WATER QUALITY ASSESSMENT OF BAGMATI RIVER IN KATHMANDU VALLEY

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T.U. Registration No: 35-9594

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A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Zoology with

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Nepal

January, 2014

DECLARATION

I hereby declare that the work presented in this thesis has been carried out by myself, and has not been submitted elsewhere for the award of any degree. All the sources of information have been specifically acknowledged by references to the authors or institutions.

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LETTER OF RECOMMENDATION

This is to recommend that the thesis entitled "Water Quality Assessment of Bagmati River in Kathmandu Valley" has been carried out by Ms. Meena Barakoti for the partial fulfillment of the requirements of Master's Degree of Science in Zoology with special paper Ecology. This is her original work and has been carried out under our supervision. To the best of our knowledge, this thesis work has not been submitted for any other degrees in any university.

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LETTER OF APPROVAL

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ABSTRACT

Water quality assessment of Bagmati River in the Kathmandu valley was carried out at pre-monsoon (March and April) and monsoon (July and September) season. The standard methods (APHA 1998 and Trivedy and Goel 1986) were followed for chemical analysis. Five sites viz. Sundarijal, Aryaghat, Thapathali, Sundarighat and Khokana were selected. The major work of the study was analysis of physical (Temperature, pH, Electrical Conductivity) and chemical (DO, BOD, NO_3-N, PO_4-P, NH_3-N) parameters along the Bagmati River, classification of River based on polluted sites, comparing river water quality in past and present and determining the self- dilution capacity.

The water quality of Bagmati River was classified using German Water Quality Index and Netherland Water Quality Index. Based on the German Water Quality Index, the five stations of Bagmati River were classified separately. According to this Index, Sundarijal was classified as 'low pollution 'zone in both the pre-monsoon and monsoon season while Aryaghat as 'moderate pollution' zone at both the seasons. Similarly, Thapathali was classified as 'very severe pollution' zone in pre-monsoon and 'moderate pollution' zone in monsoon while Sundarighat as 'excessive pollution' zone in pre-monsoon and 'severe pollution' zone in monsoon. Khokana was classified as 'very severe pollution' zone in pre-monsoon and 'moderate' pollution' zone in monsoon. On the other hand, based on the Netherland Water Quality Index, Sundarijal was classified as 'Excellent' zone in pre-monsoon and monsoon, Aryaghat as 'Bad' zone in pre-monsoon and 'fair' in monsoon season. Thapathali, Sundarighat and Khokana were classified as 'very bad' zone in both the seasons in all these three stations. The chemical parameters were found beyond the natural level in almost all the stations except Sundarijal. Sundarighat was found in worst condition among all. The water quality trend analysis at past and present indicated degrading condition of river. Self-dilution capacity i.e. additional flow required in the river so as to maintain permissible level of 30mg/L BOD at Sundarijal, Aryaghat and Khokana was calculated as $1.03m^3/s$, $1.74m^3/s$ and $17.7m^3/s$; respectively. The level of pollution was found to be more severe in pre-monsoon than that of monsoon season.
Key words: *Chemical Parameters, Monsoon and Pre-monsoon, Water Quality*

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
BASP	Bagmati Area Sewerage Project
BOD_5	Bio-Chemical Oxygen Demand (5 days incubation)
$Cacl_3$	Calcium chloride
CBS	Central Bureau of Statistics
DHM	Department of Hydrology and Meteorology
DO	Dissolved Oxygen
EBI	Extended Biotic Index
EC	Electrical Conductivity
E.coli	*Entamoeba coli*
ENPHO	Environment and Public Health Organization
$Fecl_3$	Ferric chloride
GPS	Geographical Positioning System
GWRDP	Ground Water Resource Development Project
H_2SO_4	Sulphuric acid
i.e.	that is
IW	Important Weight
K_2HPO_4	Potassium Hydrogen Phosphate
JICA	Japan International Co-Operation Agency
KI	Potassium Iodide
KAPRIMO	Kathmandu Participatory River Monitoring
km	Kilometer
KNO_3	Potassium nitrate
KUKL	Kathmandu Upatyaka Khanepani Limited
KVMP	Kathmandu Valley Mapping Programme
L	Litre
m	Meter
$MnSO_4$	Magnesium sulphate
MoPE	Ministry of Population and Environment
Nacl	Sodium chloride
$Na_2s_2o_3$	Sodium thiosulphate
NAST	Nepal Academy of Science and Technology

NESS	Nepal Environmental Scientific Services
NH_4cl	Ammonium chloride
NH_3-N	Ammonia- Nitrogen
nm	Nano meter
NO_3-N	Nitrate- Nitrogen
NRCT	Nepal River Conservation Trust
NTNC	National Trust for Nature Conservation
pH	Percentage of hydrogen
PO_4-P	Phosphate Phosphorus
RONAST	Royal Nepal Academy of Science and Technology
sq km	Square Kilometer
SWQC	Saprobic Water Quality Class
TSS	Total Suspended Solids
UGR	Unit Generation Rate
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
µS	Micro Siemens
WECS	Water and Energy Commission Secretariat
WQ	Water Quality
WQI	Water Quality Index
Viz	such as

INTRODUCTION

1.1 Background

Bagmati River is originated from Baghdwar above the Southern edge of the Shivapuri Hill about 15km North-East of Kathmandu. It has a catchment area of 3710 square kilometers in Nepal. It flows directly to the south- west cutting the Mahabharat range and flows down the plain of Nepal in south to join the Ganges in India. The river is fed by natural springs and monsoon rainfall (NTNC2009).

The river flows south-west about ten kilometres through terraced rice fields in Kathmandu Valley. Resistant rock strata interrupt the flow in places, including at Pashupatinath Temple. Beyond the temple, the river flows south until joined by the larger west-flowing Manahara River, then turns west itself. After entering Kathmandu's urban area more tributaries enter: relatively unpolluted Dhobikhola and sewage-laden of Tukucha Khola. Then the river bends south and the Bishnumati enters from the right at Teku Dovan. The Bishnumati also rises in the Shivapuri Hill about six km west of the Bagmati's source. It flows south past Nagarjun Hill, Swayambhu Stupa and Durbar Square in Kathmandu. As it passes the center of Kathmandu, this tributary becomes heavily polluted (Davis 2007).

Flowing generally the south although with many curves, the Bagmati reaches the edge of the Kathmandu Valley and enters Chobar Gorge near the Dakshinkali temple complex. The gorge cuts through the Mahabharat Range or Lesser Himalaya. The Bagmati also crosses the lower Sivalik Hill before reaching the Terai, and then crosses into India at Dheng. It flows across Bihar districts Sitamarhi, Sheohar and finally Muzaffarpur where the Lakhandei joins above the Bagmati's confluence with the Koshi (Davis2007).

Altogether there are 24 major tributaries originating from Mahabharat and Sivalik Lekh which fed the Bagmati River. The major tributaries that lie within the Kathmandu valley include Manahara, Dhobikhola, Tukucha, Bishnumati, Balkhu and Nakhu. There are also several sub-tributaries among which five major sub tributaries are considered as important for restoration of Bagmati River which include Godavari, Kodku, Hanumante, Sangla and Mahadevkhola (Tuladhar1979 Pradhan 1998).

The Bagmati River can be divided into three parts based on the morphology and land use: (WECS2008).

1. The Lower Bagmati Basin: the basin in the Terai and India.
2. The Middle Bagmati Basin: remainder of the basin in the hills.
3. The Upper Bagmati Basin (662sq.km): the drainage area of the Bagmati downstream as Bhandarikharka (downstream of Chovar)
   (The upper Bagmati basin has been considered for the purpose of the study)

The upper part of the Bagmati River is composed of highly stratified forms of life and habitats represented by an equally rich diversity species and clean except some negligible amount of human disturbances. It starts receiving excess amount of sewage and effluents after Gokarna. The river receives the effluents of carpet industries of Boudhanath and Chabahil and also the untreated sewage of this part of the city, before reaching Pashupatinath. Besides these, intense sewage from the household, cremation ash from dead bodies, discharged waste from industries and accumulation of solid wastes are also considered as the factors affecting the aquatic life tremendously and deteriorating the water quality (Rai 2005).

At present, the Bagmati River and its tributaries have been used as dumping sites for solid wastes, outlets for domestic sewages and industrial and agricultural effluents. Also the river banks are being encroached by slum dwellers, municipalities are dumping household garbage in and on the bank of the river after collection and also sand being extracted from the river in huge amount which are the burning problem of current situation. All these activities are exerting pressure on the Bagmati River causing biological degradation as well as decrease in water discharge (Ale et al. 2011).

The rapid increase in population is also one of the major factor that is aggravating the quality of water. Due to several facilities such as economic opportunities, education facilities, urban glamour etc, Kathmandu is being the centre of attraction for people from all over the country. This is leading to the over population in valley and this uncontrolled growth of population is affecting the natural balance of the river (CBS 2002).

Preliminary Population Census of 2011 shows that population of Kathmandu till date is, 1,740,977.With the increase in population, the demand for water is also increasing but the supply is the same which has resulted into shortage of water (Subedi 2010).

The table1.1 below shows the trend of population growth in Kathmandu Metropolitan city.

Table 1.1: Population growth rate of Kathmandu valley

Administrative district	Area (Km^2)	Population (2001 Census)	Population (2011 Census)	Population density ($/km^2$)
Kathmandu	395	1,081,845	1,740,977	4408
Lalitpur	385	337,785	466,784	1212

Source: (CBS 2011)

The table 1.1 indicates that the population is growing briskly. Due to over population and its stress on the environment, the water quality and quantity both are getting worse.

Comprehensive assessment of water quality would be an essential step not only to address the consequences of present and future threats of contamination but also to raise awareness among the people and provide a basis for future action at all levels (Pradhan 2005).

1.2 Statement of Problem

Bagmati River is considered sacred in our religious belief. It constitutes the major source of drinking water in Kathmandu valley. Nearly all the surface water of Kathmandu valley has been tapped for drinking water purposes(NESS1997).As the water of Bagmati River (especially in upstream region) has been used for various purposes such as drinking, irrigation, recreation etc, degrading water quality of the river is a matter of concern to all of the inhabitants of the valley. Bagmati River is getting polluted day by day due to human activities such as discharge of untreated sewage, dumping of solid waste into river water and on its bank, industrial and agricultural effluents discharged into the river, deforestation, encroachment at the bank of river by slum dwellers etc. (Poudel 2004). Sand extraction from the river area is also another reason causing changes in river courses and contributing to the river water pollution (Sayami 2007).

Besides, unsafe agricultural practices along the bank of river and some of the non - biodegradable substances like plastics accumulated in the river water too bring about serious problem for aquatic fauna as they cannot be decomposed biologically over long periods of time. Water contaminated with fecal matter is very harmful to aquatic animals as it produces different types of diseases (Rai 2005).

However, in the rainy season i.e. June to September, mostly due to excessive runoff, water quality of Bagmati River improves noticeably due to dilution than in Pre-monsoon. River has self- purification capacity. By virtue of dilution and self-purification effects, Bagmati River is capable of assimilating a certain amount of pollution but the river will be unable to perform its natural purification process if additional pollution load occurs (Pradhan 2005).

1.3 Rationale of the Study

Water quality assessment of Bagmati River is very crucial for determining the existing condition of water quality status. The fundamental weakness that exists in the river water quality assessment is the lack of regular monitoring of river water quality. Though there have been made some attempts to study the organic and industrial pollution in the river, more quantitative work on the river pollution are needed before remedial action priorities can be set. Similarly, there are few studies which classify water based on different water quality indices.

The quality of the water of Bagmati River is degrading continuously. Hence, in order to conserve the river ecosystem, it is necessary to identify the causes of pollution, its control measures as well as a simple scientific monitoring method which may be helpful for researchers and policy makers.

1.4 Objectives of the Study

The general objective of the present study was to determine the water quality status of Bagmati River along the flow in Kathmandu Valley.

The specific objectives of the study were as follows:

- To analyze the water quality (based on physico-chemical parameters) of Bagmati River at different GPS locations.
- To classify river water quality with reference to water quality index.
- To compare the change in water quality of Bagmati River at past and present.

- To calculate the BOD free water to maintain self-dilution capacity of the river.

1.5 Limitations of the Study

- Calculation of self-dilution capacity of the Bagmati River was limited to only three stations such as Sundarijal, Aryaghat and Khokana depending upon the data available at DHM.
- Only the physico-chemical parameters of water were considered for determining water quality.
- Due to the limitation of time, the study was not sufficient to cover the every facet of water quality parameters.

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LITERATURE REVIEW

The physico-chemical parameters and biological indicators of Bagmati River have been studied by many researchers viz. Shrestha 1980, Shrestha 2007, Khadka 1983, Upadhya and Roy1982,Vaidya and Karmacharya 1986,Khattri1986, Pradhanaga et al. 1987,Bottino1988, Sharma and Rijal1988, Shrestha 1990,Yadav2002 andChhetri2006 which shows water quality of Bagmati River is degrading day by day and pollution level is increased as river passes through the dense settlements. According to their researches, original communities of aquatic fauna have completely disappeared and two groups of fauna eg, Tubificids and Chironomids typically of polluted water have appeared in the river of Kathmandu valley.

Some rivers can safely handle large quantities of pollution, while others degenerate from relatively small quantities of waste. A solution for pollution abatement rests, therefore, fundamentally on evaluation of self -purification capacity of river water. Thus, the BOD. of pollution and the DO of the river water can be the important assets to evaluate the self-purification capacity of river (Velz 1947).

Shrestha (1990) classified Bagmati River into six zones- a healthy zone, moderate upstream pollution zone, polluted zone, moderate downstream pollution zone, recovery zone and clear zone. The chief sources were identified as domestic waste, garbage, fecal matter, finely divided organic matter in suspension, detergents, acid, alkali and salts from hospitals, laboratory, tanneries and distillery, petroleum products from laundaries and automobile workshops.

Excess nitrogen and phosphorus cause eutrophication (excess algae growth) in surface waters and health problems in humans and livestock as a result of high intake of these nutrients (Baird 1990).

The study of (Devkota and Neupane 1994) revealed that industrial effluents to the rivers constitute 7% of the total effluents (domestic and industrial) in the Kathmandu Valley. Industrial pollution has been measured in terms of wastewater volume, and total suspended solid (TSS) loads of the effluents. Vegetable oil, distillery and leather industries are the major polluting industries leading to the relative contribution of BOD load.

The study carried out on Bagmati Basin, using Netherland Water Quality Index, revealed that the Bagmati, Bishnumati, Dhobikhola and Tukucha rivers were extremely polluted and according to this study municipal sewage was confirmed as the main source of pollution (StanelyInternational1994).

The pH value, conductivity (⇑S/cm), DO (mg/L) and NH_3(mg/L) at Gaurighat were found as 6.5, 360, <0.5 and 16.8; respectively. The values of same parameters at Sundarighat were recorded as 7.1,740, <0.5 and 42.8; respectively and that of Khokana were 7.4, 600, <0.5 and 36.0; respectively (NESS 1997).

Bottino(1988) divided the Bagmati River in Kathmandu valley into four sections: unpolluted, slightly polluted, polluted and extremely polluted. The river maintained good chemical and biological quality until it enters the urban area. Then the ecological break down occurred. They found the river near to Pashupati Nath temple area was slightly polluted, Thapathali polluted, Sundarighat extremely polluted and Chovar polluted. Among tributaries the Manahara was slightly polluted and Dhobikhola and Bishnumati were extremely polluted.

RONAST (1988) divided the river water in four sections by monitoring the pollution level of the Bagmati River according to difference in water quality and biological features: zone of good ecological condition (from source of river to Guheshwori temple), zone of slightly polluted condition (from the side of Pashupatinath to inlet of Dhobikhola), zone of severe pollution (from Patan bridge to Chovar) and zone of recovery (downstream of Chovar). Destruction of aquatic ecosystem is due to direct discharge of untreated wastewater into the river that results in low-grade water quality and disappearance of the most of the organisms found in upstream.

If an average of 50g BOD per person per day is produced, it will produce 50,000 kg BOD per day from the one million inhabitants in the Kathmandu Valley (Tebutt 1992). An average of 20,846 kg BOD/day has been recorded for the Bagmati River at the outlet, constituting 42% of the total BOD load produced (CEMAT2000).

According to the microbial testing for total coliform, *E.Coli*, and H_2S producing bacteria at drinking water sources, treatments plants, distribution points and consumption points, 50% of well sources were found microbially contaminated and surface water sources were contaminated in 100% of samples (Wolfe 2000).

Water quality in terms of BOD and DO before Sundarijal headwater and after Sundarighat end point, the Kathmandu urban area, analyzed from 1988 to 1999 revealed that the water at the Sundarighat site, particularly since 1994 is highly polluted, as indicated by the high value of BOD and low value of DO, as a result of high concentration of domestic and industrial effluent (UNEP 2001).

Ground Resource Development Project (2001) conducted a study during pre-monsoon from 17 locations of the Bagmati River where ten stations were on its main tributaries. It reported that pollution increases as river enters urban area and gets improved as it flows further away from the urban areas. The water quality along the Bagmati River and that of tributaries were heavily polluted due to biological pollutants. In the report, maximum coliform bacteria were enumerated. The concentration of dissolved oxygen in water is dependent on factors such as water temperature. At $70^{O}F$, the saturated level of dissolved oxygen in water is about 9mg/L. Depletion of dissolved oxygen below this level can result in the microbial reduction of nitrate to nitrite and sulfate to sulfide, giving rise to odor problems. Low DO levels can also result in corrosion of metal pipes. When DO levels are substantially below the saturation level, organisms cannot receive the amount of oxygen they need to live, and organisms in the water will begin to die (Green et al. 2003).

At Sundarighat the Bagmati River receives pollutants from the river upstream. At Sundarighat, the river fails self-purification through dilution, settling and biological degradation of the pollution, and hence this area is considered to be the dirtiest section of the Bagmati River. The River is basically an open sewer at Sundarighat. It is used as public toilet, and the water is dark and quite turbid at this point. The river is reported biologically dead at this point (Green 2003).

According to the study made on 2005/06 by the JICA team, the unit generation rate (UGR) of solid waste the volume of solid waste per capita per day was estimated to be about 0.416 kg/day. Based on the estimation, the total quantity of solid waste generation within the valley (including all five municipalities) was 435 tones per day. Waste analysis carried out by Kathmandu Valley Mapping Program (KVMP),revealed that the waste density is around 0.225 ton/cubic meter and the waste composition comprises 60-75% biodegradable waste (from organic origin) and 10-12% plastic waste among the non-biodegradable components. Over the last few decades, the population has grown rapidly at over two percent per annum, with migrations as the main cause of rapid growth in the valley's urban areas are resulting the demands for housing and exerting more pressure on the existing water supply (Pradhan 2004).

Dissolved oxygen content in the river was found to be extremely low within the Kathmandu valley river stretch. It was found to be declined to zero without any fresh water aquatic lives. Similarly, the pH of the Bagmati River was found to be in the range of 7.23 to 8.36 which indicates that the pH of the Bagmati River is not critical in terms of the pH (Shrestha 2004).

Based on the study from Sundarijal to Khokana using Extended Biotic Index (EBI) revealed that the most polluted location is at Sundarighat just upstream of the confluence of Bagmati and Bishnumati River (Pandey 2005).

Total of 73% sampling sites along the Bagmati River in the valley were selected and classified different sites into different water quality classes based on the saprobic approach. High positive correlation was found between *E.coli* and facial Streptococcus with SWQC, indicating the pollution of Bagmati River water due to raw domestic sewage (Pradhan2005).

In the Kathmandu valley, there are few Waste Water Treatment Plants within the valley which includes-Carrousel type Oxidation Ditch at Gaurighat, Waste Stabilization Pond at Kodku, Lalitpur, Waste Stabilization Ponds at Hanumante and Sallaghari, Bhaktapur, and Waste Stabilization Ponds at Dhobighat. Among these only the Waste Water Treatment Plant at Gaurighat is in full Operation while Kodku Treatment Plant is partially operated (Nyachhyon 2006).

Thermal pollution is the rise or fall on temperature of a natural body of water caused by human influence. Thermal pollution, unlike chemical pollution, results in a change in the physical properties of water. A common cause of thermal pollution is the use of water as a coolant by power plants. Similarly, if the water is treated before it is returned to the river, its temperature is raised than it was before. Human activities, industrial manufactures and urban run off may also elevate temperature in surface waters (Goel 2006).

DO (mg/L), BOD (mg/L), pH and Oxygen Saturation at Sundarijal were recorded as 8.38, 2, 7.02 and 96.1; respectively. Similarly at Gaurighatit was found 7.56, 5.5, 7.06, 93; respectively and the value of same parameters recorded at Thapathali were 2.15, 117.5, 7.18 and 27.5; respectively (KAPRIMO 2007).

To alter biological degradation rate of organic pollutants, Nepal River Conservation Trust (NRCT) had initiated Bagmati River Conservation Campaign called Bagmati River Festival in 2001. This festival comprises several events such as cleanup campaign, tree plantation program, rafting for public, training on waste management to several groups of women living along the bank of the Bishnumati, Bagmati River etc. (Mahat et al. 2007).

Waste water discharged into Bagmati River due to haphazard and tremendous urban growth of valley resulted failure of self-purification of the river water (Andre2008).

Bagmati River System is important for small scale hydro-electricity, irrigation and as drinking water sources. About 82% of water volume is extracted daily from the surface water sources for drinking water supply in the valley which can affect the balance of riverine ecology (Ale et al. 2011).

Phosphorous enters into river water from a number of sources. Human and animal wastes flushed into the river, poorly treated sewage , broken pipes or run off, industrial waste, removal of trees and grasses from the river banks, fertilizers used at farm fields near the water sources are some of the sources that increase the level of phosphorous in water. Excessive amount of phosphorus in water lead to the growth of tiny plants like algae. When plant growth increases, the water turns pea-green and becomes cloudy. The green colour comes from the chlorophyll of floating plants. When these plants die, they sink to the bottom where bacteria decompose the dead plant parts. They use up most of the oxygen in the water. They use more oxygen than the amount added by the plants through photosynthesis. Therefore, too many plants in the water form too much phosphorous leading deficiency of oxygen in the water and killing fish or aquatic lives (www.eeweek.org).

MATERIALS AND METHODS

3.1 Study Area

For this study, different sites along the Bagmati River in the Kathmandu and Lalitpur districts were selected. Sundarijal, Aryaghat, Thapathali and Sundarighat were selected as sampling sites in Kathmandu while Khokana was selected in Lalitpur. These sites were selected to understand the status of Bagmati River inside Kathmandu valley. Altogether five sampling sites were chosen for sampling. (Figure 3.1).

Table 3.1: Sampling locations along the Bagmati River

Stations	Locations	GPS Locations
I	Sundarijal	27°75' 525"N 85°42' 14"E
II	Aryaghat	27°71' 007"N 85°42' 14"E
III	Thapathali	27°68' 872"N 85°31' 695"E
IV	Sundarighat	27°67' 458"N, 85°29' 34"E
V	Khokana	27°63' 18"N 85°29' 291"E

Sundarijal:

This site is located about 22km downstream from the Baghdwar reservoir, about two km away from the hydropower plant. This site is under the protected zone of Shivapuri National Park with little interference of human activities. The site is surrounded by hills with dense forest. The substratum at this site is composed of boulder, large pebble, small pebble, gravel, sand and silt.

Aryaghat:

This site is located at Pashupatinath temple which is about 31 km from the source. Aryaghat is also called as cremation Ghat. Most of the dead bodies are cremated in the Ghat at the right bank of the river in this stretch. This river receives the pollutants from different area such as Chabahil, Boudha and Jorpati area. The situation of this site becomes more provocative during the time of festivals like Shivaratri, Rishi Pachami and Rishi Tarpani when mass bathing take place there.

Thapathali:

This site is situated about 36km from the source. During its flow, the river at this point receives waste water carried by other streams such as Manahara, Dhobikhola, and Tukucha. Human activities like encroachments, sand quarrying, excavation in the bank etc. are also the major factors leading to water pollution.

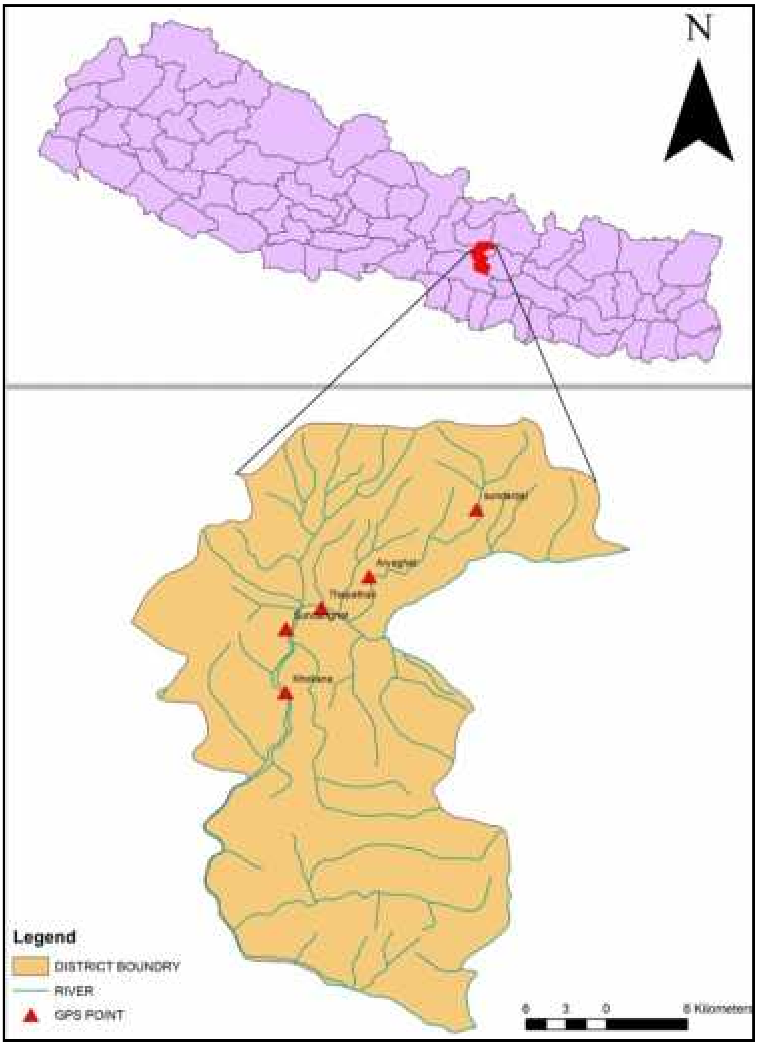

Figure3.1: Map of Study Area

Sundarighat:

Sundarighat is situated about 39km from the source and the site is selected near the suspension bridge. There is a high amount of sewage and black layer indicator of petrification processes. This site receives the urban sewage of Kathmandu, Patan and the highly polluted water of Bishnumati river. It also carries the waste discharged from Nepal Eye Hospital, Veterinary Hospital and Teku Hospital.

Khokana:

This site is near the suspension bridge which is about 45km away from the source. This site is located to the south of Kathmandu. It was industrial-service town of Kathmandu valley and was famous for mustard oil production. Khokana was regarded as "Gem of Civilization" in Malla period. Lavishly decorated brick houses, carved windows, open spaces, socio-cultural activities, built heritages are the main attraction of this area. However, today this site is losing its character due to growing urbanization of the valley. Domestic wastes from sub-urban area of Bungmati, massive agricultural field along both side of the river have significant role in river water pollution at this site (Tamrakar 2011).

3.1.1Sampling Frequency

The analysis of water quality was done during the period of pre-monsoon (March and April) and monsoon season (July and September).

3.2 Data Collection

In this study, both the primary and secondary data were used. Primary data was generated from the fieldwork as well as laboratory work. Eight physico-chemical parameters(pH, Temperature, Electrical Conductivity, DO, BOD, Nitrate, Phosphate and Ammonia) of water were considered for determining water quality. The secondary data was collected from work published by different Project/Institutes/Journals/Thesis as available.

3.2.1 Sampling Procedure

Water samples were collected from different sites selected along the Bagmati River. Sampling was made by dipping plastic bottle of 100mLupto the depth of 5-10 cm. The bottles were filled to the neck and air tightened. For analysis of BOD and DO, water samples were taken in BOD bottle from each station. pH, conductivity, temperature and DO were analyzed in the situ. The water samples for BOD_5 analysis were incubated on the same day. Each chosen parameter for the sample from each station was analyzed three times. Samples were collected between 10am to 2pm.

3.3 Methods of Measurement

Analytical grade reagents were used for the study and the methods used for the measurement of physico-chemical parameters of the river water were listed in Annex- IA.

3.3.1 Methods

Water quality analysis was carried out by using standard (APHA 1998 and Trivedy and Goel 1986) methods. Water samples were collected in plastic bottles of 100ml capacity and carried to laboratory within four hours. The samples were stored in refrigerator at around 4⌈C. Sample analysis was done for physical (temperature, pH & Conductivity) and chemical (DO, BOD, Phosphorus, Nitrate and Ammonia) parameters.

i. Temperature: It was carried out by dipping the standard mercury thermometer in water samples.

ii. pH: For measuring pH, water samples were collected in beakers and digital pH meter (HACH Sension) was used to record pH.

iii. Conductivity: Water samples were collected separately in beakers and a digital conductivity meter (Model HI8633) was used to measure conductivity.

iv. Dissolved Oxygen: For the measurement of DO, Winkler's method was followed (Trivedy and Goel 1986). BOD bottle of 300mL was first rinsed with sample water. The bottle was then immersed below the water surface in a slanting position in the direction of flow and the water was slowly allowed to rush into it. Then it was fixed immediately by adding 2mL of $MnSO_4$ and 2mL of alkaline KI using separate pipette. Then the bottle was rotated vigorously to ensure complete mixing. A brown precipitate was formed. The precipitate was allowed to settle down completely. After complete settlement, 2mL of concentrated H_2SO_4 was added for complete dissolution of precipitate. Then within the next 10 minutes, the amount of DO in the sample was measured by titration. For this, 50mL of sample was taken in a conical flask from the BOD bottle and a few drops of starch indicator were added. The sample turned bluish in color. Then the sample was titrated against Sodium thio-sulphate (0.025N) solution until the disappearance of blue color. Then the quantity of dissolved oxygen was calculated in mg/L by using the following equation;

$$DO\,(mg/L) = \frac{(mL \times N)\ of\ Na_2S_2O_3 \times 8 \times 1000}{\frac{V_2(V_1 - V)}{V_1}}$$

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

V_2 = Volume of the part of contents titrate

V = Volume of $MnSO_4$ and alkaline KI added.

Percent saturation of oxygen (O_2-S) (%)

DO is measured either in "milligram per liter (mg/L)" or "percent saturation". Milligram per liter is the amount of oxygen in a liter of water. Percent saturation is the amount of oxygen in a liter of water relative to the total amount of oxygen that the water can hold at that temperature. As temperature increases, the concentration at 100% saturation decreases (Mortimer 1956).

It was calculated by using the following formula:

O_2-S (%) = $C/C_S \times 100\%$

Where,

C = Observed dissolved oxygen at field temperature in mg/L

C_S = Saturated dissolved oxygen at that temperature in mg/L

The value of saturated dissolved oxygen (C_s) was taken from the Annex-V.

v. Bio-Chemical Oxygen Demand (Trivedy and Goel 1986)**:** The dilution water was prepared in a glass container by bubbling compressed air in distilled water for about 30 minutes. Then 1ml each of Phosphate buffer, Magnesium sulphate, and Calcium chloride and Ferric chloride solution was added for each liter of dilution water and mixed thoroughly. The pH was adjusted around 7.0. For the samples having low DO value, suitable dilution was made so that the dissolve oxygen would not be exhausted after 5 days. It was done by using the dilution water. Then two sets of BOD bottles were filled with diluted samples. One set of BOD bottles were kept in BOD incubator at 20°C for 5 days and DO content of other set were determined immediately. The DO of sample bottles after the completion of 5 days incubation was determined. Similarly for the blank, two BOD bottles having dilution were taken. The DO in one was determined immediately and other was incubated for 5 days and after 5 days completion, DO was determined. Then, for the calculation of the concentration of BOD, the following equation was used.

BOD (mg/L) = (DO_1-DO_5) × dilution factor

Where, DO_1 = Initial DO of the sample

DO_5 = DO after 5 days

vi. Nitrate (NO_3-N): Nitrate was analyzed using Brucine Absorbitivity method (APHA 1998). In this method, 10mL of filtered sample was taken in a beaker, in which 2mLNacl was added followed by 10mLsulphuric acid. While adding sulphuric acid, the beaker with sample was kept in a cold water bath. After this, 0.5mLBrucine was added and boiled in a water bath for about 20 minutes. The sample was allowed to cool in a cold water bath. Same procedures were followed for working standards. Then the absorbance of the samples wastaken at 410nm in a spectrophotometer. The standard curve was prepared between the concentrations vs. absorbances in a graph paper. The concentration of nitrate was calculated from the standard curve drawn.

vii. Phosphate (PO_4-P): Phosphate was analyzed using Ammonium Molybdate method (APHA 1998). Here 50mL of filtered sample was taken in a conical flask. In the flask 2ml Ammonium molybdate was added followed by 5 drops of $SnCl_2$ solution. Blue color was appeared and the reading of absorbance of the sample was taken at 690nm in a spectrophotometer using distilled water blank with the same amount of chemicals. The reading was taken after 5 minutes of the addition of the reagent. The standard curve was prepared between the concentrations Vs. absorbances. The concentration of phosphate was calculated using the standard curve.

viii. **Ammonia (NH_3-N):** Nessler's Reagent method was used for analysis of ammonia (APHA 1998). In this method, the stock solution of ammonium chloride was prepared at different concentrations ranging from 1mg/L to 50mg/L. From the stock solution, 50mLof sample was taken in a volumetric flask and two drops of Rochelle salt solution was added followed by 2mL of Nessler's reagent and left undisturbed for 15 minutes to develop the color. Then the absorbance at 420nm was noted down from spectrophotometer. The blank was prepared in ammonia free water by taking 50mL of ammonia free water and added 2mL of Nessler's reagent. The spectrophotometer was calibrated with blank solution and absorbance at different concentration of standards solutions was taken. The calibration curve was drawn and concentration of sample water was estimated.

3.4 Data Analysis

Water quality index was developed to assess the water quality of Bagmati River. Water quality index (WQI) is a tool that compares large amounts of data to standards and consolidates the information into an index score (Lohani 1981).

The results were analyzed by comparing with the standard values of river quality parameters and the water quality index developed by different countries. In the present study German Water Quality Index published in *Journal of Applied Chemistry* **(Downing and Lowden 1955)**and Netherland Water Quality Index (Shakya 2001) were used.

3.5 Procedure for Self-Dilution Capacity

To calculate the quantity of BOD free water, secondary data (BASP 1997, DHM 2010, Green et al. 2003 and Poudel 2000) was collected. The resultant concentration of BOD_5 after mixing of sewage effluents was calculated by using the Streeter Phelp's equation as follows:

$$(Q_1+Q_2)\times C = Q_1C_1+Q_2C_2$$ (Streeter and Phelps1925)

Where,

Q_1 = Average flow of river

Q_2 = Quantity of sewer flow

C_1 = BOD_5 of the river

C_2 = BOD_5 of sewage flowing to river

C = BOD_5 of the resultant river and the sewer

Then equivalent flow of water with permissible value of BOD_5 was calculated by using a formula

$$Q\times \text{Permissible value} = C\times (Q_1+Q_2)$$

Here, permissible value is a reference value of 5-days BOD which is taken to maintain healthy water quality. The permissible value is taken as 30mg/L (Poudel 2000).

Therefore, BOD free water that should be added to maintain permissible level (30mg/L) was calculated as,

Discharge to be augmented $= Q-(Q_1+Q_2)$

RESULTS

4.1 Results

The result of the study is mentioned under the following headings:

4.1.1 Water Quality Analysis

After the analysis of physical (Temperature, pH, Electrical Conductivity) and chemical (DO, BOD, NO_3-N, PO_4-P, NH_3-N) parameters of water samples collected from five sites of Bagmati River, following result was obtained:

a: Temperature

Maximum temperature (29.8^{o}C) was recorded at Aryaghat in pre-monsoon, while it was 23.3⌠C at Sundarijal in monsoon season. Pre-monsoonal temperature was more than the temperature measured in monsoon (Figure 4.1).

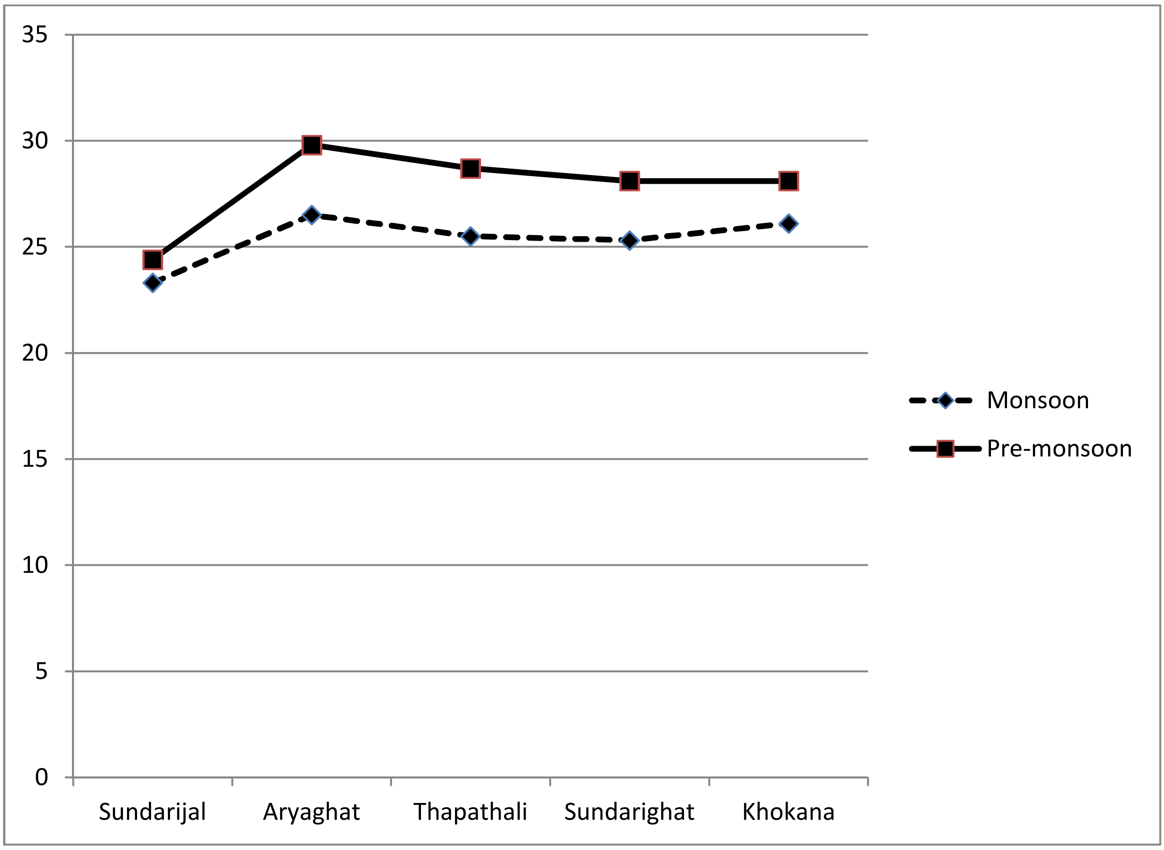

Figure 4.1: Temperature variation along the Bagmati River

b: pH

Maximum pH (pH 7.5) was measured in the samples collected from Sundarijalsite in pre-monsoon while the minimum pH (pH 6.7) was measured at Aryaghatsite in monsoon. Pre-monsoonal pH was found to be more in comparison to the pH measured in monsoon (Figure 4.2).

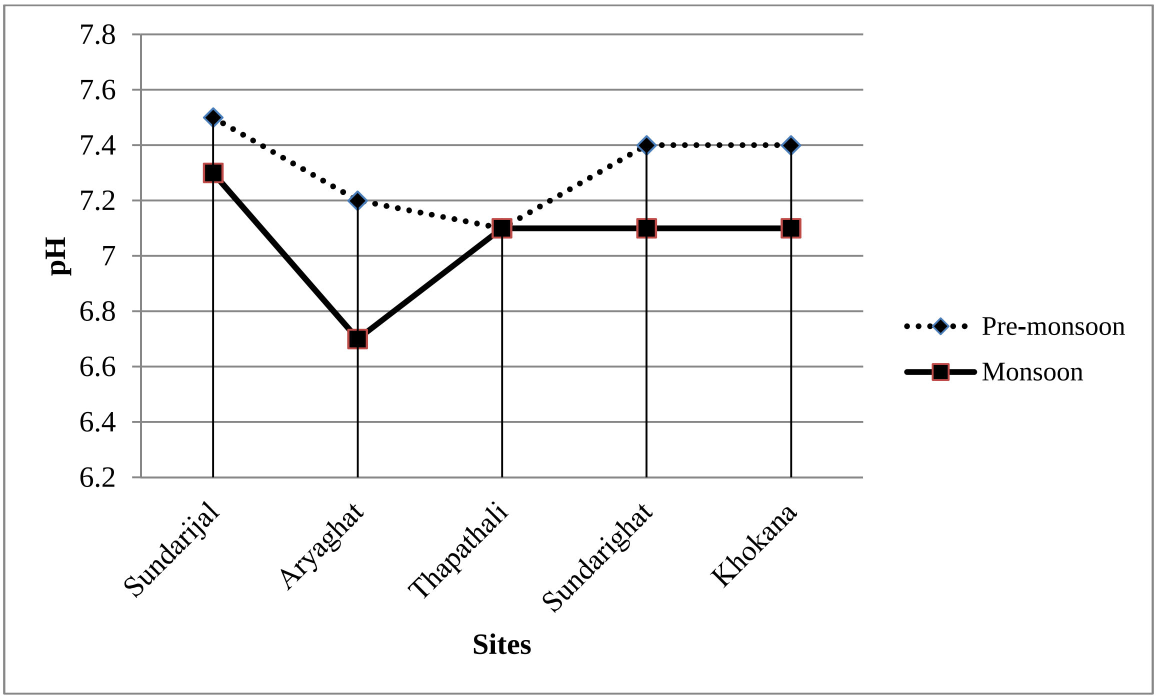

Figure 4.2: pH variation along the Bagmati River

c: Electrical Conductivity (EC)

Maximum electrical conductivity was recorded at Sundarighat site (745.7µS/cm) in pre-monsoon. The minimum value of conductivity was found at Sundarijal site (32.3µS/cm) in monsoon season. Similarly, the conductivity of water at Aryaghat, Thapathali and Khokana were measured 250.1µS/cm, 526.6µS/cm, 510.2µS/cm; respectively inpre-monsoon season. Conductivity of water in monsoon was found to be lower than pre-monsoon (Figure 4.3).

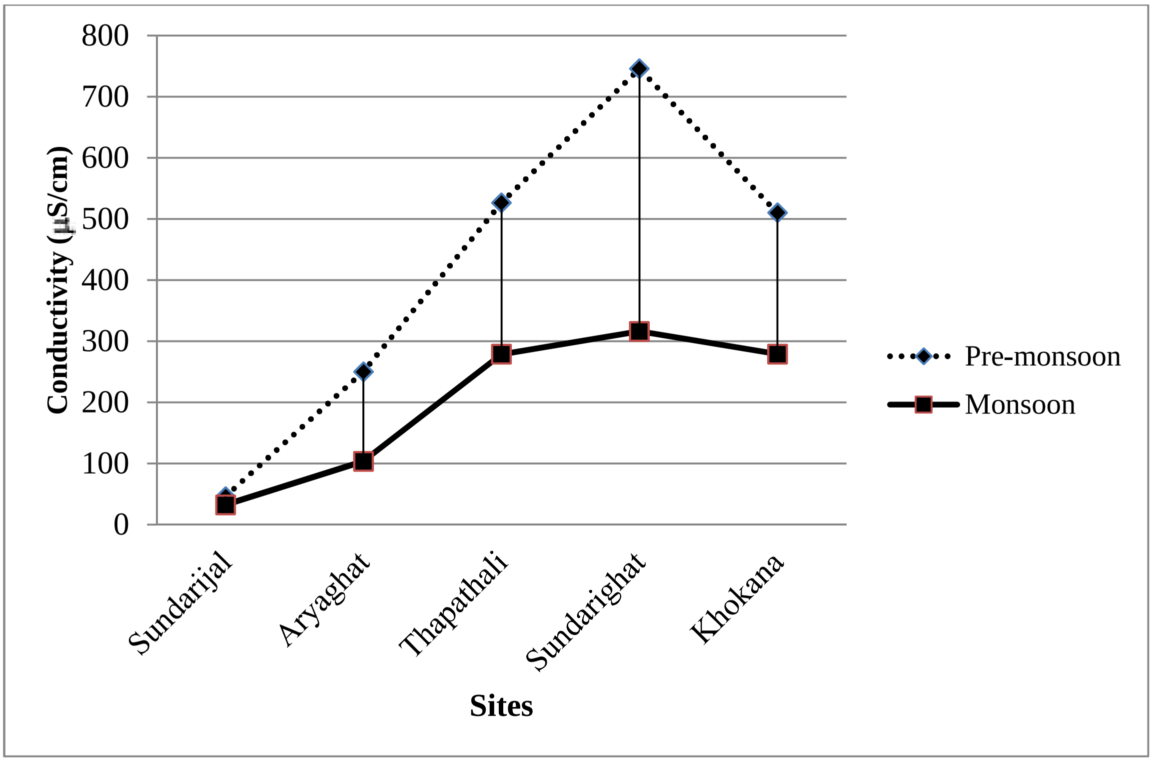

Figure 4.3: Conductivity variation along the Bagmati River

d: Dissolved Oxygen (DO)

The maximum value of O_2- saturation (%) was found at Sundarijal i.e. 98.1(Annex-IC) in monsoon and the value was found decreasing to minimum value of zero level at three stations Thapathali, Sundarighat and Khokana in pre-monsoon period.

The maximum value of DO (8.4mg/L, Fig.4.4) was recorded at Sundarijal in monsoon season. The values of DO at Thapathali, Sundarighat and Khokana were found to be very low in comparison to that of Aryaghat in both the seasons. The lower value of DO was reported in pre-monsoon than that of monsoon season.

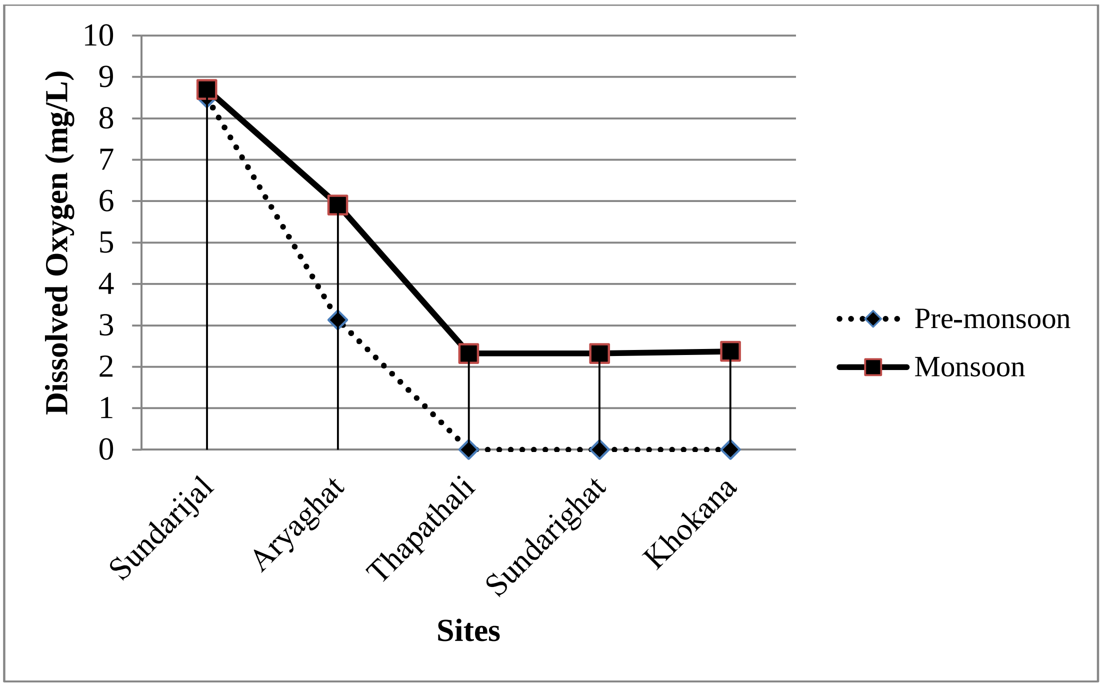

Figure 4.4: DO variation along the Bagmati River

e: Biological Oxygen Demand (BOD)

Minimum value of BOD was found at Sundarijal in both the seasons (2.3mg/L in pre-monsoon and 1.7mg/Lin monsoon). Similarly, maximum value of BOD was found at Sundarighat in pre-monsoon i.e. 226.2mg/L(Fig.4.5). Monsoonal BOD was found less than that of pre-monsoonal period.

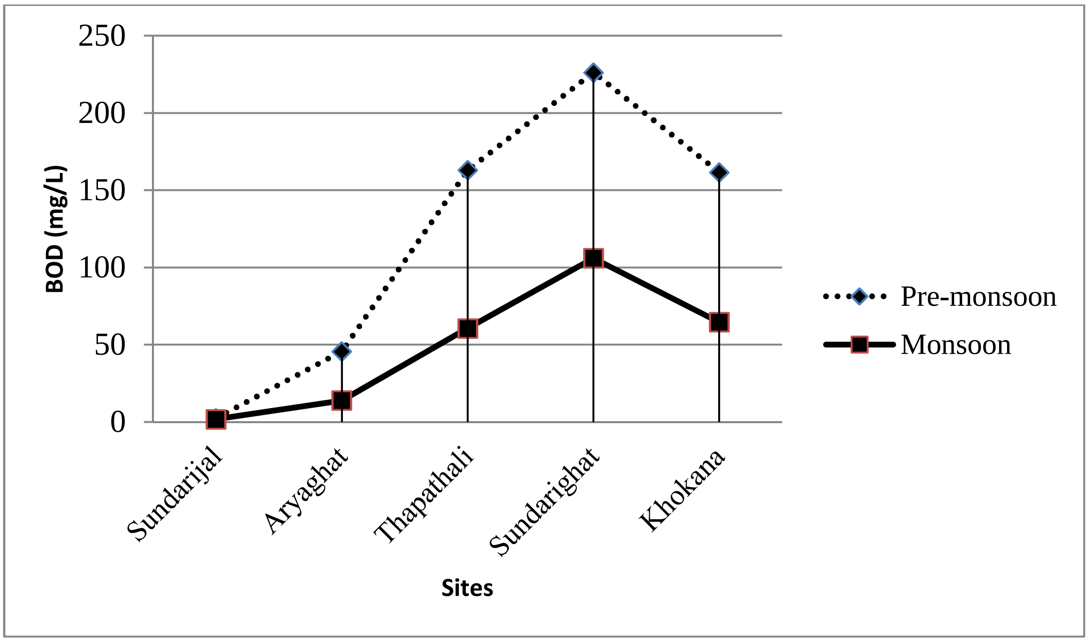

Figure 4.5: BOD_5 variation along the Bagmati River

f: Nitrate (NO_3-N)

Minimum value of NO_3-N (0.19mg/L in pre-monsoon and 0.16mg/L in monsoon) was found at Sundarijal in both the seasons while maximum NO_3-N was detected at Sundarighat. It was found 5.35mg/L in pre-monsoon and 3.03mg/L in monsoon (Fig. 4.6).

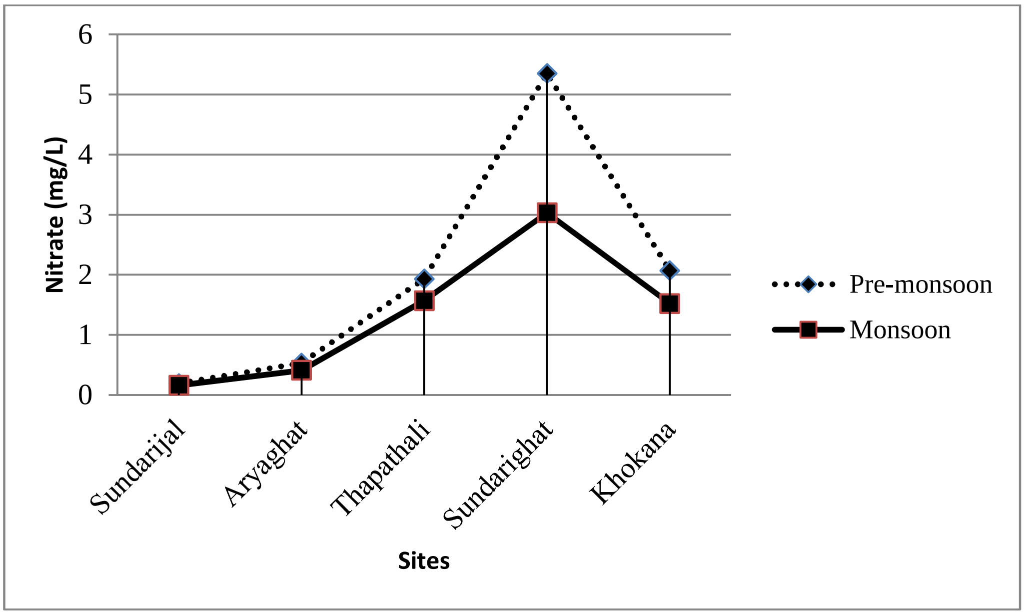

Figure 4.6: NO_3-N variation along the Bagmati River

g: Phosphate (PO_4-P)

The concentration of PO_4-P was 0.06mg/L and 0.09mg/L at Sundarijal site. These were the minimum values detected at the site in pre-monsoon and monsoon; respectively. Maximum values of phosphorous (12.98mg/L and 7.18mg/L) was obtained at Sundarighat site in pre-monsoon and monsoon seasons (Figure 4.7).

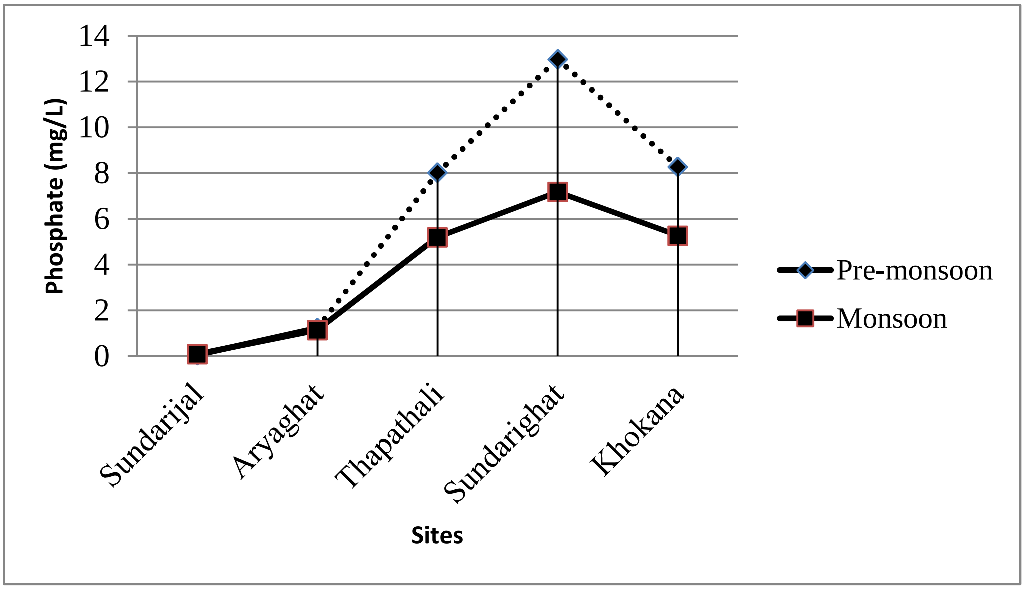

Figure 4.7: PO_4-P variation along the Bagmati River

h: Ammonia (NH_3-N)

Minimum value of NH_3-N was found at Sundarijal site. It was found 0.06mg/L in pre-monsoon and 0.11mg/L in monsoon season. The maximum value of NH_3-N was found at Sundarighat with 46.33mg/L inpre-monsoon. At Thapathali and Khokana the concentration of ammonia was found slightly reduced than that of Sundarighat. At these sites the values were 36.68mg/L and 36.5mg/L; respectively (Figure 4.8).

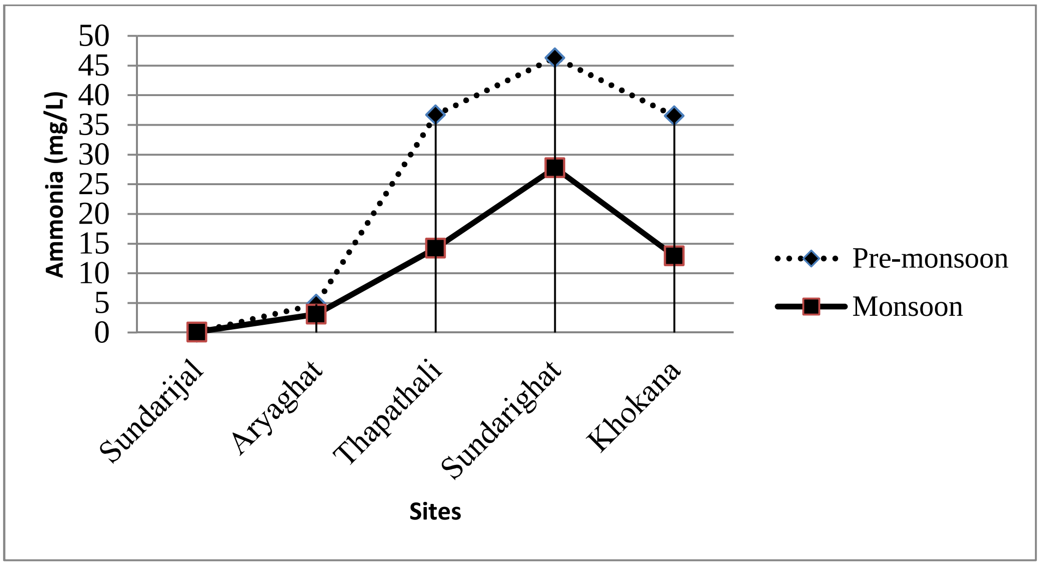

Figure 4.8: NH_3-N variation along the Bagmati River

4.1.2 Water Quality Status

To determine water quality status of each sampling site based on **German WQI**, following tables were used:

Table 4.1: Parameters for German Water Quality Index

Variables	**Unit**	**Importance Weight (W)**
O_2-S	%	0.2
BOD_5	mg/L	0.2
Temperature	°C	0.08
Ammonia (NH_3-N)	mg/L	0.15
Nitrate (NO_3-N)	mg/L	0.1
PO_4-P	mg/L	0.1
pH	NA	0.1
Electrical Conductivity	µS/cm	0.07

NA = Not available.

Source: (Downing and Lowden 1955)

Table 4.2: Description of German Water Quality Index

Class Interval	**WQ Class**	**Descriptor Words**
0-17	I	No or very low pollution
17-27	I-II	Low pollution
27-44	II	Moderate pollution
44-56	II-III	Critical pollution
56-73	III	Severe pollution
73-83	III-IV	Very severe pollution
83-100	IV	Excessive pollution

Source: (Downing and Lowden 1955)

Water Quality Index is the weighted sum of all sub-indices. The product (IW) of Importance Weight (W) and Parameter Value (I) was calculated for each parameter and their summation (∑IW, Annex-II) was taken as the Water Quality Index value which was campared to Table 4.2. The total value describes the quality of water as represented in the following table:

Table 4.3: Water Quality Status (German Water Quality Index)

Station	Value of IW		WQ class		Quality level	
	Pre-monsoon	Monsoon	Pre-monsoon	Monsoon	Pre-monsoon	Monsoon
Sundarijal	24.4	23.3	I-II	I-II	Low pollution	Low pollution
Aryaghat	38.92	28.30	II	II	Moderate pollution	Moderate pollution
Thapathali	78.94	42.85	III-IV	II	Very severe pollution	Moderate pollution
Sundarighat	109.22	56.92	IV	III	Excessive pollution	severe pollution
Khokana	77.52	43.72	III-IV	II	Very severe pollution	Moderate pollution

Water quality status of each sampling site based on **Netherland WQI** was determined by using following tables:

Table 4.4: Parameters of Netherland Water Quality Index

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

Source: (Shakya 2001)

Table 4.5: Description of Netherland Water Quality Index

Class Interval	WQ Condition
3.0-4.5	Excellent
4.6-7.5	Good
7.6-10.5	Fair
10.6-13.6	Bad
13.6-15	Very Bad

Source: (Shakya 2001)

Water Quality status of each sampling site was categorized with the help of total points awarded (Annex- III) and comparing those values with table 4.5.

Table 4.6: Water Quality Status (Netherland Water Quality Index)

Station	Total Value of Points Awarded		Quality Level	
	Pre-monsoon	Monsoon	Pre-monsoon	Monsoon
Sundarijal	3	3	Excellent	Excellent
Aryaghat	13	10	Bad	Fair
Thapathali	15	15	Very Bad	Very Bad
Sundarighat	15	15	Very Bad	Very Bad
Khokana	15	15	Very Bad	Very Bad

4.1.3 Water Quality Trend

To compare water quality trend, the water quality map of '1991', '2004' and '2012' were drawn based on the Netherland Water Quality Index using the data from the table (Annex-IV).

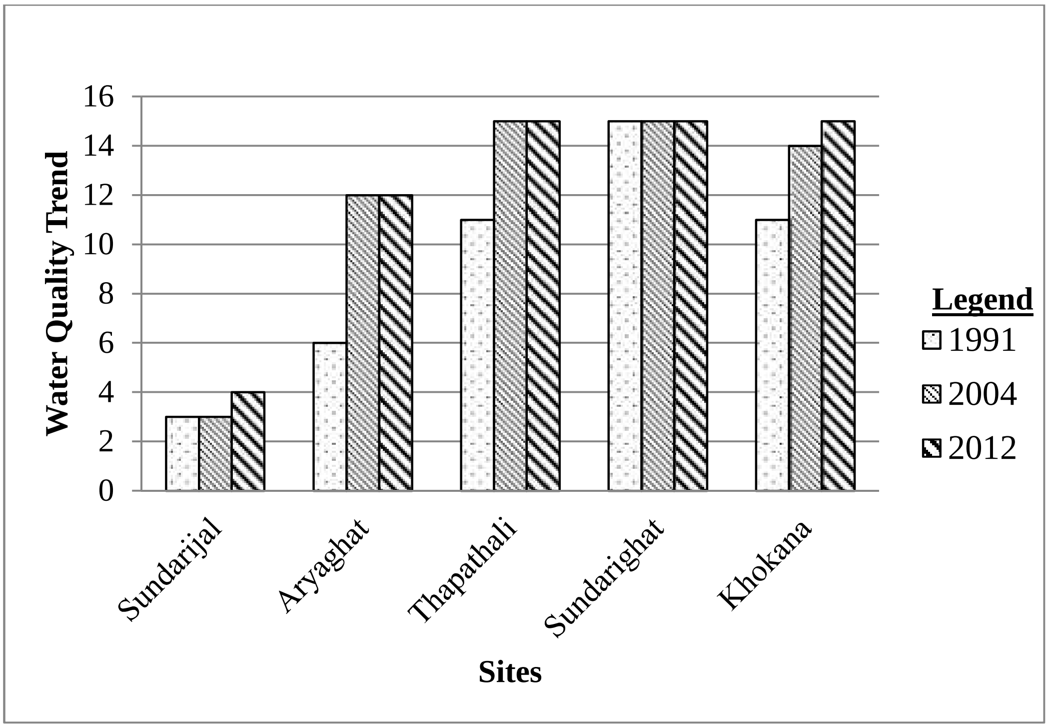

Figure-4.9: Water Quality Trend

Source: (Shrestha et al. 1991 and Poudel 2004)

4.1.4 Calculation of Self-Dilution Capacity

The self-dilution capacity of river refers to the required flow in the river to acquire the BOD value in the permissible level of 30mg/L (Poudel 2002).

In the present context, Bagmati River is receiving excessive sewer water than natural water which is affecting its self-dilution capacity, demanding additional flow in the river. Calculation for self-dilution capacity of river at different sites was based on the secondary data available from the department of Hydrology and Meteorology (DHM) and Bagmati Area Sewerage Project (BASP).

The average monthly and yearly discharge value of Bagmati River for five years was taken from DHM. The data for Sundarijal and Khokana was available from 2006 to 2010 and for Aryaghat it was available from 2002 to 2006.

Table 4.7: Average monthly and yearly discharge in m^3/s

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Average annual flow (m^3/s)
Sundarijal	0.36	0.31	0.26	0.30	0.43	0.90	1.77	3.10	2.5	1.05	0.65	0.45	1.01
Aryaghat	0.68	0.66	0.70	0.76	1.10	1.59	9.65	13.36	8.54	3.06	0.99	0.46	3.46
Khokana	3.25	3.37	3.15	3.52	5.37	11.69	34.44	33.36	33.72	10.97	5.31	4.02	12.68

Source: (DHM 2010)

For the calculation, primary data of BOD_5 was also taken. The BOD of domestic wastewater discharged into Bagmati Rivervaries from 150mg/L to 312mg/L (BASP1997). So here for the calculation average value of 231mg/L has been taken.

The Guheswori Waste Water Treatment Plant was designed in 1996 to serve a population of 58,0000 with the treatment capacity of $0.199m^3/s$ (Green et al. 2003). Hence, the value $0.199m^3/s$ was taken as the quantity of sewer flow.

Since, the flow in the river becomes lowest and maximum DO exertion takes place during pre-monsoon, self-dilution capacity of this period was calculated.

Calculation of self-dilution capacity for Bagmati River at Sundarijal

Self-dilution capacity was calculated using the given formulae:

Average pre-monsoon flow of river (Q_1) = $0.33m^3/s$ (DHM 2006-2010, average value, Table number 4.7)

BOD_5 of the river water (C_1) =2.3mg/L (Annex-IC)

Quantity of sewer flow (Q_2) =$0.199m^3/s$ (Green et al. 2003)

BOD_5 of the sewage flowing to the river (C_2) =23mg/L (average value, BASP)

Now, the resultant concentration of BOD_5 of the flow at the down-stream is given by Streeter Phelp's equation as

$(Q_1+Q_2)\times C = Q_1C_1+Q_2C_2$ ……………………. (1)

Substituting the values in equation (1), we get,

$C = 88.33 mg/L$

Hence, equivalent flow of water with 30mg/L BOD_5 is given by a formula,

$Q \times$ Permissible value of BOD_5 = Resultant concentration $\times (Q_1+Q_2)$……. (2)

Or, $Q \times 30 = 88.33 \times 0.529$

$Q = 1.56 m^3/s$

Now, average flow in the Sundarijal during pre-monsoon can be taken as $0.529 m^3/s$ and the additional quantity of BOD free water that should be added to maintain 30mg/L BOD level is calculated as,

$Q - (Q_1+Q_2)$
$= (1.56-0.529)$

$= 1.03 m^3/s$

Hence, the required flow needed to maintain the permissible value of 30mg/Lat Sundarijal=$1.03 m^3/s$.

Similarly, the self- dilution capacity at Aryaghatand Khokana was calculated and the required flow needed to maintain the permissible value of 30mg/L was obtained as $1.74 m^3/s$ and $17.7 m^3/s$; respectively.

From the above calculation, the self-dilution capacity to maintain the permissible value of BOD in the river at Sundarijal, Aryaghat and Khokana was calculated as $1.03 m^3/s$, $1.74 m^3/s$ and $17.7 m^3/s$; respectively.

DISCUSSION

5.1 Discussion

The discussion was based on the findings and supported literatures and published data of similar works.

5.1.1 Water quality parameters

a. Temperature

Temperature impacts both the chemical and biological characteristics of surface water. Increased temperature accelerates the chemical reaction in water which affect the dissolved oxygen level in water and also amplifies the tastes and odor. If the water temperature changes by even a few degrees, it could indicate a source of unnatural warming of the water or thermal pollution. Pollution caused by human activities is one factor that can affect water temperature. Many industries use river water in their processes. Temperature is an important parameter which help in the determination of pH, conductivity, saturation level of gases, alkalinity etc. (Trivedy and Goel 1986).

Maximum temperature was measured 29.8^{o}Cat Aryaghatin pre-monsoon (Fig. 4.1). This might be due to the discharge of treated water into the site by Guheswori Waste Water Treatment Plant. If water is treated before it is returned to the river, its temperature is raised than it was before (Goel 2006).Minimum temperature (23.3^{o}C) was recorded at Sundarijal in monsoon. This might be due to lowest level of pollution, less human interference and presence of plants at the periphery of the river site. Trees along the river side provides shade which help to reduce water temperature (Jayaraman et al. 2003).

Pre-monsoonal temperature was found to be more in comparison to monsoonal value at all the sites. This may be due to low discharge value in the river. Less amount of rainfall in pre-monsoon leads to low water flow in the river which results poor water quality (Lawson 2011).

b. pH

pH is the measure of acidity and alkalinity. Acidity and alkalinity depends upon the presence of H^+ or OH^- ions in water. If free H^+ ions are more than OH- ions then water is said to be acidic. Similarly, if free OH^- ions are more, then water is said to be alkaline.

Determination of pH is one of the important objectives in treatment of the waste (Trivedy and Goel 1986).

Maximum pH value 7.5 (Fig. 4.2) was found at Sundarijal in pre-monsoon. This has also been observed by (KAPRIMO2007) which was recorded as 7.02.This reveals the normal condition of water which may be due to less human interference at this site. Minimum pH was measured at Aryaghat i.e. 6.7.

Pre-monsoonal pH was found to be more in comparison to monsoonal pH. This may be due to low water flow in the river in pre-monsoon season resulting into poor water quality.

Electrical Conductivity (EC)

The conductivity of water depends on the presence of ionic substances. Conductivity of distilled water ranges from 1-5µS/cm. Pressure of salts and contamination with wastewaters increase the conductivity (APHA 1998).

Maximum conductivity of water (745.7⇑S/cm) was measured at Sundarighat (Fig. 4.3) in pre-monsoon indicating the high pollution of Bagmati River. This site receives untreated sewage discharged from Kathmandu and Patan area. Similar result (740µS/cm) was obtained in a study conducted by (NESS 1997) at the Sundarighat site. Minimum value of conductivity was found at Sundarijal (32.3µ S/cm) in monsoon season.

Monsoonal conductivity values at all the locations were found to be lower than pre-monsoonal value, which might be due to more dilution capacity of river during monsoon season (Lawson 2011).

Dissolved Oxygen (DO)

Dissolved Oxygen (DO) oxygen is one of the most important parameter for water quality analysis and reflects the physical and biological process prevailing in the water. Non polluted waters are normally saturated with dissolved oxygen. Oxygen saturated waters have a pleasant taste while the waters lacking oxygen have an insipid taste. The oxygen contained in water is necessary for the survival of animal and plant organisms as well as for the degradation of chemical and biological contaminants. Its presence is also essential for maintaining higher forms of biological lives and to those organisms, which are responsible for the self-purification process of natural waters. Organisms have specific requirement of oxygen. For example game fish requires at least 5mg/L and Coarse fish about 2mg/L of minimum dissolved oxygen in water (Trivedy and Goel 1986).

The maximum value of O_2- saturation (%) was found at Sundarijal (98.1mg/L) in monsoon and the value was found decreasing to minimum value of zero level at Thapathali, Sundarighat and Khokana in pre-monsoon. The maximum value of DO (8.4mg/L) was measured at Sundarijal in monsoon season (Fig. 4.4). This value agrees the findings of (KAPRIMO 2007) where the DO was measured 8.38mg/L. This result revealed that the water quality of Bagmati River at Sundarijal is comparatively less polluted which might be due to the less human interference activities.

The value of DO at Thapathali, Sundarighat and Khokana was measured 0mg/L. This might be due to increased level of pollutants along downstream of Bagmati River as can be seen at most of the places untreated sewer and industrial effluent is directly discharged into Bagmati River. A study carried out by (UNEP 2001) to analyze DO at different places of Bagmati River also supports the findings of this report. Similarly, the value of DO at Sundarighat and Khokana was <0.5mg/L (NESS 1997).The DO at Aryaghat site (3.13mg/L in pre-monsoon) and (5.91mg/L in monsoon) was found satisfying the level suggested by (Trivedy and Goel 1986).

DO value of Bagmati River at Thapathali, Sundarighat and Khokana area revealed no any aquatic lives can survive in water. The minimum value of DO was reported in pre-monsoon which might be due to low discharge value of river with less amount of rainfall in pre-monsoon season. Low discharge value of river causes the increased rate of use of oxygen than the re-aeration rate from the atmosphere (Lawson 2011).

Biological Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is the measure of degradable organic wastes present in water. The BOD can be defined as the amount of oxygen required by micro-organisms to stabilize biologically degradable organic matters under aerobic conditions.

Minimum value of BOD was found at Sundarijal in pre-monsoon (2.3mg/L)and monsoon (1.7mg/L) indicating low level of water pollution (Fig. 4.5). The BOD was found exceeding as the river enters gradually into the urban area. Maximum value of BOD

(226.2mg/L) was found at Sundarighat in pre-monsoon (Fig.4.5). The increased concentration of BOD might be probably due to greater quantity of untreated sewer discharge, encroachment along the bank of the river by slum dwellers, mixing of highly polluted rivers (Bishnumati, Tukucha) into the Bagmati River and high concentration of domestic and industrial effluents. This fact was also supported by (UNEP2001). A report presented by (CEMAT 2000) indicates, outlet of the Bagmati River generate 20,846 kg BOD per day which constitute 42% of the total BOD load.

Nitrate (NO_3-N)

Nitrate represents the oxidized form of nitrogen. The most important source of nitrate in Bagmati River is biological oxidation of nitrogenous substances which are available in sewage and industrial wastes or produced indigenously in the water. Domestic sewage contains maximum amount of nitrogenous compounds. Run off from agriculture fields also contain nitrate (Trivedy and Goel 1986). The natural level of NO_3-N in water is reported as 0.1mg/L NO_3-N (ENPHO 1997).

At Sundarijal, 0.19mg/L and 0.16mg/L nitrate was measured in pre-monsoon and monsoon season; respectively. Similarly, at Sundarighat it was 5.35mg/L and 3.03mg/L in pre-monsoon and monsoon; respectively. The difference of nitrate at these sites shows that the river at Sundarijal site is less polluted than the Sundarighat. Pandey (2005) also recorded Sundarighat as the most polluted site.

Phosphate (PO_4-P)

Phosphorus occurs in water mostly in the form of phosphate. Natural source of phosphorus is weathering of phosphorus bearing rocks while the other sources are domestic sewage, detergents, agricultural effluents and industrial waste waters. The higher concentration of phosphorus in water is indicative of pollution. In most natural surface waters, phosphorus ranges from 0.005-0.20mg/L as PO_4-P (ENPHO 1997).

In this study, minimum value of PO_4-P was estimated (0.06mg/L in pre-monsoon and 0.09mg/Lin monsoon) at Sundarijal site (fig. 4.7). This result revealed that the phosphorus concentration agreed the recommended guidelines of waste waters discharged into surface waters (ENPHO 1997). Maximum value of PO_4-P was found at Sundarighat (12.98mg/L in pre-monsoon and 7.18mg/L in monsoon). This site is considered highly polluted and biologically dead area of the Bagmati River due to appearance of dark and turbid water, lack of an opportunity to self-purification of water and discharge of open sewer into the river (Green 2003).

Aryaghat area showed minimum amount of phosphate and Nitrate in comparision to Thapathali, Sundarighat and Khokana area (Fig. 4.6 & 4.7). This might be due to waste water treatment plant established at Guheswori from where the treated waste water is discharged into Bagmati River. Even after treatment of water, the phosphate concentration of the river water was 1.23mg/Lin pre-monsoon & 1.15mg/L in monsoon. This might be due to cultural and religious activities as well as cremation of dead bodies at Aryaghat near Pashupati area.

Ammonia (NH_3-N)

Ammonia occurs naturally in water arising from the breakdown of nitrogenous organic and in-organic matter in soil and water, excretion by biota, reduction of the nitrogen gas in water by micro-organisms and from gas exchange with atmosphere (Trivedy and Goel 1986). The natural level of Ammonia in water is 0.010mg/L as nitrogen (ENPHO1997).

In this study ammonia was detected in minimum concentration at Sundarijal. It was measured 0.06mg/Lin pre-monsoon and 0.11mg/L (fig.4.8) in monsoon season. These values were close to the amount of ammonia in natural water reported by (ENPHO1997).

The maximum value of NH_3-N was found at Sundarighat (46.33mg/L) in pre- monsoon season and 27.77mg/L in monsoon which were exceeding the concentration of ammonia in natural water. NESS (1997) reported 42.8mg/L NH_3-N in pre-monsoon at the Sundarighat site. This result reveals the increased pollution level of river at Sundarighat.

The reason of maximumNO_3-N, PO_4-P, NH_3-N detected at Sundarighat site might be due to untreated sewage receiving from the squatter settlements, mixing of lather from the soap and detergents used to wash the clothes and utensils near the source of water and mixing of pollutants from Teku Hospital, Nepal Eye Hospital and Veterinary Hospital which were observed during the study.

5.1.2 Water Quality Status

Water quality status of Bagmati River at different sites was determined by analyzing the physical (Temperature, pH, Electrical Conductivity) and chemical (DO, BOD, NO_3-N, PO_4-P, NH_3-N) parameters and comparing the results with German WQI and Netherland WQI (Annex-II and III).

Based on the German WQI, five sites were classified and categorized:

1. Sundarijal: 'low pollution' zone in both the pre-monsoon (summation IW:25.03) and monsoon -season (summation IW: 25.01). Free from dense human settlement areas might be the supportive reason to classify Sundarijal as low pollution zone.
2. Aryaghat: 'Moderate pollution' zone in both the pre-monsoon (summation IW: 38.92) and monsoon season (summation IW: 28.30).RONAST (1988) also classified Pashupati as 'slightly polluted' zone. The main reason behind to set Aryaghat as Moderate pollution zone might be the presence of Guheswori Waste Water Treatment Plant nearby the site.
3. Thapathali: 'Very severe pollution' zone in pre-monsoon (summation IW: 78.94) and 'moderate pollution' zone in monsoon season (summation IW: 42.85). Sand quarrying activities, untreated sewage, industrial effluent, urinating directly into the river, mixing of rotten vegetables might be the main reasons behind this.
4. Sundarighat: 'Excessive pollution' zone in pre-monsoon (summation IW: 109.22) and 'Severe pollution' zone in monsoon season (summation IW: 56.92). Bottino (1988) and Pandey (2005) classified Sudarighat as extremely polluted and most polluted location; respectively. Encroachment by slum dwellers, accumulation of collected garbages on the bank of the river by municipality, lack of green environment, direct mixing of sewage and fecal contamination in the river, livestock farming might be the major reasons that supported this site to classify as extremely polluted zone.
5. Khokana: 'Very severe pollution' zone in pre-monsoon (summation IW: 77.52) and 'moderate pollution' zone in monsoon season (summation IW: 43.72). Agricultural run-off and excessive sewage from the village area might be the main reason behind this.

According to Netherland WQI, five sites were classified as below:

1. Sundarijal: ' Excellent' zone with (Total value: 3) in both the seasons.
2. Aryaghat-'Bad' zone with (Total value: 13) in pre-monsoon and 'fair zone' (Total value 10) in monsoon.

3. Thapathali-'very bad' zone with (Total value: 15) in both the seasons.
4. Sundarighat and Khokana were also classified as 'very bad' zone with (Total value: 15) in both the pre-monsoonal and monsoonal period.

The German Water Quality Index and Netherland Water Quality Index revealed that more the deviation of the water quality parameters from the permissible level more will be the level of pollution.

The result of both the Indices also revealed that water quality goes on degrading as it flows downstream.

5.1.3 Water Quality Trend of Bagmati River

The figure 4.9 showed that water quality of Bagmati River has changed significantly from 1991 to 2012. Thapathali, Sundarighat and Khokana were found at Saturated level since 2004 to 2012 indicating the optimum level of pollution at almost all the sites of Bagmati River.

a. Sundarijal

At Sundarijal, water quality has not changed significantly from 1991 to 2012. It was classified as 'excellent zone'. Less pollution at this site might be due to less human settlement.

b. Aryaghat

At Aryaghat site, water quality has shifted from 'good' in 1991 to 'bad' from 2004 to 2012 (fig.4.9).

The reason of increased pollution might be unplanned urbanization and haphazard settlement of residential areas, cultural and religious practices, cremation of dead bodies along the bank of river, establishment of factories and industries nearby the Bagmati River.

Although the Guheswori waste water treatment plant is in operation and water is treated before to discharge in the river, the water quality is still 'bad'. This might be due to human activities. Pilgrims offer puja (prey) at Pashupati and Guheswori temples and discard flowers and remaining materials into the river. Moreover, the clothes and remaining of dead bodies after cremations are also thrown into the river resulting into increase of water pollution level of Bagmati River.

c. Thapathali

At Thapathali site, water quality has shifted from 'bad' in 1991 to 'very bad' from 2001 - 2012 (fig.4.9).

The reason of increased pollution level might be due to discharge of untreated sewage, industrial effluent, garbages either into river or at the bank of river. Other reasons of increased pollution may be open urination / excretion and sand quarrying activities in and near the Bagmati River. Heavy foul odour was observed at this site during sampling in pre-monsoon. This might be due to open fecal defecation practices by slum dwellers as well as street children which were observed during the site visit. The bridge overhead the river might be another reason which made people easy to throw garbages into the river.

d. Sundarighat

Water quality of Bagmati River at Sundarighat area shows that water pollution is extremely worse and condition is stable from 1991 to 2012.

Dumping of solid waste along the bank of river, sand quarrying activities, encroachment, mixing of detergents, increased pressure of livestock farming might be the major causes of pollution in the area. Similarly, another reason of degradation of water quality at this site might be due to encroachment by slum dwellers and accumulation of garbages on the bank of river by municipality.

e. Khokana

Water quality of the river at Khokana shows that water pollution is shifting from 'Bad' in 1991 to 'very bad' from 2004 to 2012.

Khokana was found receiving less amount of solid disposal carried from other sites due to the several twists and turns passing from Sundarighat to Khokana. Despite of this, it was still found polluted. This might be due to discharge of sewage from Bungmati areas and unsafe agricultural practices along the bank of the river leading to rise in nitrate, phosphate and ammonia level due to fertilizer runoff and removal of plants into the river water (www.eeweek.org). Rainfall causes transport of nutrients such as agricultural residues; salt particles etc. thus affecting the chemical composition of water (Viner 1975).

5.2.4 Self-Dilution Capacity

Table 5.1 Self-dilution capacity of Bagmati River at Sundarijal, Aryaghat and Khokana:

Sites	2004	2012
Sundarijal	NA	1.03m^3/s
Aryaghat	2.5m^3/s	1.74m^3/s
Thapathali	NA	NA
Sundarighat	NA	NA
Khokana	12.3m^3/s	17.7m^3/s

Self-dilution capacity i.e. additional flow required in the river at Aryaghat was recorded 2.5m3/s in 2004 and found decreasing to1.74m3/s in 2012 which might be due to the discharge of treated water. At Khokana it was12.3m3/s in 2004 while increased value 17.7m3/s was detected in 2012 showing the increased amount of required flow in the river which might be due to the untreated discharge from Bungmati area.

CONCLUSION AND RECOMMENDATIONS

Conclusions

- The results showed that overall water quality of Bagmati River is in miserable condition except at the source.
- Water pollution at Sundarijal site was not severe as is at Aryaghat, Thapathali, Sundarighat & Khokana. Among these five stations Sundaright was found in timorous situation.
- According to GWQI, Sundarijal was classified as less pollution zone in both the seasons while Sundarighat as excessive pollution zone in pre-monsoon and severe pollution zone in monsoon. Aryaghat was classified as moderate zone.
- According to NWQI, Sundarijal was classified as excellent zone and Thapathali, Khokana and Sundarighat as very bad zone in both the seasons.
- Water pollution level of Bagmati River has been increasing tremendously since 1991 to 2012.
- Self-dilution capacity i.e. required flow in the river was found increasing as it flows down-stream.
- The water quality level was found in improved condition during monsoon season in comparison to pre-monsoon season.

Recommendations

- Discharge of untreated sewage and waste waters are the main sources of water pollution of Bagmati River. Hence, untreated waste waters & sewers must be treated before discharging into the river. Waste water treatment plant should be installed in the dense settlement areas and only the treated water should be allowed to discharge into river water.
- The river water at Aryaghat was found less polluted in comparison to Thapathali, Sundarighat and Khokana areas. Cremation of dead bodies may be one of the main cause imparting water pollution at this site. Hence, it is recommended to establish electrical crematorium system at Aryaghat and also recommended not to discard remained of cremation as well as flowers & other materials which may cause pollution.
- The construction of septic tank in each house would definitely help to improve the condition of Bagmati River. Hence, safety tank construction should be mandatory.
- Squatter settlement along the bank of river is also the burning problem. In order to minimize the pollution in river such settlements should be managed. During the present study, squatter settlements from the Sundarighat area were on the process of displacement. Such initiations should be continued by the government.

  It is recommended to provide public awareness about the river water conservation with the help of related sector.
- Safe agricultural practices should be promoted.

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Annex: I (A)

List of required materials and analytical reagents used for water quality analysis

S.N	Variables to be Measured	Methods of Measurement	Materials Used	Analytical Reagents
1.	Temperature	Thermometric	Mercury Thermometer	
2.	pH	Electrometric	pH meter (Model, HACH Session 1)	
3.	Conductivity	Electrometric	Conductivity meter (Digital conductivity meter, model HI8633)	
4.	Dissolved Oxygen (DO)	Winkler's Method	Measuring cylinder Reagent bottles Conical flask BOD bottles Pipettes	Alkaline KI $MnSO_4$ Conc. H_2SO_4 Starch indicator $Na_2S_2O_3$ (0.025N)
5.	BOD_5	5-Day Test Titration Method	Measuring cylinder Conical flask BOD bottles Pipette, burettes, carbon paper BOD incubator Air compressor	$MgSO_4$ $CaCl_3$ $FeCl_3.6H_2O$ Phosphate Buffer
6.	Nitrate (NO_3-N)	Brucine Absorbity Method	Buckler filter Measuring cylinder Porcelain basin Drying oven Volumetric flask Spectrophotometer (digital spectrophotometer, model 301E, Electronics India)	Brucine-Sulfanilic Acid Solution H_2SO_4 acid solution Nacl solution Standard Nitrate solution
7.	Phosphate	Ammonium Molybdate Method	Buckler filter Measuring cylinder Volumetric flask	Ammonium molybdate solution Stannous chloride

			Pipettes Conical flask Spectrophotometer (digital spectrophotometer, model 301 E, Electronics India)	solution Standard phosphate solution
8.	Ammonia (NH_3-N)	Nessler's Reagent Method	Buckler filter Measuring cylinder Pipettes Volumetric flask Spectrophotometer (digital spectrophotometer, model 301E, Electronics India)	Nessler's reagent solution Rochelle Salt Solution $KHPO_4$

Source: (APHA 1998, Trivedyand Goel 1986)

Annex: I(B)

Observation Values for Water Quality Parameters of Study Sites

(a): Sundarijal

Parameters	March, 2			April, 26			Pre-monsoon average	July, 2			September, 5			Monsoon average
	S_1	S_2	S_3	S_1	S_2	S3		S_1	S_2	S_3	S_1	S_2	S_3	
Temperature (ºC)	25.4	25.1	25.2	23.4	23.5	24.0	24.4	24.4	23.8	23.7	22.1	23.3	22.5	23.3
pH	7.3	7.3	7.4	7.9	7.4	7.7	7.5	7.2	7.0	7.5	7.3	7.4	7.2	7.3
Conductivity (µS/cm)	44.9	43.6	44.2	48.4	47.8	47.0	46.0	36	24	26	37	35	36	32.3
DO (mg/L)	8.0	8.3	8.3	8.1	8.0	8.1	8.1	8.2	8.4	8.4	8.3	8.5	8.5	8.4
BOD_5 (mg/L)	2.4	2.6	2.5	2.2	2.1	2.0	2.3	1.9	1.7	2.0	1.3	1.8	1.5	1.7
NO_3-N (mg/L)	0.06	0.18	0.11	0.24	0.24	0.31	0.19	0.20	0.19	0.17	0.12	0.14	0.13	0.16
PO_4-P (mg/L)	0.06	0.05	0.03	0.07	0.09	0.07	0.06	0.10	0.13	0.12	0.07	0.08	0.06	0.09
NH_3-N (mg/L)	0.05	0.05	0.06	0.08	0.06	0.08	0.06	0.12	0.15	0.13	0.05	0.09	0.10	0.11
O_2-Saturation (%)							96.4							98.1

Site (b): Aryaghat

Parameters	March, 2			April, 26			Pre-monsoon average	July, 2			September, 5			Monsoon average
	S_1	S_2	S_3	S_1	S_2	S_3		S_1	S_2	S_3	S_1	S_2	S_3	
Temperature (ºC)	29.7	28.9	29.6	30.4	29.9	30.1	29.8	26.9	26.2	27.0	26.5	25.8	26.5	26.55
pH	7.2	7.1	7.1	7.3	7.4	7.2	7.2	6.3	6.8	6.4	6.8	7.0	6.9	6.7
Conductivity (µS/cm)	240.2	267.8	243.1	256.7	249.3	243.6	250.1	112.3	110.4	107.6	101.2	90.8	99.9	103.7
DO (mg/L)	2.79	3.23	3.51	3.13	3.09	3.05	3.13	5.41	5.96	6.12	5.67	6.1	6.2	5.91
BOD_5 (mg/L)	44.5	47.2	44.0	49.8	44.0	43.9	45.6	15.8	15.3	14.9	12.6	11.8	12.3	13.8
NO_3-N (mg/L)	0.54	0.57	0.51	0.42	0.57	0.59	0.53	0.41	0.43	0.40	0.45	0.37	0.39	0.41
PO_4-P (mg/L)	1.20	1.17	1.23	1.4	1.25	1.10	1.23	1.29	1.18	1.31	1.1	1.02	1.01	1.15
NH_3-N (mg/L)	4.7	4.5	4.1	4.9	5.3	5.2	4.78	4.0	3.18	3.16	3.02	2.54	2.8	3.12
O_2-Saturation (%)							41.5							74.3

Site (c): Thapathali

Parameters	March, 2			April, 26				July, 2			September, 5			Monsoon average
	S_1	S_2	S_3	S_1	S_2	S_3	Pre-monsoon average	S_1	S_2	S_3	S_1	S_2	S_3	
Temperature (ºC)	28.1	27.8	28.3	29.4	29.3	29.5	28.7	25.1	25.3	26.2	26.2	24.7	25.2	25.5
pH	7.1	7.0	7.1	7.2	7.2	7.2	7.1	7.2	7.1	7.3	6.9	7.1	6.7	7.1
Conductivity (µS/cm)	507.1	602.2	501.4	518.3	514.8	515.7	526.5	280.1	290.3	286.8	272.7	273.2	269.0	278.7
DO (mg/L)	0	0	0	0	0	0	0	2.7	2.5	2.3	1.74	2.1	2.6	2.32
BOD_5 (mg/L)	154.3	150.7	153.1	174.9	175.3	168.8	162.9	63.2	62.1	60.18	60.3	59.2	58.1	60.5
NO_3-N (mg/L)	2.24	2.13	2.16	1.25	1.93	1.85	1.93	1.59	1.62	1.7	1.53	1.5	1.48	1.57
PO_4-P (mg/L)	8.1	8.0	7.3	8.3	8.8	7.6	8.02	5.4	5.6	5.6	5.0	4.9	4.7	5.2
NH_3-N (mg/L)	33.6	36.9	37.4	37.4	38.1	36.7	36.68	15.4	14.7	15.3	13.9	12.6	13.4	14.32
O_2-Saturation (%)							0							28.4

Site (d): Sundarighat

Parameters	March, 2			April, 26				July, 2			September, 5			
	S_1	S_2	S_3	S_1	S_2	S_3	Pre-monsoon average	S_1	S_2	S_3	S_1	S_2	S_3	Monsoon average
Temperature (ºC)	27.1	27.0	27.4	29.3	28.9	28.8	28.1	25.2	25.2	26.1	24.0	25.4	25.8	25.3
pH	7.3	7.5	7.4	7.4	7.4	7.4	7.4	6.9	6.9	7.2	6.7	7.6	7.3	7.1
Conductivity (µS/cm)	744.9	749.1	736.5	748.2	743.5	752.1	745.7	292	324	305	354	333.6	288.3	316.2
DO (mg/L)	0	0	0	0	0	0	0	2.58	2.9	2.2	1.65	2.2	2.4	2.32
BOD_5 (mg/L)	223.7	226.6	221.7	225.8	225.1	234.4	226.2	109.2	107.6	110.1	101.5	104.6	103.2	106.03
NO_3-N (mg/L)	5.3	5.1	4.9	5.8	5.6	5.4	5.35	3.9	3.6	3.2	2.8	2.3	2.4	3.03
PO_4-P (mg/L)	12.6	12.8	11.9	13.2	14.3	13.1	12.98	6.9	7.3	7.6	7.2	7.0	7.1	7.18
NH_3-N (mg/L)	42.8	44.4	45.6	49.1	48.6	47.5	46.33	26.9	25.4	26.6	28.6	30.0	29.1	27.77
O_2-Saturation (%)							0							28.3

Site (e): Khokana

Parameters	March, 2			April, 26			Pre-monsoon average	July, 2			September, 5			Monsoon average
	S_1	S_2	S_3	S_1	S_2	S_3		S_1	S_2	S_3	S_1	S_2	S_3	
Temperature (ºC)	27.2	27.1	27.4	29.1	28.6	29.0	28.1	26.1	26.3	26.2	25.9	26.2	26.1	26.1
pH	7.2	7.1	7.1	7.7	7.7	7.3	7.4	7.1	7.2	7.3	7.0	6.9	7.2	7.1
Conductivity (µS/cm)	510.1	508.3	502.3	510.4	516.3	513.9	510.2	286.3	286.1	297.0	272.3	263.5	268.2	278.9
DO (mg/L)	0	0	0	0	0	0	0	2.3	2.2	2.1	2.5	2.7	2.4	2.37
BOD_5 (mg/L)	153.4	150.7	151.6	173.6	170.8	169.2	161.6	65.2	67.8	68.4	62.2	63.7	60.3	64.6
NO_3-N (mg/L)	2.12	2.3	2.5	2.0	1.9	1.6	2.07	1.5	1.6	1.8	1.3	1.5	1.4	1.52
PO_4-P (mg/L)	8.1	8.3	7.6	8.9	8.6	8.1	8.27	5.95	6.0	5.05	4.9	5.0	4.7	5.27
NH_3-N (mg/L)	36.3	36.1	35.0	37.6	37.4	36.8	36.53	13.4	14.6	15.1	12.3	11.7	10.5	12.93
O_2-Saturation (%)							0							29.3

Annex: I(C)

Water Quality Variation in Pre-monsoon Season

Location	Temp-erature (ºC)	pH	Conductivity (µS/cm)	DO (mg/L)	BOD_5 (mg/L)	NO_3-N(mg/L)	PO_4-P(mg/L)	NH_3-N (mg/L)	O_2-Satura-tion (%)
Sundarijal	24.4	7.5	46.0	8.1	2.3	0.19	0.06	0.06	96.4
Aryaghat	29.8	7.2	250.1	3.13	45.6	0.53	1.23	4.78	41.5
Thapathali	28.7	7.1	526.6	0	162.9	1.93	8.02	36.68	0
Sundarighat	28.1	7.4	745.7	0	226.2	5.35	12.98	46.33	0
Khokana	28.1	7.4	510.2	0	161.6	2.07	8.27	36.53	0
Std. dev	10.13	0.16	293.7	2.40	93.33	1.82	5.17	22.14	28.41

Water Quality Variation in Monsoon Season

Location	Temp-erature (ºC)	pH	Conductivity (µS/cm)	DO (mg/L)	BOD (mg/L)	NO_3-N (mg/L)	PO_4-P (mg/L)	NH_3-N (mg/L)	O_2-Saturation (%)
Sundarijal	23.3	7.3	32.3	8.4	1.7	0.16	0.09	0.11	98.1
Aryaghat	26.5	6.7	103.7	5.91	13.8	0.41	1.15	3.12	74.3
Thapathali	25.5	7.1	278.7	2.32	60.5	1.57	5.2	14.22	28.4
Sundarighat	25.3	7.1	316.2	2.32	106.03	3.03	7.18	27.77	28.3
Khokana	26.1	7.1	278.9	2.37	64.6	1.52	5.27	12.93	29.3
Std. dev	1.08	0.2	136.19	3.03	51.79	1.37	4.01	10.07	40.16

Annex: II

Water Quality Status

For the calculations of German WQI, the **value (I)** was taken from the primary data (Annex-IB) obtained after the analysis. Importance **weight (W)** is the standard value (Table 4.1) and IW is the product of **value (I)** and importance **weight (W)**.

German Water Quality Index at Sundarijal

Parameter	**Pre-monsoon**			**Monsoon**		
	Value (I)	**Importance weight (W)**	**IW**	**Value (I)**	**Importance weight (W)**	**IW**
O_2-S (%)	96.4	0.2	19.28	98.1	0.2	19.62
BOD_5(mg/L)	2.3	0.2	0.46	1.7	0.2	0.34
Temperature (ºC)	24.4	0.08	1.95	23.3	0.08	1.86
Ammonia(NH_3–N) (mg/L)	0.06	0.15	0.01	0.11	0.15	0.17
Nitrate (NO_3-N)(mg/L)	0.19	0.1	0.02	0.16	0.1	0.02
Phosphate (PO_4-P)(mg/L)	0.06	0.1	0.01	0.09	0.1	0.01
pH	7.5	0.1	0.075	7.3	0.1	0.73
Conductivity (µS/cm)	46.0	0.07	3.22	32.3	0.07	2.26
Total (ρIW)=			**25.03**			**25.01**

Total value of IW for pre-monsoon season: 25.03

Total value of IW for monsoon season: 25.01

Physico-chemical quality at Sundarijal was classified as 'low pollution' in both pre-monsoon and monsoon season. The different values of IW indicate different level of pollution of the Bagmati River.

German Water Quality Index at Aaryaghat

Parameter	Pre-monsoon			Monsoon		
	Value (I)	**Importance weight (W)**	**IW**	**Value (I)**	**Importance weight (W)**	**IW**
O2-S (%)	41.5	0.2	8.3	74.3	0.2	14.86
BOD5(mg/L)	45.6	0.2	9.12	13.8	0.2	2.76
Temperature (ºC)	29.8	0.08	2.38	26.5	0.08	2.12
Ammonia (NH 3 –N) (mg/L)	4.78	0.15	0.72	3.12	0.15	0.47
Nitrate (NO3-N) (mg/L)	0.53	0.1	0.05	0.41	0.1	0.04
Phosphate (PO4-P) (mg/L)	1.23	0.1	0.12	1.15	0.1	0.12
pH	7.2	0.1	0.72	6.7	0.1	0.67
Conductivity (µS/cm)	250.1	0.07	17.51	103.7	0.07	7.26
Total (pIW)=			**38.92**			**28.30**

German Water Quality Index at Thapathali

Parameter	Pre-monsoon			Monsoon		
	Value (I)	Importance weight (W)	IW	Value (I)	Importance weight (W)	IW
O2-S (%)	0	0.2	0	28.4	0.2	5.68
BOD5(mg/L)	162.9	0.2	32.58	60.5	0.2	12.1
Temperature (ºC)	28.7	0.08	2.30	25.5	0.08	2.04
Ammonia (NH 3 –N) (mg/L)	36.68	0.15	5.50	14.22	0.15	2.13
Nitrate (NO3-N) (mg/L)	1.93	0.1	0.19	1.57	0.1	0.16
Phosphate (PO4-P) (mg/L)	8.02	0.1	0.80	5.2	0.1	0.52
pH	7.1	0.1	0.71	7.1	0.1	0.71
Conductivity (µS/cm)	526.6	0.07	36.86	278.7	0.07	19.51
Total (pIW)			**78.94**			**42.85**

German Water Quality Index at Sundarighat

Parameter	Pre-monsoon			Monsoon		
	Value (I)	Importance weight (W)	IW	Value (I)	Importance weight (W)	IW
O2-S (%)	0	0.2	0	28.3	0.2	5.66
BOD5(mg/L)	226.2	0.2	45.24	106.03	0.2	21.21
Temperature (ºC)	28.1	0.08	2.25	25.3	0.08	2.02
Ammonia (NH 3 –N) (mg/L)	46.33	0.15	6.95	27.77	0.15	4.17
Nitrate (NO3-N) (mg/L)	5.35	0.1	0.54	3.03	0.1	0.30
Phosphate (PO4-P) (mg/L)	12.98	0.1	1.30	7.18	0.1	0.72
pH	7.4	0.1	0.74	701	0.1	0.71
Conductivity (µS/cm)	745.7	0.07	52.20	316.2	0.07	22.13
Total (pIW)			**109.22**			**56.92**

German Water Quality Index at Khokna

Parameter	Pre-monsoon			Monsoon		
	Value (I)	**Importance weight (W)**	**IW**	**Value (I)**	**Importance weight (W)**	**IW**
O2-S (%)	0	0.2	0	29.3	0.2	5.86
BOD5(mg/L)	161.6	0.2	32.32	64.6	0.2	12.92
Temperature (ºC)	28.1	0.08	2.25	26.1	0.08	2.09
Ammonia (NH 3 –N) (mg/L)	36.53	0.15	5.48	12.93	0.15	1.94
Nitrate (NO3-N) (mg/L)	2.07	0.1	0.21	1.52	0.1	0.15
Phosphate (PO4-P) (mg/L)	8.27	0.1	0.81	5.27	0.1	0.53
pH	7.4	0.1	0.74	7.1	0.1	0.71
Conductivity (µS/cm)	510.2	0.07	35.71	278.9	0.07	19.52
Total (ρIW)			**77.52**			**43.72**

Annex: III

Water Quality Status:

For calculations of Netherland WQI, the **value** for each parameter was taken from the primary data (Annex-IB) and **points were awarded** according to the table 4.4

Netherland Water Quality Index at Sundarijal

Parameters	**Pre-monsoon**		**Monsoon**	
	Value	**Points awarded**	**Value**	**Points awarded**
O_2-S	96.4	1	98.1	1
BOD_5	2.3	1	1.7	1
Ammonia (NH_3-N)	0.06	1	0.11	1
Total (p**IW**)		**3**		**3**

Total value of points awarded for pre-monsoon season: 3

Total value of points awarded for monsoon season: 3

Water quality of the Bagmati Riverat Sundarijal is 'Excellent' in both the pre-monsoon and monsoon season.

Netherland Water Quality Index at Aryaghat

Parameters	**Pre-monsoon**		**Monsoon**	
	Value	**Points awarded**	**Value**	**Points awarded**
O_2-S	41.5	4	74.3	2
BOD_5	45.6	5	13.8	4
Ammonia (NH_3-N)	4.78	4	3.12	4
Total (p**IW**)		**13**		**10**

Netherland Water Quality Index at Thapathali

Parameters	Pre-monsoon		Monsoon	
	Value	Points awarded	Value	Points awarded
O_2-S	0	5	28.4	5
BOD_5	162.9	5	60.5	5
Ammonia (NH_3-N)	36.68	5	14.22	5
Total (pIW)		**15**		**15**

Netherland Water Quality Index at Sundarighat

Parameters	Pre-monsoon		Monsoon	
	Value	Points awarded	Value	Points awarded
O_2-S	0	5	28.3	5
BOD_5	226.2	5	106.03	5
Ammonia (NH_3-N)	46.33	5	27.77	5
Total (pIW)		**15**		**15**

Netherland Water Quality Index at Khokana

Parameters	Pre-monsoon		Monsoon	
	Value	Points awarded	Value	Points awarded
O_2-S	0	5	29.3	5
BOD_5	161.6	5	64.6	5
Ammonia (NH_3-N)	36.53	5	12.93	5
Total (pIW)		**15**		**15**

Annex: IV

Water Quality Status at Present and Past

Site	Sundarijal			Aryaghat			Thapathali			Sundarighat			Khokana		
	1991	2004	2012	1991	2004	2012	1991	2004	2012	1991	2004	2012	1991	2004	2012
pH	7.3	7.35	7.4	7.04	7.1	7.0	7.31	7	7.1	7.37	6.85	7.3	7.58	7.2	7.3
Conductivity (µS/cm)	36	40.2	39.15	75	156.3	176.9	250	391.5	402.56	449	527.2	530.95	334	286.3	394.55
DO (mg/L)	9.7	8.45	8.6	7.7	4.6	4.5	6.7	1.2	1.2	2.9	1.1	1.2	5.4	3.25	1.2
BOD_5 (mg/L)	1.9	2.1	2.0	8.9	26.4	29.7	16	109.4	111.7	49.5	166.8	166.1	11.5	45	113.1
NO_3-N (mg/L)	0.07	0.12	0.18	0.22	0.5	0.47	0.88	1.7	1.75	0.41	3.9	4.19	0.59	2.8	1.80
PO_4-P (mg/L)	0.06	0.07	0.15	0.07	1.14	1.19	0.32	8.61	6.61	0.92	10.08	10.08	0.47	6.55	6.77
NH_3-N (mg/L)	0.03	0.09	0.09	0.11	3.9	3.95	2.67	23.9	25.45	14.94	33	37.05	6.6	15.4	24.73
O_2-Saturation (%)	96	96.5	97.25	88	58.4	57.9	78	15.25	14.2	34	13.7	14.15	85	39.05	14.65
Quality level	Excellent	Excellent	Excellent	Good	Bad	Bad	Bad	Very Bad	Very Bad	Very Bad	Very Bad	Very Bad	Bad	Very Bad	Very Bad

Source: (Shrestha 1991 and Poudel 2004)

Annex: V

Saturation values of Dissolved Oxygen with Temperature

Temperature (°C)	**DO (mg/L)**	**Temperature (°C)**	**DO (mg/L)**
0	14.60	23	8.56
1	14.19	24	8.40
2	13.81	25	8.24
3	13.44	26	8.09
4	13.09	27	7.95
5	12.75	28	7.81
6	12.43	29	7.67
7	12.12	30	7.54
8	11.83	31	7.41
9	11.55	32	7.28
10	11.27	33	7.16
11	11.01	34	7.16
12	10.76	35	6.93
13	10.52	36	6.82
14	10.29	37	6.71
15	10.07	38	6.61
16	9.85	39	6.51
17	9.65	40	6.41
18	9.45	41	6.41
19	9.26	42	6.22
20	9.07	43	6.13
21	8.90	44	6.04
22	8.72	45	5.95

Source: (Mortimer 1956)

Annex: VI

Photographs

Photograph-1: Analyzing pH at Sundarijal

Photograph-2: Sampling site at AryaghatBehind the PashupatiNath Temple

Photograph-3: Recording GPS Value at Thapathali Below the Bridge

Photograph-4: Sampling site at SundarighatBelow the Suspension Bridge Along the Way to Nayabato, Kirtipur

Photograph-5: Sampling Site at Khokana Belowthe Suspension Bridge

Photograph-6: Analyzing Physico-chemical Parameters in the NAST Lab.