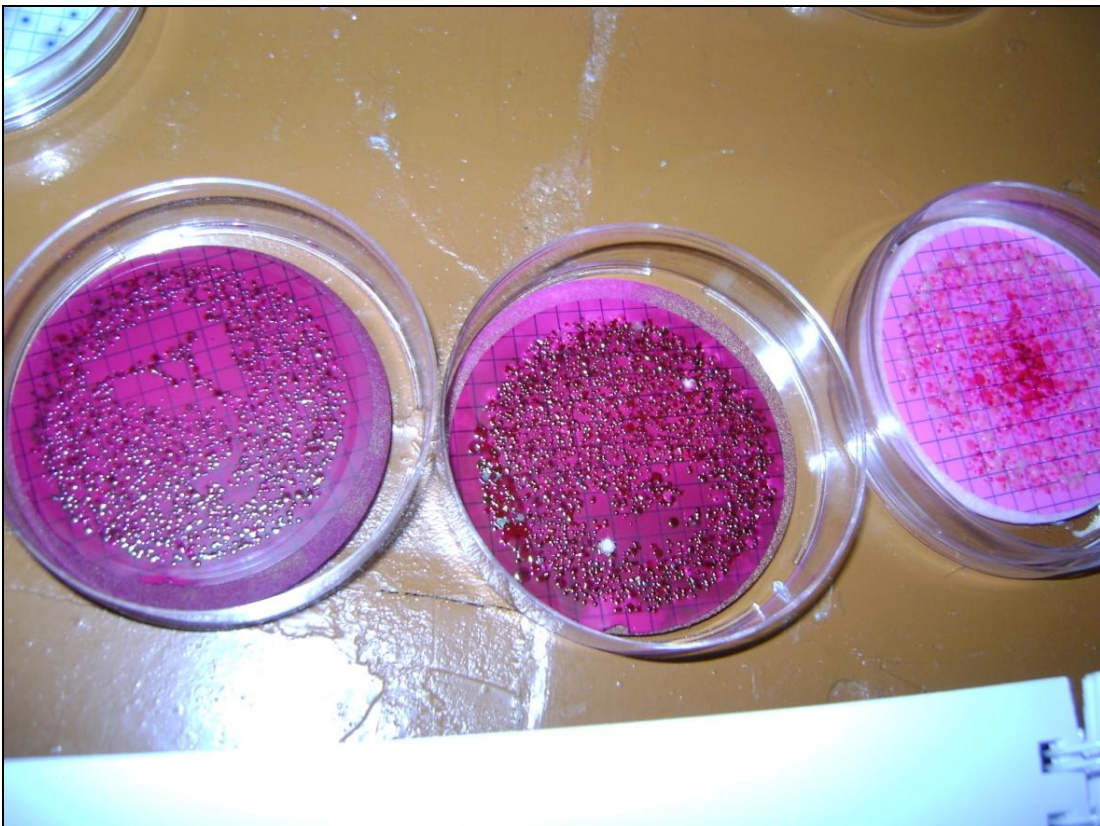


b) Working in Laboratory of Central Department of Botany, Kirtipur, Kathmandu.

Plate 11: Laboratory work.



a) Working in Laboratory at Namche.



b) Bacterial analysis in Namche.

Plate 12: Laboratory work.

FINAL Once [2071.3.29]