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URBAN GROWTH AND WATER QUALITY IN THIMPHU, BHUTAN

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Abstract: Detailed study was undertaken in 2008 and 2009 on assessment of water quality of River Wang Chhu which flows through Thimphu urban area, the capital city of Bhutan. The water samples were examined at upstream of urban area, within the urban area and its downstream. The water quality was analyzed by studying the physico-chemical, biological and benthic macro-invertebrates. The water quality data obtained during present study are discussed in relation to land use/land cover changes (LULC) and various ongoing human activities at upstream, within the each activity areas and it's downstream. Analyses of satellite imagery of 1990 and 2008 using GIS revealed that over a period of eighteen years the forest, scrub and agricultural areas have decreased whereas urban area and road network have increased considerably. The forest cover, agriculture area and scrub decreased from 43.3% to 42.57%, 6.88% to 5.33% and 42.55% to 29.42%, respectively. The LULC changes effect water quality in many ways. The water temperature, pH, conductivity, total dissolved solids, turbidity, nitrate, phosphate, chloride, total coliform, and biological oxygen demand were lower at upstream and higher in urban area. On the other hand dissolved oxygen was found higher at upstream and lower in urban area. The pollution sensitive benthic macro-invertebrates population were dominant at upstream sampling sites whereas pollution tolerant benthic macro-invertebrates were found abundant in urban area and its immediate downstream. The rapid development of urban infrastructure in Thimphu city may be posing serious threats to water regime in terms of its quality. Though the deterioration of water quality is restricted to a few localized areas, the trend is serious and needs proper attention of policy planners and decision makers. Proper treatment of effluents from urban areas is urgently needed to reduce water pollution in such affected areas to check further deterioration of water quality. This present study which is based on upstream, within urban area and downstream of Thimphu city can be considered as an eye opener.

Keywords: Thimphu, Land use/land cover change, water quality, physico-chemical, benthic macro-invertebrates

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INTRODUCTION

Water occupies a special place among other natural resources found on earth. It is indeed a valuable natural resource vital to the existence of all living organisms. It is an indispensable liquid required for several purposes such as drinking, sanitation, irrigation, navigation, aquaculture, recreation, industrial uses etc. The water bodies are closely related to human life and his livelihood. The metabolic activities essential for life take place in aqueous medium inside the living body.

All enzymes, hormones and other biomolecules exist and function in presence of water. Water dissolves nutrients and distributes them to cells, regulates body temperature, supports structures, and removes waste products. Thus, all forms of life on earth depend on water and all living things, from plants to animals, from desert dwellers to aquatic inhabitants and from microscopic bacteria to gigantic whale, need water to survive. It is believed that life first originated in water. Water forms three-fourth of the weight of a living cell (United Nations Environment Programme (UNEP) Report, 2006). The health and well-being of all the living beings on earth is closely tied up with the quality of water (United Nations World Water Assessment Programme (UN-WWAP) Report, 2003).

Currently, humanity is facing a serious water crisis (UN-WWAP, 2003). The United Nations World Water Assessment Programme Report (2003) states that water crises of availability, degradation, conservation and sustainability can be observed more pronouncedly in developing countries all over the world. All indicators suggest that the situation is worsening day by day and it is going to be alarming unless corrective measures are taken soon. The world is facing a number of challenges with regard to the availability, accessibility, use and sustainability of freshwater resources. This would result in serious implications for present and future generations of humanity and also for natural ecosystems. It is estimated that at present 2.8 billion people live under conditions of water stress and by 2030 almost half the world population will live under these conditions if effective measures are not implemented (UNEP, 2009; Bates *et al.*, 2008; OECD, 2008).

Freshwater bodies vary from streams and rivulets to huge rivers, ponds and lakes to reservoirs and recreational pools. These aquatic ecosystems are characterized by complex interactions between abiotic and biotic components of the water system. Thus, study on physico-chemical characteristics and biotic attributes of different water bodies is essential to understand the quality of water. Such studies in relation to anthropogenic land use changes and diversified human activities taking place in the catchment area are keys to understanding the causes and extent of degradation of water resources. Keeping this view in mind, a study on water quality in relation to land use/land cover changes was carried out during 2008 and 2009 in Bhutan, one of Asia's smallest nations situated on the southern slope of the eastern Himalayas (latitude 26˚40' − 28˚20'N; longitude 88˚45' − 92˚25'E). It has a geographical area of 38 394 km² with mountainous and heavily forested landscapes. The present study was carried out at upstream of urban area, within the urban area and its downstream of Thimphu, the capital city of Bhutan.

STUDY AREA, MATERIAL AND METHODS

Thimphu, the capital of Bhutan is located in the North West at an altitude of 2320 meters above sea level. The urban area of Thimphu lies in the valley surrounded by forests. River Wang Chhu flows through the Thimphu city. The river originates in the north from snow and glaciers and it flows south-easterly through west-central Bhutan. It serves as a source of water for two hydro power, agriculture and domestic purposes including drinking, sanitation and recreation. The water body receives a variety of wastes ranging from agricultural, domestic and natural sources. The study area and sampling locations are shown in **Fig. 1.**

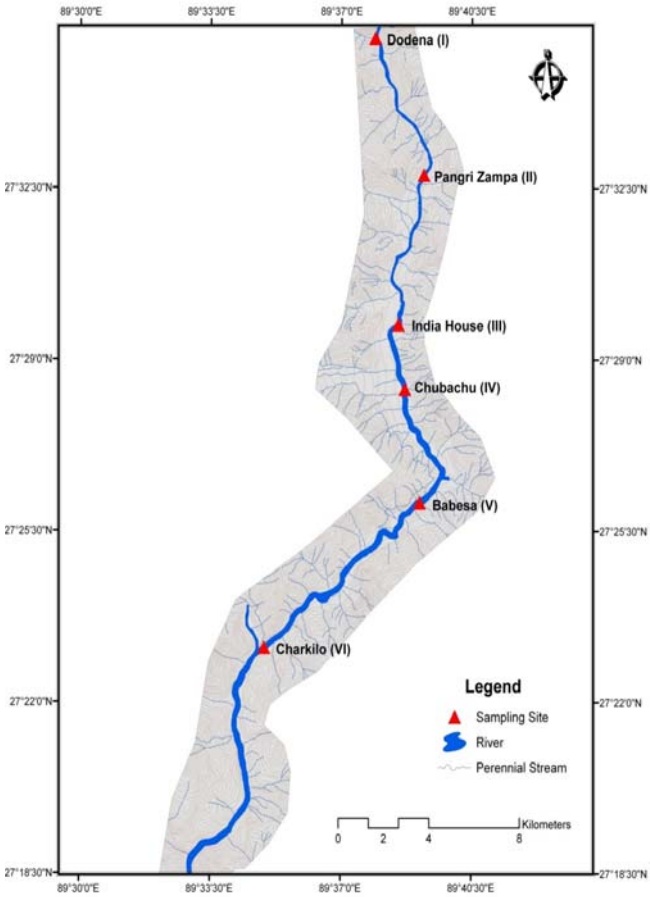

Fig. 1 Location of different sampling sites at Thimphu study area.

Table 1. Salient features of sampling sites

Sl. No.	Study Area	Altitude (meters)	Longitude	Latitude	Upstream/Downstream Location
1.	Dodena (I)	2600	89°37′38″E	27°35′40″N	Upstream of urban area
2.	Pangri Zampa (II)	2480	89°38′19″E	27°34′13″N	Upstream of urban area
3.	India House (III)	2320	89°36′24″E	27°31′53″N	Within the urban area
4.	Chubachu (IV)	2317	89°38′38″E	27°29’45″N	Within the urban area
5.	Babesa (V)	2280	89°39′40″E	27°26’34″N	Downstream of urban area
6.	Charkilo (VI)	2160	89°35′16″E	27°23’26″N	Downstream of urban area

The study area covers a distance of about 50 km starting from Dodena which is located at an altitude of 2600 meters, (longitude 89°37′38″E; latitude 27°35′40″N) till Charkilo located at an altitude of 2160 meters (longitude 89°35′16″E; latitude 27°23′26″N). To study the impact of urbanization on water quality, sampling was done from six sites, two each from upstream of urban area (I & II), within the urban area (III & IV) and downstream of the urban area (V &VI). Details of six sampling sites selected for the study of physico-chemical analysis of water and benthic macro-invertebrates are given in **Table 1.**

The sampling sites I and II namely Dodena and Pangri Zampa are located in forest area at upstream of Wang Chhu. The sampling sites III and IV namely, India House and Chubachu are located in Thimphu city. The sampling sites V and VI namely Babesa and Charkilo are placed downstream of urban area.

Duration of the study

The study was carried out during the year 2008–2009 beginning from January. The water samples and benthic macro-invertebrates were studied during three different seasons namely, pre-monsoon, monsoon and post-monsoon.

Collection of water samples

The water samples were collected in one litre sterilized polythene container using grab sampling method as outlined in American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater (2005). The samples were also collected in 300 ml BOD bottles for the estimation of Dissolved Oxygen. The water samples were collected from one foot below the surface of the water and immediately sealed with a stopper. Three replicates were taken for each parameter. The samples were kept in ice box and maintained temperature below 4°C while transferring it to the laboratory.

Collection of Benthic macro-invertebrates

The shallow locations (less than 1 m) of river were selected for the study of benthic macro-invertebrates. The sampling sites were located at upstream, within the urban area and downstream, as done in case of water samples. The sampling sites at upstream represent the reference or control in all cases. In order to carry out comparison of macro-invertebrate communities attempts were made to choose similar habitat features (similar bottom substrate, depth and flow velocity) for all sampling sites. The substrate chosen contained mainly gravel, cobbles, sand and clay. The substrate samples were analysed to find out its contents.

A simple random sampling was done in all the stations for collection of benthic macro-invertebrates. The random sampling was also carried out in different substrates, current velocities, depth and temperature to cover the density of benthic macro-invertebrates. Three replicate sampling units per sampling site were carried out during each period. The Surber or Square foot stream bottom sampler was used to collect benthic macro-invertebrates. The overall method of sampling, as described in APHA (2005) was followed.

For sampling the sampler was positioned securely at the bottom of the shallow river with net portion facing downstream. When the sampler was in place, all stones and gravels inside the frame were carefully hand rubbed to dislodge organisms clinging to them. All gravels and sand were thoroughly stirred to a depth of 5cm to dislodge bottom dwelling organisms. The organisms were collected from the net by inverting it into sample container. The sampler net was rinsed after every use. The organisms were taken out from the net and preserved in 70% ethanol. The soft bodied animals like annelid (oligochaetes) were first kept in 5 to 10% buffed formalin for some time and then transferred to 70% ethanol. This is done to prevent constriction during preservation.

The collected benthic macro-invertebrates were placed in a shallow white tray with water for sorting. In order to facilitate sorting, the organisms were stained with 200 mg/L rose Bengal in the formalin or ethanol preservative for 24 hours. The organisms were separated into different taxonomic categories by using a hand lens and dissection microscope. The references used for taxonomic work were Pennack, (1953) & (1978); Thorp & Kovick (1991); Ward & Whipple (1992). The organisms were sorted and kept in vials filled with 70%

ethanol. All procedures followed were according to the Standard Method for Water and Wastewater Analysis (APHA, 2005).

Analysis of physical, chemical and biological parameters of water

United Nations Environment Programme, (2006) states "Water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter". There is a range of physical, chemical and biological components that determine the water quality. These components can be examined and measured accurately to ascertain the quality of water. Various parameters analysed in the present study are described below. For determination of these parameters, the procedures described in APHA (2005) and Maiti (2001) were followed. A summary of the methods for estimation of various water quality parameters is presented in **Table 2**.

RESULTS AND DISCUSSION

Rainfall

In 2008 the monthly rainfall ranged between 0.00 to 27.5 mm during pre-monsoon, 68.6 to 152.3 mm during monsoon and 0.00 to 46.7 mm during post-monsoon. The total rainfall recorded in Thimphu study area during the 2008 study period was 593.3 mm. In 2009 the monthly rainfall ranged between 0.00–146.6 mm during pre-monsoon, 18.8–127.3 mm during monsoon and 1.00–108.5 mm during post-monsoon. The maximum rainfall recorded was 152.3 mm in July, 2008 and 146.6 mm in May, 2009. The total rainfall recorded in Thimphu study area during the 2009 study period was 561.6 mm as indicated in **Table 3.**

Land use/land cover changes

The study area covered an area of 145.431 km^2 starting from Dodena in the north to Charkilo in the south. In this study, land use changes taken place between 1990–2008 was analysed using satellite imageries. For accurate analysis of land use changes the study area was classified into eight categories namely, forests, agriculture, water bodies, scrub, sandy area, urban area, industry and road. The summary of land use/land cover changes during 1990-2008 in Thimphu study area is presented in **Table 4**. The dominant land uses in 1990 were forests and scrub which occupy 85.85% of the study area. The forest cover occupied 43.3% (62.97 km^2) in 1990. The percentage of forest cover in 2008 had decreased to 42.57% (61.906 km^2). The slight decrease in forest cover of 0.73% (1.064 km^2) is attributed to expansion of urban boundaries and construction of road network.

Table 3. Monthly rainfall at Thimphu study area during the study period

Month	Rainfall in mm/Month 2008	Rainfall in mm/Month 2009
January	15.8	1.0
February	0.0	0.0
March	17.7	0.0
April	15.1	27.0
May	27.5	146.6
June	132.9	18.8
July	152.3	80.9
August	115.1	127.3
September	68.6	46.1
October	46.7	108.5
November	0.0	1.2
December	1.6	4.2
Total	593.3	561.6

Source: Meteorology Section, Department of Energy, Ministry of Economic Affairs.

Table 2. Summary of procedures used for the measurement of Physico-chemical and biological parameters of water samples

Parameters	Unit	Method	Reference
Temperature	ºC	0-110°C Mercury thermometer	APHA (2005)
pH	—	pH meter (Delux pH meter 101, EI Product	Maiti (2001)
Conductivity	µS/cm	Conductivity meter (conductivity-TDS meter 307)	APHA (2005)
TDS	mg/L	Gravimetric method	Maiti (2001) and APHA (2005)
Turbidity	NTU	Nephelometric method (Digital Turbidity meter 31, EI Products)	APHA (2005) and Maiti (2001)
Dissolved Oxygen	mg/L	Winkler modified method	APHA (2005)
Nitrate	mg/L	Phenol Disulphonic acid (PDA) (Spectrophotometer – 169)	Maiti (2001)
Phosphate	mg/L	Stannous chloride Colorimetric method	APHA (2005)
Chloride	mg/L	Argentrometric method	APHA (2005)
Total Coliform	No./100ml	MPN or MF method	Maiti (2001) and APHA (2005)
BOD	mg/L	5 day incubation method	APHA (2005) and Maiti (2001)
Flow Velocity	m s^{-1}	Electromagnetic current meter (PVM-2A)	APHA (2005)

Table 4. Land use changes in Thimphu study area during 1990−2008

Land Use Category	Area in 1990		Area in 2008		Land Use Change	
	Total in km^2	Percentage	Total in km^2	Percentage	Area in km^2	Percentage
Forests	62.97	43.3	61.906	42.57	1.064	−0.73
Agriculture	10.01	6.88	7.75	5.33	2.26	−1.55
Water bodies	1.508	1.04	1.532	1.05	0.024	+0.02
Scrub	61.88	42.55	42.78	29.42	19.1	−13.13
Sandy area	0.012	0.01	0.301	0.21	0.289	+0.20
Urban	7.13	4.9	26.51	18.23	19.38	+13.33
Industries	0	0	0	0	0	0
Roads	1.921	1.32	4.652	3.20	2.731	+1.88
Total	145.431	100	145.431	100	44.848	30.84

The agricultural area occupied 6.88% (10.01 km^2) of study area in 1990. The main crops grown in the agriculture field are paddy, maize and wheat. Apple, peach and apricot are the main cash crops grown in the area. By 2008 the agricultural land decreased to 5.33% (7.75 km^2). Most of the agricultural land has been converted into infrastructure development. In 1990 the water bodies occupied 1.04% (1.508 km^2) of study area. The water bodies increased from 1.04% in 1990 to 1.05% in 2008. The slight increase of 0.02% (0.024 km^2) in water bodies is due to the spread of river water caused by silting and construction of sewerage treatment plant for Thimphu city at Babesa in 1998. The scrub area decreased from 42.55% (61.88 km^2) in 1990 to 29.42% (42.78 km^2) in 2008. Within a span of eighteen years 13.13% (19.10 km^2) of scrub has been converted into forests and urban area as indicated by the land use map of 2008 (**Fig. 3**). The sandy area had increased to 0.21% (0.301 km^2) in 2008. In 1990 urban area occupied 7.13 km^2 (4.90%) of the study area. Within a span of eighteen years urban area expanded by more than three times measuring 26.51 km^2 (18.23%).

With the increase in urban area the agricultural land and scrub decreased by 13.33% (19.38 km^2). The increase in urban area led to the increase in road network. In 1990 road network covered 1.32% (1.921 km^2) which increased to 3.20% (4.652 km^2). The land use/land cover maps of 1990 and 2008 are presented in **Fig. 3.**

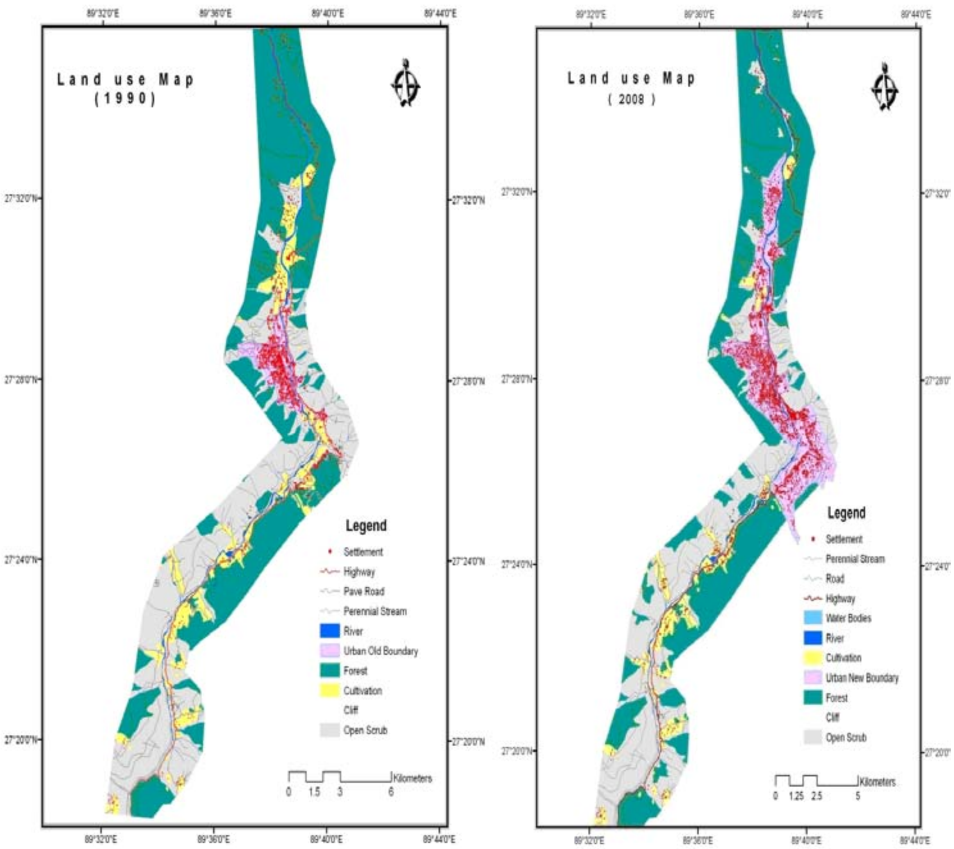

Fig. 3: Land use land cover map of 1990 and 2008

Urbanization in Bhutan began in 1961 with the start of first five year development plan by the late king, Jigme Dorji Wangchuck. Prior to 1961, an urban settlement in Bhutan was limited to a few traditional clustered villages in the valleys. Before 1953, Thimphu had just a dzong (fort) surrounded by a few cluster of traditional houses. The developmental activities in Thimphu started in a rapid pace with its designation as capital of Bhutan by the late king, Jigme Dorji Wangchuck in 1953. The establishment of infrastructural, educational and health facilities attracted job seekers and entrepreneurs. The public sector and private sector expanded quickly to provide various services. This led to the migration of people from rural areas to Thimphu urban area. However, the land availability for urban area is severely limited by the topography.

In 1990 the population of Thimphu urban area was barely 28 012. By 2008 the population of Thimphu urban area increased to over one lakh (National Statistical Bureau, 2008). It is estimated that the population growth rate in Thimphu is 10% per annum. The rapid increase in population caused housing shortage in urban area. This has led to the exponential growth of unauthorized housing in the outskirt of the urban boundary. Starting from 1990, the population of Thimphu urban area increased rapidly.

The expansion of urban area and increase in population in urban area is seen as a worldwide phenomenon. The United States Environmental Protection Agency (USEPA, 2001) report confirmed that every urban area has expanded substantially in land area in recent decades. The percentage of the world's population living in urban areas was less than 5 percent in 1800, which had increased to 47 percent in 2000 and it is expected to reach 65 percent by 2030 (United Nations Human Development Report, 1990; 1991).

Rao (1991) reported that land available for productive use in India is decreasing in the alarming trend in the per capita availability of arable land from 0.48 ha in 1951 to 0.20 ha in 1981. Sharma *et al.* (2007) further stated that increase in population pressure and limited productive agriculture land has been the key factor for the conversion of forest land to other uses.

Demirici *et al.* (2006) analyzed land use changes of Kucukcekmece watershed in Istanbul by using remote sensing and GIS from 1963 to 2005 and found that forest and agriculture land had decreased considerably whereas the industrial and residential areas had increased. Singh *et al.* (1983) and Rai *et al.* (1994) reported that the land use/land cover changes from forest to other uses have been widespread in the Himalayan region. Sharma *et al.* (1992) also stated that agricultural land area had increased considerably over the past four decades in the Himalayas at the cost of other land uses, particularly forests.

Our results on agricultural land use change are not in line with Klein Goldewijk (2000) who found that in the past 300 years agriculture land and pastureland have increased globally by 460% and 560%, respectively. This may be due to small sample size in the present study and also due to less population pressure in Bhutan compared to other developing countries where food production to meet the requirements of growing population is more extensive as well as intensive. If LULC change for entire country is analyzed, which was beyond the scope of the present study, there is possibility that result on agriculture area may be different from the present study. Bruinsma (2003) also reported that in the developing countries, agriculture land for food production is projected to increase by 13% whereas it is declining in developed countries. It is well known that when LULC changes occur and forest land is converted to other uses, the water regime of the area is altered. Such alterations may be quantitative and/or qualitative, which include deterioration in water quality, increase in volume and velocity of runoff, increase in frequency and severity of flooding, reduction in ground water recharge and perennial flow of streams and rivers, increase in TDS due to erosion etc. (Calder, 2000).

(d) Study on water quality

The studies on Physico-chemical and biological parameters were carried out from 2008 to 2009. The physico-chemical parameters of water analysed at upstream, within the urban area and downstream were water temperature, pH, conductivity, total dissolved solids, turbidity, dissolved oxygen, nitrate, phosphate, chloride, sulphate and biochemical oxygen demand. The qualitative and quantitative variations in benthic macro-invertebrates population were also studied. The results are presented separately and sequentially for each parameters studied. The following parameters were assessed to study the water quality in and around Thimphu urban area:

Water Temperature

The minimum water temperature recorded during the study period was 5.88°C ± 0.47 during post-monsoon of 2009 at sampling site I and the maximum temperature measured was 19.3°C ± 0.58 during the monsoon of 2008 at sampling site VI. The water temperature increased gradually from sampling site I to VI during pre-monsoon and monsoon. This is because of the altitudinal variations of different sampling sites. Sampling site I in all three study areas are located at the highest altitude whereas Sampling sites VI are at the lowest altitude. The altitude of other sampling sites decreased gradually from site I to site VI. Therefore, with decrease in altitude the air and water temperature showed increasing trend. This is a usual feature and similar results were obtained while studying physico-chemical characteristics upstream and downstream of Yamuna River in Haryana (Ravindra *et al.,* 2003); Teesta River in North India (CISMHE, 2006); Cauvery River in south India (Begum and Harikrishna, 2008). The water temperature did not show much variation during post-monsoon. In 2005 National Environment Commission of Bhutan conducted water quality baseline study from Dodena to Babesa in Wang Chhu and recorded that water temperature increased gradually as the river flows downward (National Environment Commission Report, 2005). The seasonal variation in water temperature at different sampling sites of Thimphu study area is presented in **Fig. 4.**

pH

The pH of the water was slightly alkaline in nature in all the sampling sites as its pH values were higher than 7. The mean pH values ranging between 7.09 ± 0.16–7.71± 0.02 during 2008 and 7.08± 0.26–7.63± 0.12 during 2009. Bhattarai (2005) and National Environment Commission (2001) also reported that freshwater in Bhutan is slightly alkaline in nature. The seasonal variation in pH at different sampling sites of Thimphu study area is presented in **Fig. 5.**

The pH values of water at all the sampling sites were within the WHO's permissible limit for drinking water i.e., 6.5-8.5 (WHO, 1997). The pH of water was slightly higher in urban area and downstream which could be attributed to the overflow from septic tank, discharge of sewage and domestic waste into the river. The soap and detergents used for washing are alkaline in nature which ultimately gets into the river. The National Environment Commission of Bhutan recorded higher pH in urban area as compared to upstream of Wang Chhu (National Environment Commission Report, 2005). One of the major direct impact of urbanization is the degradation of water quality (Paul and Meyer, (2001; Tang *et al.,* 2005), which can be attributed to sewage discharge, dumping of wastes etc.

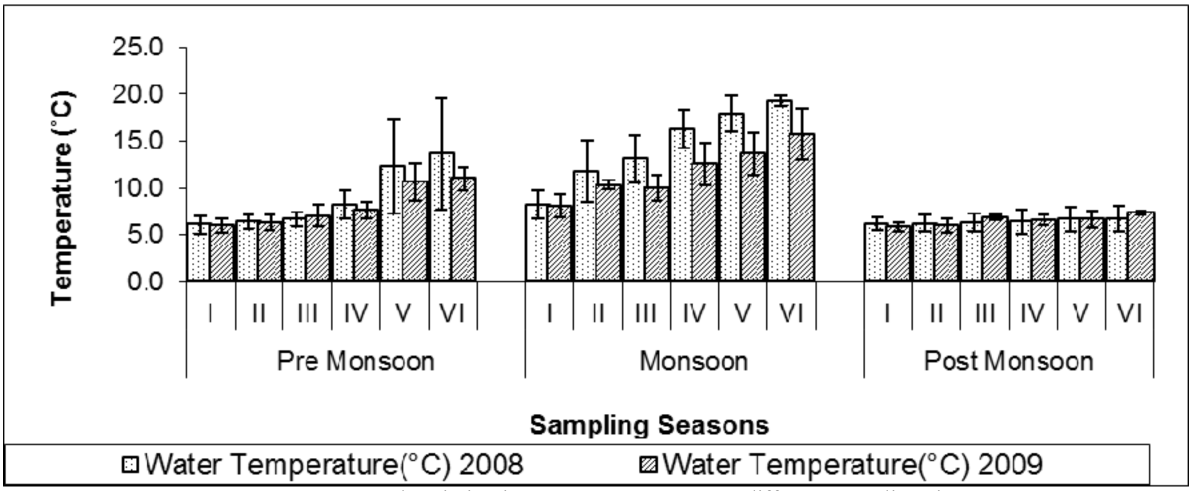

Fig. 4 Seasonal variation in Water Temperature at different sampling sites.

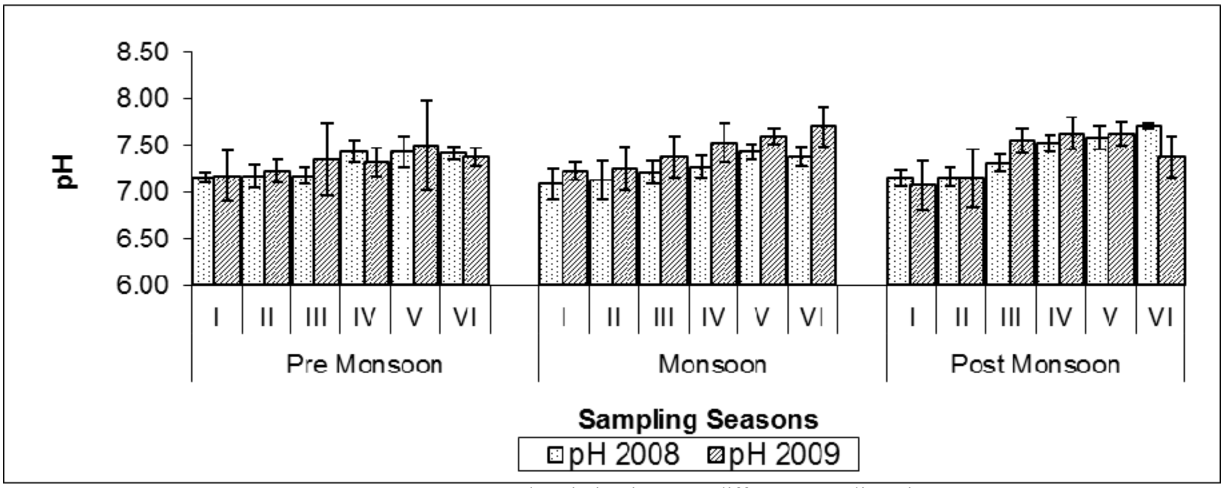

Fig. 5 Seasonal variation in pH at different sampling sites.

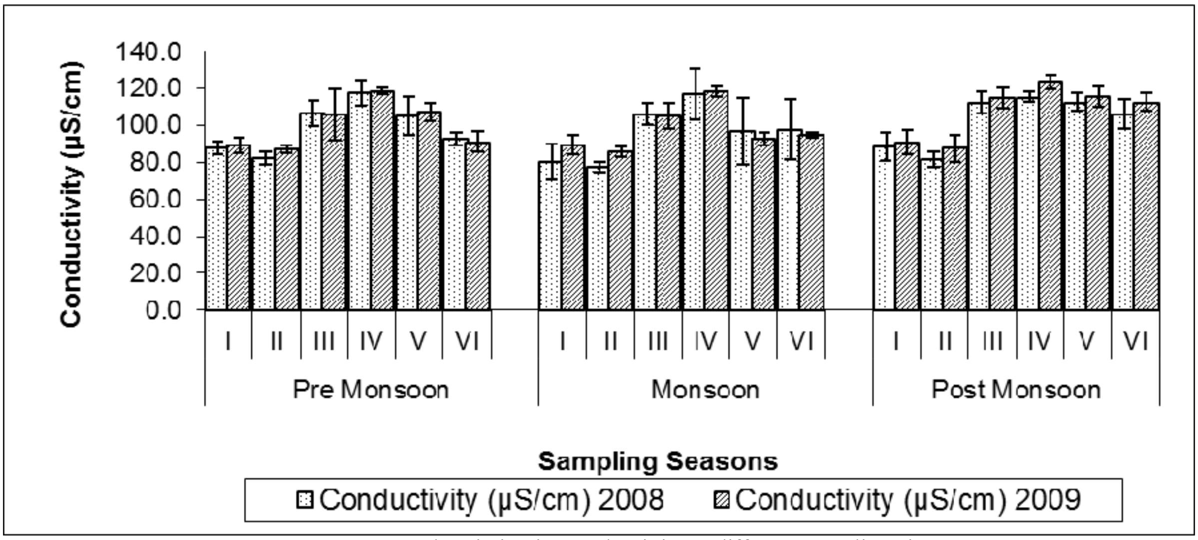

Fig. 6 Seasonal variation in Conductivity at different sampling sites.

Electrical Conductivity (EC)

The seasonal variation in conductivity at different sampling sites of Thimphu study area is presented in **Fig. 6. Figure 7** depicted higher conductivity in urban area as compared to upstream and downstream in all the seasons throughout the study period. The lowest conductivity measured was 77.39 µS/cm ± 2.97 at upstream sampling site II in 2008 and the highest was 123.73 µS/cm ± 3.68 at urban area sampling site IV in 2009. The preliminary conductivity data collected by NEC for River Wang Chhu in 2002 also indicated that conductivity increased downstream (NEC report 2002). Prasad and Patil (2008) reported that conductivity of Krishna River kept on decreasing from Sangli town to village Ghalwad. The constant decrease in conductivity indicated reduction in the number of dissolved inorganic salts. Studies done by Alam *et al.* (2007) at Surma river and Murugan (2008) at Umkhrah River in Shillong also revealed similar results.

Total Dissolved Solids (TDS)

The seasonal variation in TDS at different sampling sites of Thimphu study area is presented in **Fig. 7**. The total dissolved solids (TDS) showed similar trend as that of conductivity. Its values were recorded lower at upstream and higher in the activity areas and its immediate downstream. The concentration of TDS increased with increase in temperature and addition of ions into water bodies from industries, urban area and agriculture field. It was observed that TDS values were lower than the maximum WHO recommended value of 500 mg/L for drinking water (WHO, 1997). However, TDS values were higher in urban area which could be due to the discharge of inorganic and organic matter into water bodies. Similar results were also obtained while studying physico-chemical characteristics upstream and downstream of Yamuna River in Haryana (Ravindra *et al.*, 2003).

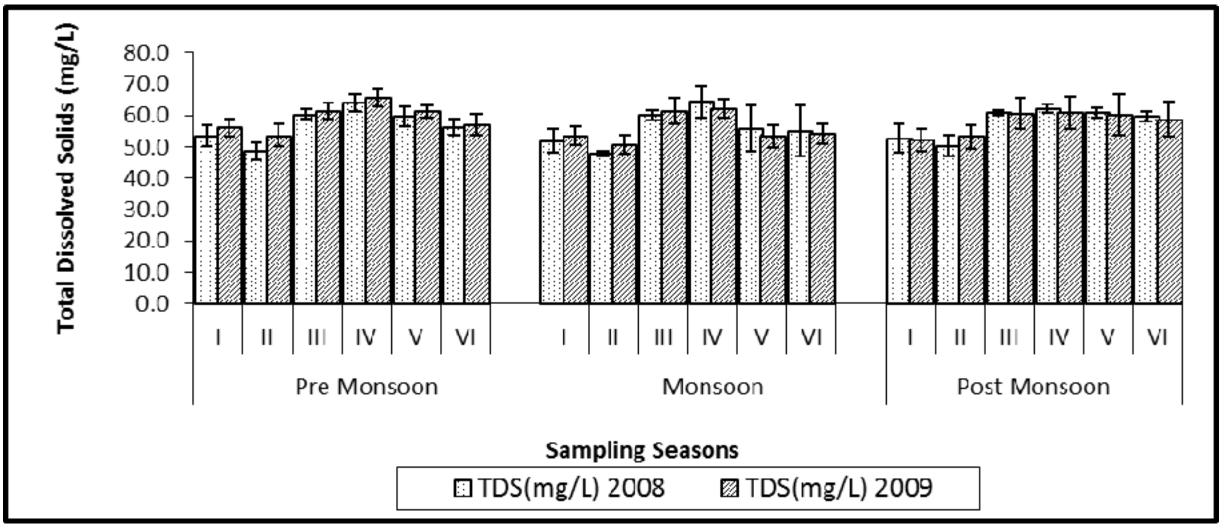

Fig. 7 Seasonal variation in Total Dissolved Solids at different sampling sites.

Turbidity

The turbidity was found lower at upstream sampling sites and higher in urban area in all the seasons. The minimum turbidity value recorded was 1.25 NTU ± 0.19 during pre-monsoon at upstream sampling site I in 2009 and the maximum was 14.56 NTU ± 2.11 in downstream at sampling site V during monsoon season of 2009. The turbidity values recorded during monsoon were much higher than during pre-monsoon and post-monsoon. This could be due to monsoon rain washing surface soil particles and other debris into the river. The increase in turbidity of Wang Chhu in urban area is also due to the direct discharge of waste water into the river. The seasonal variation in turbidity at different sampling sites of Thimphu study area is presented in **Fig. 8**.

The NEC also reported increase in turbidity as river flows from upstream to urban area (NEC Report, 2005). Similar results were reported by Lanet and Crawford (1994) who confirmed that suspended sediment yield was greater in urban catchment than in forested catchment. Paul and Meyer (2001) found that the major effect of urbanization on freshwater ecosystems was an increase in impervious surface areas within urbanized catchments. The increase in impervious surface cause increase in the volume and rate of surface runoff and decrease in ground water recharge and base flow which will lead to frequent incidents of flooding, decrease in residential and municipal water supplies and reduced base flow in streams (Carter, 1961; Field *et al.,* 1982; Hall, 1984; Lazaro, 1990; Harbor, 1994). The land use change from pervious to impervious surfaces can also impact the quality of storm water runoff. Schueler (1995) found that pollutant load increases when the surface area is impervious.

Dissolved Oxygen (DO)

It was observed that dissolved oxygen level was consistently higher at upstream and lower in urban area and downstream. Similar results were obtained in Pasakha industrial area as well. The highest DO level recorded was 10.55 mg/L ± 0.46 at upstream during post-monsoon and lowest was 7.78 mg/L ± 0.24 in urban area during monsoon of 2009. Similar trend was noticed when National Environment Commission of Bhutan conducted baseline study of Wang chhu in January 1997 (NEC report, 2005).

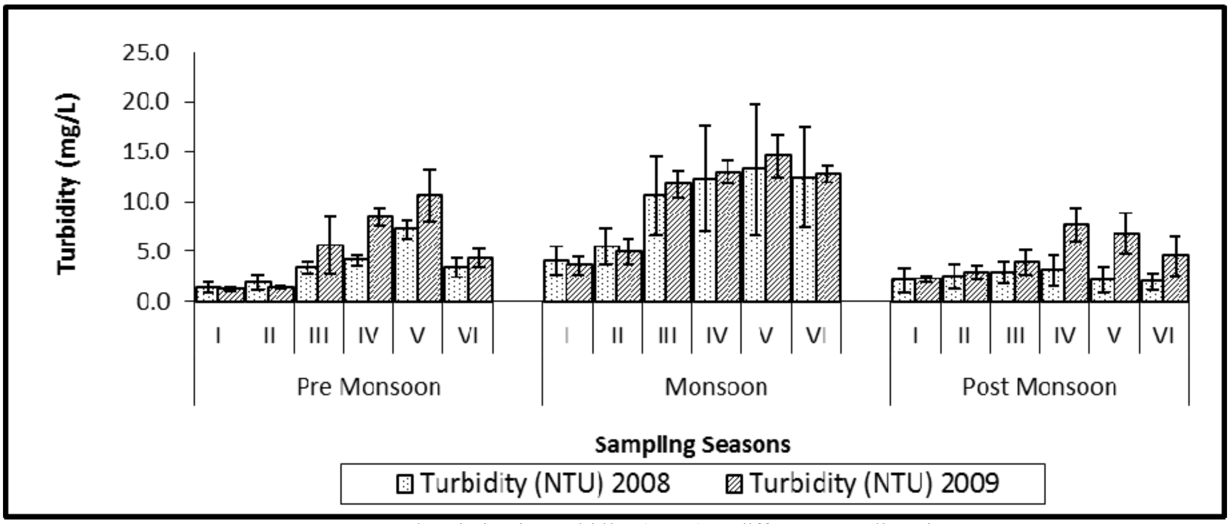

Fig. 8 Seasonal variation in Turbidity (NTU) at different sampling sites

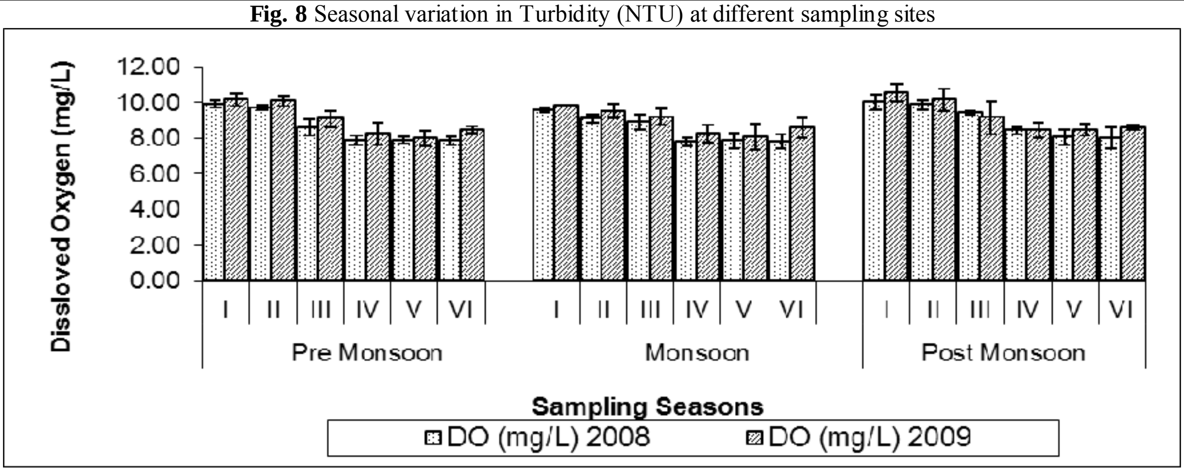

Fig. 9 Seasonal variation in Dissolved Oxygen (mg/L) at different sampling sites.

The dissolved oxygen level recorded in urban area by NEC was as low as 7 mg/L. Chattopadhyay *et al.* (2005) studied linkage between land use pattern and water quality in Chalakudy river basin in Kerala and reported that DO level in forest area was 7.62 mg/L whereas, in urban and agricultural area it was 1.73 and 5.91, respectively.

Nitrate

Figure 10 depicted low nitrate level at upstream as compared to urban area and downstream. The minimum nitrate level recoded was 0.04 mg/L ± 0.01 at upstream sampling site I during monsoon and maximum was 2.10 mg/L ± 0.45 at sampling site IV post-monsoon. The nitrate concentration were found much lower than the highest limit of 45 mg/L set by ICMR for drinking water. Since this parameter is present at low level in all the sampling sites, it does not pose any threat to aquatic and terrestrial beings. However, the slight increase in nitrate level in urban area could be attributed to the release of sewage and other domestic wastes into the river. Study by Jaji *et al.* (2007) on nitrate concentration in Ogun River, Nigeria reported that nitrate content was higher (16.7 mg/L) around urban area which could be due disposal of organic wastes.

Phosphate

The seasonal variation in phosphate at different sampling sites of Thimphu study area is presented in **Fig. 11**. Throughout the study period the phosphate level was recorded low at upstream sampling sites. The phosphate level was recorded high in activity area throughout the study period. The minimum level of phosphate recorded was 0.004 mg/L ± 0.001 at sampling site I during pre-monsoon and the maximum level recorded was 0.027 mg/L ± 0.003 at sampling site IV during post-monsoon. This could be due to the release of domestic wastes containing phosphate into water bodies.

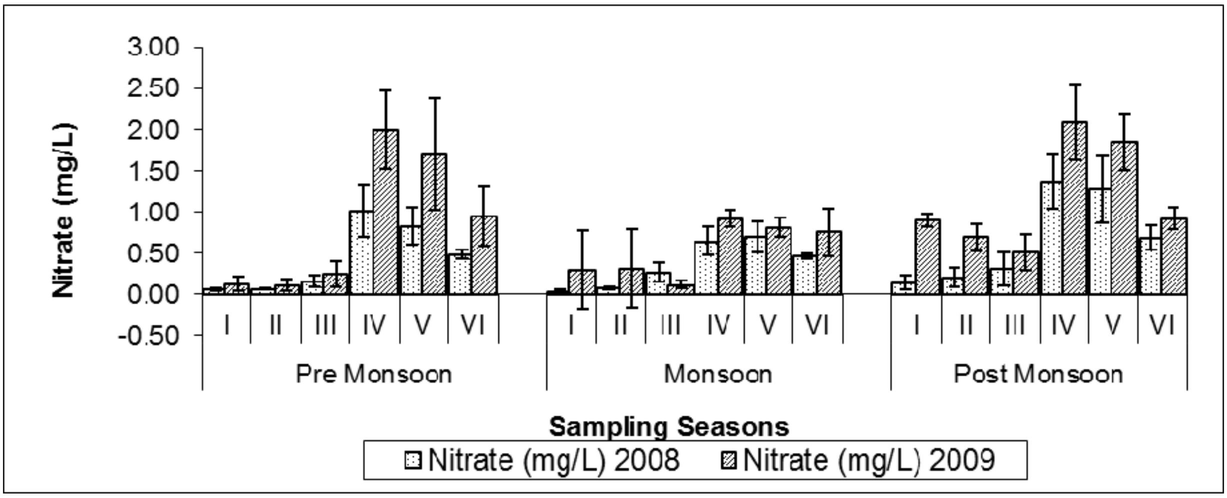

Fig. 10 Seasonal variation in Nitrate (mg/L) at different sampling sites of Thimphu study area.

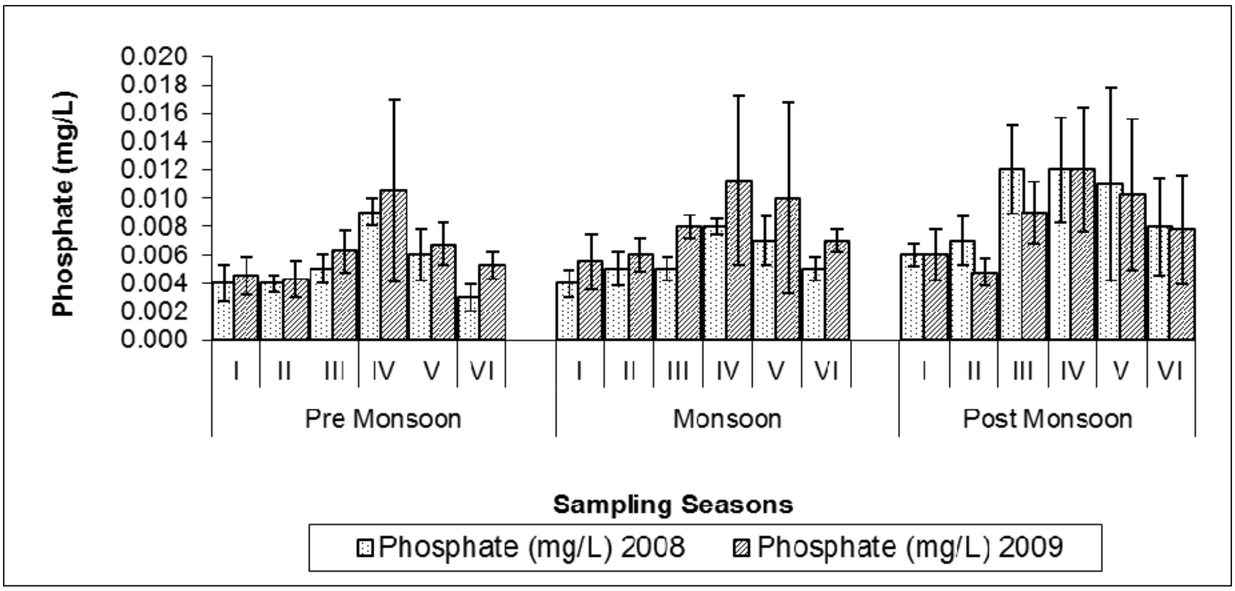

Fig. 11 Seasonal variation in Phosphate (mg/L) at different sampling sites.

Chloride

The seasonal variation in chloride at different sampling sites of Thimphu study area is presented in **Fig. 12**. The chloride concentration was found lower at upstream as compared to urban area and downstream. The minimum chloride level recorded was 4.47 mg/L ± 0.44 at upstream sampling site I during monsoon and the maximum was 9.04 mg/L ± 0.60 at downstream during pre-monsoon. The chloride level recorded throughout the study period was much lower than the permissible limit of 200 mg/L set by WHO for drinking water (WHO, 1984). Thus, indicating lesser degree of pollution that makes Wang Chhu suitable for domestic and industrial purposes. Chloride enters into surface water from natural sources like weathering of rock salts. The anthropogenic sources are domestic sewage effluents and runoff from agriculture fields through fertilizers.

Similar study was carried out by Chattopadhyay *et al.* (2005) on linkage between land use pattern and water quality in Chalakudy river basin in Kerala and reported that chloride content in forest area was lower (16.51 mg/L) and higher at urban and agricultural areas (44.09 mg/L and 18.55 mg/L). Clinton and Vose (2006) also reported that concentration of chloride in water around urban area was higher as compared to water around forest area.

Total Coliform

The seasonal variation in total coliform at different sampling sites of Thimphu study area is presented in **Fig. 13**. The total coliform counts were found consistently low at upstream throughout the study period. The coliform counts were higher in sampling sites IV and V in all the seasons. This could be attributed to the presence of fecal matter along the river as shown in **Fig. 14**. The highest total coliform recorded during the study period was 138 colonies/100 ml ± 4.96 in urban area during pre-monsoon. The National Environment Commission of Bhutan also reported high level of fecal coliform in urban area of Wang Chhu (NEC report, 2005). Study by Jaji *et al.* (2007) on Ogun River, Nigeria also reported high concentration of total coliform around urban area due to discharge of untreated sewage into water bodies and non-point source pollution such as septic tank overflow, runoff and animal wastes.

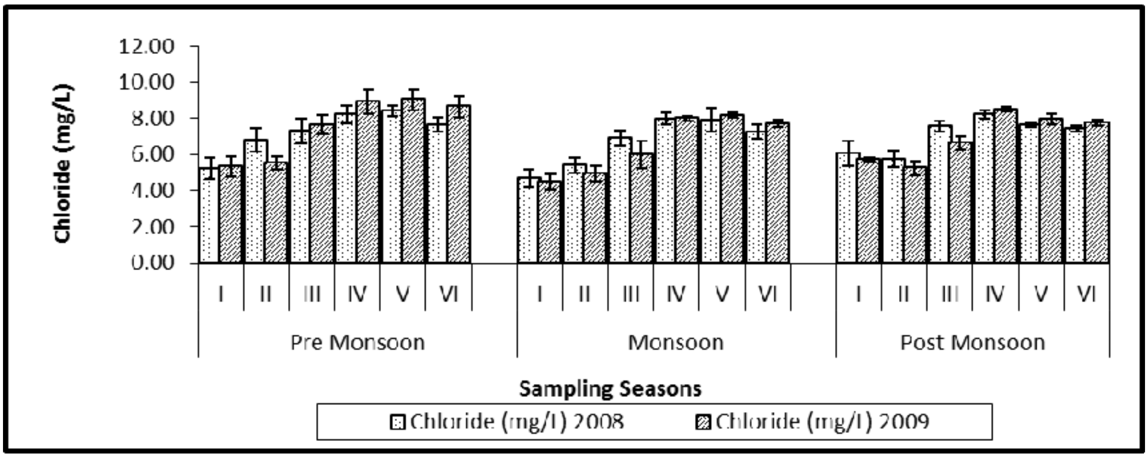

Fig. 12 Seasonal variation in Chloride (mg/L) at different sampling sites of Thimphu study area.

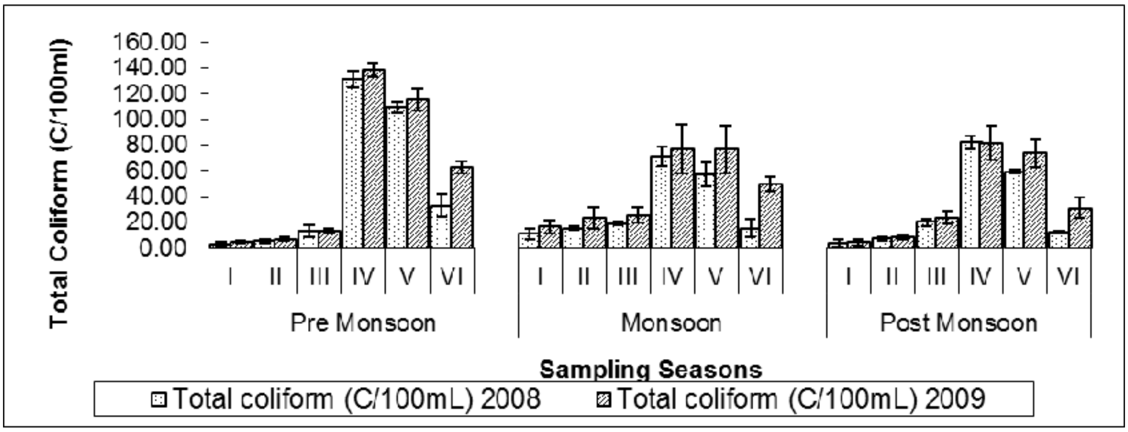

Fig. 13 Seasonal variation in Total Coliform (colonies/100ml) at different sampling sites of Thimphu study area.

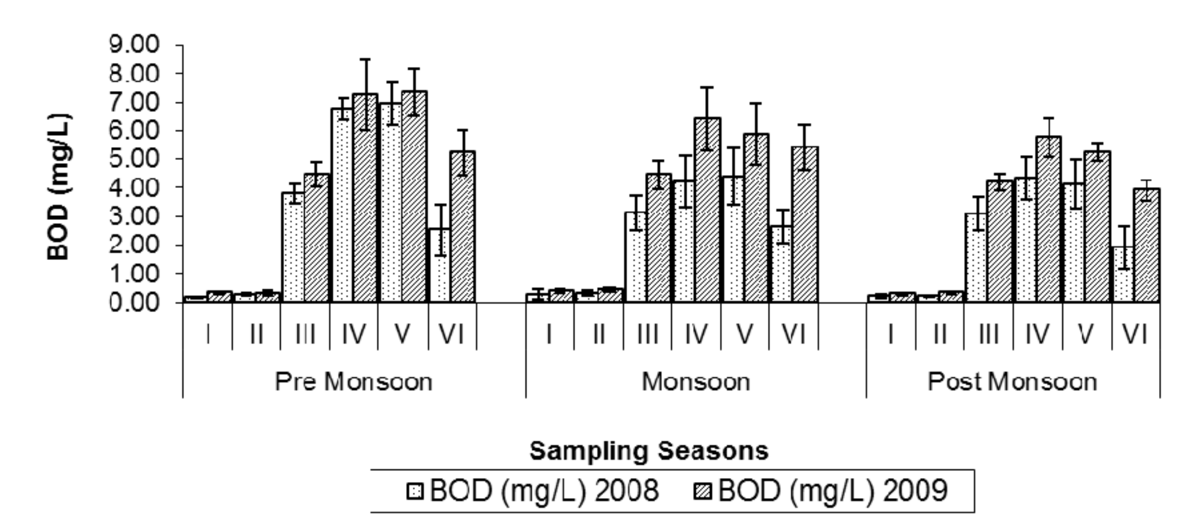

Fig. 14 Seasonal variation in BOD (mg/L) at different sampling sites of Thimphu study area.

Biochemical Oxygen Demand (BOD)

The seasonal variation in BOD at different sampling sites of Thimphu study area is presented in **Fig. 14**. The BOD values were found higher in urban area and downstream as compared to upstream. The highest BOD value recorded was 7.33 mg/L ± 0.83 at sampling site V during pre-monsoon and the lowest was 0.16 mg/L ± 0.03 at sampling site I in the same season. The biological oxygen demand values at sampling sites IV and V during pre-monsoon excided the WHO permissible limit of 6 mg/L for drinking water indicating deterioration in water quality. The BOD values during post-monsoon were within the permissible limit. This may be attributed to the low temperature during winter which decreases photosynthetic activity and less number of phytoplankton (Abdo, 2004). Ravindra *et al.* (2003) and Schueler (1995) also reported higher BOD level in urban and industrial areas.

Bio-monitoring of water quality using Benthic Macro-invertebrates

The benthic macro-invertebrates are good indicators of water quality. The studies on their community and population in water bodies provide information on pollution status of the water they inhabit. In all the three study areas variations in population of benthic macro-invertebrates were observed throughout the study period. The highly sensitive benthic macro-invertebrates belonging to the taxonomic order of Trichoptera, Ephemeroptera and Plecoptera were found mostly at upstream which indicated relatively clean water. The pollution tolerant benthic macro-invertebrates were recorded mostly in activity areas and it's downstream. Rich diversity and evenness of benthic macro-invertebrates were observed at upstream sampling sites only.

In Thimphu study area a total of 2432 individuals/m^2 benthic macro-invertebrates were recorded throughout the study period. The pollution sensitive benthic macro-invertebrates were found mostly at upstream whereas, the pollution tolerant benthic macro-invertebrates were concentrated in urban area and it's immediate downstream. The benthos present in Thimphu study are were of the taxonomic orders of Trichoptera (caddisflies), Ephemeroptera (mayflies), Plecoptera (stoneflies), Coleoptera (aquatic beetles), Diptera (true flies), Odonata (dragonflies) and tubificida (worms). The Shannon-Weiner diversity index of benthic macro-invertebrates in Thimphu urban area during pre-monsoon ranged from 1.5546–0.3389 attaining maxima at sampling site I and minimum at sampling sites III. The pollution sensitive benthic macro-invertebrates were totally absent at sampling sites IV and V which could be due to the discharge of organic and inorganic domestic waste from urban area. The Shannon-Weiner diversity index of benthic macro-invertebrates in Thimphu urban area during monsoon ranged from 1.5332–0.2880 attaining maxima at sampling station I and minimum at sampling station III. The diversity index showed benthic macro-invertebrates were not evenly distributed at upstream and downstream. The diversity index is high in the upstream and low in urban and downstream areas. This indicates impact on water quality in urban area and it's downstream. It was also observed that pollution sensitive benthic macro-invertebrates were totally absent at sampling sites III, IV and V which could be due to the discharge of organic and inorganic domestic waste from urban area. The Shannon-Weiner diversity index of benthic macro-invertebrates in Thimphu urban area during post-monsoon ranged from 1.5084 to 0.6555 attaining maximum at sampling site I and minimum at sampling station IV and V. The diversity index showed benthic macro-invertebrates were not evenly distributed at upstream and downstream. The evenness ranged from 0.9826 to 7566 attaining maximum at sampling site III and minimum at sampling site II.

Many studies have reported that benthic communities have good correlations with the water quality changes (Rosenberg and Resh, 1992; Richards and Minshell, 1992; Resh and Jackson, 1993; Resh, 1995; Mason, 1996; Omar *et al.,* 2002). Recently, study done by Duran (2006) found that compared to upper area, lower area had lower diversity of benthic macro-invertebrates at Behzat stream in Turkey which was due to the release of phosphate and nitrogen ions into the stream. Our findings are in line with earlier studies which revealed that a clean and healthy ecosystem support diversity of benthic macro-invertebrates whereas, in dirty and unhealthy ecosystem only a few types of pollution resistant organisms survive. Joshi *et al.* (2007) reported that species richness depend on abiotic factors like temperature, hardness, pH, dissolved oxygen, chloride and phosphorus which are in line with our study. Budin *et al.* (2008) stated that river or stream pollution will not just increase water shortage for daily use but also affect the aquatic species richness, diversity and population of sensitive benthic macro-invertebrates such as Ephemeroptera (E), Plecoptera (P) and Trichoptera (T) which live in clean water and prefer unpolluted aquatic ecosystems. In our study we have found maximum EPT population at upstream sampling sites where the water quality is relatively clean. Sharma *et al.* (2008) studied aquatic insect diversity of Chandrabhaga river, Garhwal Himalayas and reported that density and diversity of aquatic insects decreases with increase in turbidity, water temperature and decrease in dissolved oxygen.

CONCLUSION

Based on the results of the present study it can be concluded that there are changes in the LULC due to anthropogenic activities. The forest and agriculture land decreased during 1990-2008 and the urban area increased drastically. Such change in LULC pattern is not healthy from the environment and socio-economic point of views and therefore, is a matter of concern. The LULC changes and associated human activities have deteriorated the water quality in the study areas as evident from low DO, higher electrical conductivity, total hardness, total dissolved solids, turbidity, nitrate, chloride, sulphate, BOD and total coliform, presence of pollution tolerant macro-invertebrates etc.

In summary, the study revealed that all along, Bhutan forest land is decreasing. The development of urban infrastructure are posing threats to water regime in terms of its quantity and quality. Though the deterioration of water quality is restricted to a few localized areas, the trend is serious and needs proper attention of policy planners and decision makers. Proper treatment of effluents from industries and urban areas are urgently needed to reduce water pollution in such affected areas to check further deterioration of water quality. This present study which is based on a small a area can be considered as an eye opener. However, further studies and in-depth analysis of water quality and its impact on human health and socio-economy in Bhutan is needed for policy planning and implementation.

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