Study on Water Quality of Bhairab River in Khulna Region

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering in the Department of Civil Engineering

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DECLARATION

This is to certify that the thesis work entitled "Study on Water Quality of Bhairab River in Khulna Region" has been carried out by Md. Alhaz Uddin in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above research work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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APPROVAL

This is to certify that the thesis work submitted by Md. Alhaz Uddin entitled as "Study on Water Quality of Bhairab River in Khulna Region" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in October 2015.

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To

The Engineers those who are honest, devoted and
dedicated for the nation.

ABSTRACT

Water is an important element for all living beings on this planet. All life forms of the earth depend upon water. No life can exist without water since water is as essential for life as air is. Generally water contains many physical, chemical and biological impurities. Surface water sources may be mainly in the form of rivers, lakes, pond, glaciers and rainwater. Modern urbanization, increasing population, household wastes and industrialization day by day are deteriorating these sources. Bhairab River is not further than the ill concern. It receives huge quantities of pollutants and thus degrading its water quality gradually. This paper deals with assessment of water quality of Bhairab River and also its trends.

To fulfill the present aim of the study, a total length of 36.98 Km along the river from Rupsha ghat to Noapara Bazar ghat was divided into ten sampling stations. Water samples were collected every month from each of the sampling stations through the year 2014 for laboratory testing. Twenty water quality parameters such as temperature, pH, turbidity, conductivity, color, alkalinity, hardness, TS, TDS, SS, phosphate, nitrite, nitrate, chloride, DO, BOD, COD, manganese, fecal coliform and total coliform were examined by standard method. Among those twelve were found out of Bangladesh drinking standard. Water quality assessment was performed by determining water quality index (WQI) following National Sanitary Foundation (NSF) method. The study analyzed trend of water quality index. Present research is conducted based on field and secondary data.

In the correlation study it is found that major parameters are more or less correlated with each other. Three important parameters like chloride, TDS and conductivity each are significantly correlated with each other. It helps water quality management and monitoring. Average water quality index obtained for the year 2014 in both temporal (twelve months) and spatial (ten stations) are 64 and 65, respectively which is close to each other. As per NSF water quality index range Bhairab River is medium in quality, and this water is not suitable for drinking without treatment.

The study also reveals that water quality index is progressively decreasing with course of time. In 2005 water quality index was observed 71 while in 2014 it reduced to 64. During last ten years WQI is decreased by 7 points, so yearly average decreasing presumed 0.70 point per year. Following this rate projected water quality index of studied river assumed to be 51.39 and 35.65 for the year 2030 and 3050 respectively. After that water quality turns medium to bad. This is an alarming for the local environment. Bottom line is that water quality of Khulna region expressly Bhairab River is being deteriorated day by day.

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ABBREVIATION

APHA	:	American Public Health Association
BDS	:	Bangladesh Standard
BIS	:	Bureau of Indian Standard
BIWTA	:	Bangladesh Inland Water Transport Authority
BOD	:	Biochemical Oxygen Demand
BWDB	:	Bangladesh Water Development Board
CCMEWQI	:	Canadian Council of Ministers of the Environmental Water Quality Index
COD	:	Chemical Oxygen Demand
DO	:	Dissolved Oxygen
DoE	:	Department of Environment
ECR	:	Environmental Conservation Rule
EEES	:	Environmental Engineering and Earth Sciences
EPA	:	Environmental Protection Agency
FC	:	Fecal Coliforms
GIS	:	Géographic Information System
IWM	:	Institute of Water Modeling
KWASA	:	Khulna Water Supply and Sewerage Authority
NSFWQI	:	National Sanitation Foundation Water Quality Index
NTU	:	Nephelometric Turbidity Unit
OWQI	:	Oregon Water Quality Index
RPI	:	River Pollution Indices
SS	:	Suspended Solids
TC	:	Total Coliforms
TDS	:	Total Dissolved Solids
TS	:	Total Solids
WAWQI	:	Weight Arithmetic Water Quality Index
WHO	:	World Health Organization
WQI	:	Water Quality Index

UNITS OF MEASUREMENTS

%	Percent
cc	Cubic Centimeter
cm/sec	Centimeter per Second
cmol (+)/kg	Centimoles per Kilogram
gm	Gram
gm/cc	Gram per Cubic Centimeter
in	Inch
kg	Kilogram
kg/cap/day	Kilogram per Capita per Day
kg/day	Kilogram per Day
kg/m^3	Kilogram per Cubic Meter
m	Meter
m^3	Cubic Meter
m^3/m	Cubic Meter per Meter
meq/100g	Milliequivalents per 100g
ml	Milliliter
mm	Millimeter
µS/cm	Microsiemens per Centimeter.
N/100ml	Number per hundred Milliliter.
mg/L	Milligram per liter
^0C	Degree Centigrade
ppm	Parts per Million

CHAPTER ONE

INTRODUCTION

1.1 General

Two thirds of the earth's surface is covered by water and the human body consisting of 75 percent of it. Water is an essential element for life. Human beings live alongside water and are nourished by it. It is a source of beauty, wonder and relaxation as well as refreshment. Water has an aesthetic value.

It is a prime natural resource and precious assets, forms the chief constituents of ecosystem. Water sources may be mainly in the form of rivers, lakes, glaciers, rainwater, groundwater etc. Besides, the needs of drinking, water resource play a vital role in the various sectors of economy such as agriculture, livestock production, forestry, industrial activities, hydropower generation, fisheries and creative activities. The availability and quality of surface or groundwater are being deteriorated due to some important factors like increasing population, urbanization, industrialization etc.

Water is the most remarkable commodity. It is essential to all life, both animal and plants. It is difficult to imagine any clean and sanitary environment without water. Man can go nearly two months without foods, but can live only three or four days with no water. Potable and soft drinking water play an important role in the development of good health condition of a nation. Mainly there are two types of water sources. One is surface water coming from streams, ponds, lakes, reservoirs, rivers and ocean while the other sources are groundwater remaining in the groundwater table. The impurities present in natural water are namely, living impurities, organic impurities and water borne poisons. Mineral impurities are mainly dissolved gasses and carbonates, sulfates, sulphides etc.

1.2 Background of the Study

Bangladesh is a country of rivers which is situated at the confluence of the three largest rivers in the world, the Ganges, Brahmaputra, Meghna and their tributaries. Many rivers are flowing over the territory. Some are produced in domestically and some are entered from upper riparian country. Many rivers and its tributaries make enormous river netting over the entire territory and meeting limitless natural challenge over years. These rivers pour out into the Bay of Bengal's 580 km coastline, which is exposed to cyclones and where some of Bangladesh's poorest communities live. The country experiences significant variability in water availability during flood in the monsoon from June to October and droughts in dry season starting November to May which leads serious inland salt intrusion. Bangladesh is a country that has been grappling with these issues throughout its short history. Now with the worsening impacts from climate change, these challenges are going stronger as temperature rises and water variability increases.

Water is the fluid of life not only for human beings but also for any living organism. Oceans and seas are the enormous sources of water but they are not useable in most of the cases. The fresh liquid water sources on land surfaces and in the ground constitute only 1 percent of the total water on the earth. The main sources of water in Bangladesh are surface waters in rivers, reservoirs, lakes, canals and ponds, and the groundwater in deep and shallow aquifers (Ahmed *et al.* 2003). In the groundwater, presence of arsenic and iron are excessive almost all over Bangladesh. The rivers, main source of surface water, are also being polluted day by day. Most of the large cities and settlements have developed nearby rivers and urbanization turns into the main reason for pollution of these rivers and other water bodies (DoE, Bangladesh 2001).

Even early last century river or surface water was the main source of household uses like drinking, bathing and washing. But the modern urbanization, industrialization, technological developments and multi-use of water deteriorated and deteriorating river water quality gradually. Meanwhile many water quality parameters went up beyond tolerance limit. In South Asian countries such as Nepal, India and Bangladesh pollution of rivers are severe and critical near urban stretches due to huge amounts of pollution load discharged by urban activities (BIWTA, 2006).

During the past several decades, there has been an increasing global concern on sustainable water resource management and it is widely recognized as a major challenge to the world (Fukushi *et al.* 2010). Industrial pollution is one of the major types of water pollution, as water is an essential raw material in almost all manufacturing plant. Industries that are considered as principal source of pollution are chemicals, foods, pharmaceuticals, materials and energy. Bangladesh is not an industrialized country. But it is in the early stage of industrialization and moving onward.

The increasing urbanization and industrialization of Bangladesh have negative implications for water quality. The pollution from industrial and urban effluents in some water bodies and rivers has reached alarming levels. The long term effects of this contamination by organic and inorganic substances, many of them are toxic and reached severe means. The increasing application of chemical fertilizers and widespread use of variety of new pesticides, insecticides, herbicides and weed killers in agricultural practices are resulting in a host of new pollution hindrances from land drainage. This type of agricultural pollution has severe impact on water quality, as most of pollutants are resistant to natural degradation. Although concentrations of the pollutants are still rather low, many of these compounds are toxic to human or animal life; some of them are carcinogenic or have serious ecological implications (DoE, Bangladesh, 2001). With the rapid development of economics and the speedy growth of population, sustainable water resource management for the increasing industrial, agricultural and domestic purposes are now being a critical issue in Bangladesh. River are not pipelines, these are our lifelines. We must protect the river (Matin, 2012)

The quality of water may be described according to their physico-chemical and micro-biological characteristics. For effective maintenance of water quality through appropriate control measures, continuous monitoring of large number of quality parameters is essential. However it is very difficult and laborious task for regular monitoring of all the

parameters even if adequate manpower and laboratory facilities are available. In recent years an alternative approach based on statistical correlation, has been used to develop mathematical relationship for comparison of physico-chemical parameters.
The present study deals with study of physico-chemical parameters of Bhairab River. Systematic calculation of correlation coefficient among water quality parameters has been developed with the objective of minimizing the complexity and dimensionality of large set of data.

Khulna city is surrounded by Rupsha and Bhairab rivers and canals. Major industrial sources are Jute mills, textile mills, oil mill, starch, soda ash, dying, lime, ammonium sulphide, tobacco, power plants, match and ice factories, fish processing, flour mill, salt industry, tannery and cement factory and so on. The river is further polluted by indiscriminate throwing of household, clinical, pathological and commercial wastes and discharge of spent fuel and human excreta. In fact, the river has become a concern of pollution of many types of solid, liquid and chemical waste of bank-side population (BIWTA, 2006). Therefore, it is a very important task to know the present water quality of Bhairab River in Khulna region.

Water quality can be studied scientifically if an accurate estimate of water quality is available in the form of an index. From the manual data processing of the large number of analytical data practically prevents faster interpretation of the results so that many attempts were made to present them in more understandable and acceptable ways using water quality indices (WQI) or using river pollution indices (RPI) (Singh et al. 2008). The evaluation of water quality in developing countries has become a critical issue in recent years, especially due to the concern that fresh water will be a scarce source in the future (House, 1996). However, the overall composite water quality is somewhat difficult to evaluate from a large number of quality variables.

The concept of water quality is fundamental to the study of environmental engineering and water resources because they explore the relation between water requirements and the form with also extent of permissible departure from purity. This is inextricably linked with the term pollutants/pollutions. A substance (either natural or man-made) becomes a pollutant only when it is introduced at a level or in a form that upsets the normal functioning of an ecosystem, or that affects human or animal health.

Water quality of any specific area or specific source can be assessed by using physical, chemical and biological parameters. The values of these parameters are harmful for human health if they occurred more than defined limits (WHO, 2012; BIS, 2012). Therefore, the suitability of water sources for human consumption has been described in terms of Water quality index (WQI), which is one of the most effective ways to describe the quality of water. WQI utilizes the water quality data which are formulated by various environmental monitoring agencies. It has been realized that the use of individual water quality variable in order to describe the water quality for common people is not easily understandable (Bharti *et al.* 2011; Akoteyon *et al.* 2011).That's why, WQI has the capability to reduce the bulk of the information into a single value to express the data in a simplified and logical form (Babaei *et al.* 2011). It takes information from a number of sources and combines them to develop an overall status of a water system. They increase the understanding ability to highlight water quality issues by the policy makers for the consumers (Nasirian *et al.* 2007).

Initially, WQI was developed by Horton *et al.* (1965) in United States by selecting ten most commonly used water quality variables like dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity and chloride etc. and has been widely applied and accepted in European, African and Asian countries. The assigned weight reflected significance of a parameter for a particular use and has considerable impact on the index. Furthermore, a new WQI similar to Horton's index has also been developed by the group of Brown in 1970 (Brown *et al.* 1970), which was calculated based on weights to individual parameter. Recently, many modifications have been considered for WQI concept through various scientists and experts (Bhargava *et al.* 1998; Dwivedi *et al.* 1997).
A general WQI approach (Fernandez *et al.* 2014) is based on the most common factors, which are described in the following three steps

1. Parameter Selection: This is carried out by judgment of professional experts, agencies or government institutions that is determined in the legislative area. The selection of the variables from the five classes namely oxygen level, eutrophication, health aspects, physical characteristics and dissolved substances, which have the considerable impact on water quality, are recommended (Dunnette *et al.* 1979).

2. Determination of Quality Function (curve) for each Parameter Considered as the Sub-Index: sub-indices transform to non-dimensional scale values from the variables of its different units (ppm, saturation percentage, counts/volume etc.).

3. Sub-Indices Aggregation with Mathematical Expression: This is frequently utilized through arithmetic or geometric averages.

However, a huge number of water quality indices viz. Weight Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Oregon Water Quality Index (OWQI) etc. have been formulated by several national and international organizations. These WQI have been applied for evaluation of water quality in a particular area (Lumb *et al.* 2002; Chaturvedi *et al.* 2010). Moreover, these indices are often based on the varying number and types of water quality parameters as compared with respective standards of a particular region. Water quality indices are accredited to demonstrate annual cycles, spatial and temporal variations in water quality and trends in water quality even at low concentrations in an efficient and timely manner. On the basis of reviewed literature, available indices have many variations and limitations based on number of water quality variables used and not accepted worldwide (Bordalo *et al.* 2001). Hence, it needs worldwide acceptability with varying number of water quality variables.

Environmental protection agency (EPA) defines comprehensive sets of determinants (water quality parameters) to monitor water quality which is particularly important in reporting status of river water (OJEC 2000). Internationally, there are number of attempts taken to produce a method that meaningfully integrates the data sets and interprets them into simplified quantitative information for easy understanding (Nagels *et al.* 2001). In the United States National Sanitation Foundation (NSF) guides for defining water quality with Water

Quality Index (WQI). It is a weighted linear system of products with the sub-indices of individual parameter and a weighted value (Ashok *et al.* 2000). This study attempts to express the values of the water quality parameters by a simple number (NSF water quality index) which will be understandable by the general people of the country.

Sustainable water management is becoming a necessity for development of fish production, livelihood of people and the environment in the coming decades (Fukushi *et al.* 2010). The aim of the present study consists of assessment of water quality of the Bhairab River by using National Sanitation Foundation (NSF) water quality index, to identify pollution factors affecting the river water quality and identification of its probable use in various purposes.

1.3 Objectives of the Study

The present study contains the following objectives:

1. To assess the present water quality, through analysis of some selected water quality parameters.
2. To compare the results with the international and Bangladesh standard.
3. To develop correlation among physico-chemical water quality parameters.
4. To analyze future trends of water quality.
5. To suggest some mitigation measures for controlling water pollutions.

1.4 Scope of the Study

The concept has versatile scope for various reasons. The major scopes are

- The study gives a clear idea of water quality index of the river water.
- The present study deals with physico-chemical correlation among water quality parameters for minimizing the complexity and dimensionality of large set of data.
- It will reveal water quality index of Bhairab river.
- The study gives an assessment about Bhairab river and propose guidelines for sustainable water quality management of this river by correlation.
- The present study will be helpful to them who desire to further study in this sector.

1.5 Organization of the Thesis

The thesis has been presented in six distinct chapters comprising different aspects of the study. The chapters represent the testing of various water quality parameters of collected water sample and to identify pollution factors affecting river water quality, development of correlation among parameters, assessment of water quality by using NSF water quality index and also investigate future trend of water quality index and movement of salinity. Finally proposal of guidelines for sustainable water quality management in the Bhairab River suggested.

Chapter-1	:	This chapter includes titled introduction and background of the study, objectives, scope and limitation with highlight the whole study.
Chapter-2	:	Comprises a comprehensive literature review encompassing the general, study area description, river system, effect of industrial effluents, description of various water quality parameters, water quality index method, history of water quality indices, NSF water quality index and ecology.
Chapter-3	:	Contains the elaborate description of the methodology and laboratory testing procedure of each parameter.
Chapter-4	:	Presents the results obtained from laboratory tests, tabular, graphical and analytical representation of the experimental data including detailed discussions.
Chapter-5	:	Sketches final conclusions based on tested results, discussion along with provides several recommendations for the future studies and development of statistical correlation among water quality parameters.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Bangladesh is a low lying plain country with big inland water bodies, including some of the biggest rivers in the world and is extremely vulnerable to climate change because of its geophysical characteristics (Matin *et al.* 2010). Demographic factors combined with an increase in per capita demand and a decrease in readily available resources have resulted in the current era of global freshwater scarcity. Rapid urbanization, water pollution and global warming are aggravating the situation. Bangladesh is a land of rivers. Around 230 rivers flow in the country including 53 international rivers. Most of the big cities and settlements situated near those water bodies. Surface water quality of the rivers of Bangladesh is highly polluting day by day (DoE, 1993; Hossain, 2001).

Water, a prime natural resource and precious asset, forms the chief constituent of ecosystem. Water sources may be mainly in the form of rivers, lakes, glaciers, rain water, groundwater etc. Besides the need of water for drinking, these resources play a vital role in various sectors of economy such as agriculture, livestock production, forestry, industrial activities, hydro-power generation, fisheries and other creative activities. The availability and quality of water either surface or ground, have been deteriorated due to some important factors like increasing population, industrialization, urbanization etc. (Shweta *et al.* 2013). Bangladesh has the widest spectrum of inland open water and marine resources.

The concept of water quality is fundamental to the study of environmental engineering. A substance (either natural or man-made) becomes a pollutant only when it is introduced at a level or in a form that upsets the normal functioning of an ecosystem, or that affects human or animal health.

2.2 Previous Studies

Jabed *et al.* (2013) explored seasonal variation and water quality assessment of Bhairab River in Khulna, Bangladesh. They assessed sixteen important physico-chemical parameters in summer and rainy seasons. The overall pollution load was significantly higher in summer than rainy season. They expressed that the river has become more or less of a flowing dumping yard. The physico-chemical parameters such as chloride, pH, DO, hardness sulphate, chromium, copper, zinc, TKN and lead were compliance with Bangladesh (ECR, 1997).

(Diffuse pollution conference Dublin 2003) The principal industries of Khulna (South-East of Bangladesh) are jute mills, oil mills, newsprint, cable factory, shipyards, tobacco, match factories, hardboard and other dispose molasses, starch, oil, sodium-sulphate, ethen, lissapol, soda ash, dying, sulphuric acid, salicylic acid, lime, ammonium sulphate, chrome etc. A few study at Bhairab River shows a very alarming water quality data, conductivity 390-9500 µS/cm, total solids 260-3500 mg/L, TDS 260-3200 mg/L. The pollution aspects of Bhairab and Rupsha river is very critical as the Rupsha does not receive a continuous flow of fresh water from the parent river, one the other hand, the Bhairab river, being subject to tides, has marked backwater effects which reduce the purification capacity of the river.

Shamsuddin and Alam (1988) examined on significant variation in water properties between the non-industrial and the industrial sections of the Sitalakhya River and they found significant differences between the industrial and the non- industrial stretches in both dry and wet seasons and hence, provide an indication of the extent of pollution in the industrial section.

Kudesia (1990) explained sources and nature of various types of industrial effluents and their constituents which are discharged by the industries. He revealed the various techniques involved in collection, preservation and tabulation of industrial samples. He further examined on water pollution principles of disinfection of drinking water, sanitary technology in environmental conditions of our sub-continent. It reveals a comprehensive account of the mechanisms involved in purification of drinking water with various oxidizing disinfectants. It also explains the possible measures to be adopted for controlling the problem of water pollution.

Kudesia (1990) worked on pollution and revealed that, various types of pollution occurring in man's life due to interference with nature. These various sources of pollution have caused mental disorder, skin ailments, stomach, diseases, blindness and genetic changes; he also explained the techniques for the detection of pollutants have been described in very lucid style so that a common man may understand them.

Trivedy (1990) examined on river water pollution. He revealed that pollution of a river first affects its chemical quality and then systematically destroys the community the delicate food web. Diverse uses of the river are seriously impaired due to pollution and even the polluters like industry suffer due to increased pollution of the river.

Bhuiya *et al.* (1994) investigated the sample of Dhaka city surface water bodies. Fifty water samples from different water bodies were drawn for parametric tests and measurements revealing physical and chemical characteristics of water quality or pollution. Parametric values have been obtained for the determinants of water quality of pollution viz. temperature, hardness, turbidity, CO2, pH, DO and BOD. The physical and chemical characteristics of water samples are determined by the methods of American Public Health Association (APHA).

Khan *et al.* (1996) studied on sewage pollution in Chittagong metropolitan area. They found that all the parameters of the discharged sewage in the canals such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) etc. fluctuated substantially. Dissolved oxygen (DO) was always remarkably low.

Rahman *et al.* (2000) studied to investigate the effects of pollutants of the Jamuna Fertilizer Company Limited (JFCL) discharged into the river water of the Jamuna. The study shows that the pollutants in general had little effects on the river water.

Dalwar and Hadiuzzaman (2005) analyzed the available data on the water quality of the Balu and Shitalakhya Rivers and the present assessment of the water quality of these two rivers suggest that the water quality at the intake point of the Saidabad water treatment plant is significantly affected by the high pollution loading of the Balu River, especially in the dry season. High ammonia levels in the Norai Khal and Balu River that this probably the most significant source of ammonia at the intake point. Besides, high ammonia concentrations and a number of other quality parameters, such as organic matter and heavy metals, may also pose serious problems for the Saidabad water treatment plant in future, if the water quality of the rivers does not improve. Since the current trend of pollution is likely to continue, at least in the future, the water quality at the intake point is likely to get worse in the coming years, especially in the dry season

Kamal and Ahmed (2007) studied physico-chemical properties of water of the Mouri River, Khulna. They develop correlations among the water quality parameters. They also revealed that the physico-chemical water quality of the river Mouri is not reasonable. The dissolved oxygen, BOD, hardness, phosphate and nitrite used in the study showed that the quality of water is not now in safe limit (EQS, 1991) and no longer good to support micro flora and fauna, but the situation is alarming and degradation is in continuous process, therefore immediate action is required for its better management.

Singh *et al.* (2007) deals with the assessment of physico-chemical parameters of the samples of Kosi River during 2004 and 2005 in pre monsoon, monsoon and post monsoon. Statistical studies have been carried out by calculating correlations coefficients among different pairs of parameters and t-test was applied for checking significance. It is found that an appreciable significant positive correlation holds for chloride with pH, Mg, Na, hardness and suspended solids; as a consequence sodium with hardness, EC and sulphate. A significant negative correlation was found between potassium with turbidity, Cl^-, EC and hardness. All the physico-chemical parameters of the Kosi water are within the highest desirable limit set by WHO except turbidity and BOD which recorded a high value.

Rumman *et al.* (2011) determined that water quality index (WQI) along the Faridpur -Barisal road following weighted arithmetic method and National Sanitation Foundation (NSF) method of total 128 km length. Six most important parameters pH, total dissolved solids, dissolved oxygen, BOD, electrical conductivity and temperature difference were considered for calculation of WQI. According to the arithmetic mean method WQI value varied between 19 and 96, wherein NSF method WQI values found between 55 and 91.

Bhavtosh *et al.* (2013) Discussed about different types of water quality method like National Sanitation Foundation (NSF), Canadian Council of Ministers of the Environment Water Quality Index, Oregon Water Quality Index and Weighted Arithmetic Water Quality Index. They also compared merits and demerits among the water Quality indices.

Verma *et al.* (2014) studied on river Pundu, Uttar Prodesh and was carried out to assess water quality indicators and correlations among physico-chemical parameters. The study clearly revealed that river is polluted to a considerable extent of all through its entire stretch passing through Kanpur. They established strong positive correlations among temperature, pH, total solids, phosphate and sulphate.

2.3 Description of Study Area

Khulna is the third largest city in Bangladesh. It is located on the banks of the Rupsha and Bhairab rivers in Khulna district. It is the individual headquarters of Khulna division and a major industrial and commercial center. Khulna is located in South-Western Bangladesh with a total area of 59.57 km^2, while the district itself is about 4394.46 km^2. It lies South of Jessore and Narail, East of Satkhira, West of Bagerhat and North of the Bay of Bengal. It is a part of the largest delta in the world. In the southern part of the delta lies the Sundarban, the world's largest mangrove forest. The city of Khulna is in the northern part of the district and is maily an expansion of trade centers close to the Rupsha and Bhairab Rivers. The population of the city under the jurisdiction of the city corporation was 1,000,000 in 2010 estimation. The wider statistical metropolitan area had at the same time an estimated population of 1,435,422. A large number of population 25.1 percent is engaged in agriculture. Of total population in Khulna the number of agricultural labour is 11.3 percent. Others include 1.7 percent in fishing, 7.2 percent as wage laborers, 16.4 percent as industry workers, 4.1 percent in transport, 1.5 percent in construction, 18.9 percent in service sector and 12.2 percent in other activities. There are a number of factories in the district such as paper mill, hard board mill, textile mill, match facory, shipyard, steel mill, cable factory, rice mill, flour mill, ice factory etc. Fishing sector is an important sector of the economy.

Waste from different mills and factories are falling in the Bhairab river and polluting the river water. The whole Khulna city is becoming unsuitable for living because of environmental degradation. Industrial units at Khalishpur and Daulatpur in Khulna are posing threat to the environment continuously polluting air, water and soil of the areas. Local physicians claim people of the Khalishpur and Daulatpur industrial area which are affected by water pollution caused by the industrial units. A recent report said, there were 58 industrial units in this area in 2001. But now, there about 350 industrial units in the region. Among them, 230 including jute mills, power plants, soyabean mills, shirmp processing units and cement factories are on the banks of the Bhairab River. The major industries in Khulna are Shipyard, Koraeshi Steel Mill, Bangladesh Match Factory, Dada Match Factory, Khulna Textile Mill, News Print Mill, Hard Board Mill, Daulatpur Jute Mill, Platinum Jute Mill, Crescent Jute Mill, Peoples Jute Mill, Star Jute Mill, Senhati Re-rolling Mill, Jute Press, Anser Flour Mill, Ajax Jute Mill, Sonali Jute Mill, Mohsin Jute Mill, Cables Facory, Twin Mill, Afil Jute Mill, Eastern Jute Mill, Alim Jute Mill. More than 22 shirmp processing factories are also polluting the environment of Khulna areas. Chemical wastes and bleaching powder disposed by the industries and plants are polluting water and soil to a great extent. There are a number of factories in the district such as Sigma Sea Foods Ltd., Lockpur Fish Processing Co. Ltd., Bionic Fish Processing Ltd. International Shirmps Export (Pvt.) Ltd., Salam Sea Foods Ltd. and Modern Sea Food Industries Ltd. Oil pollution affects different species of organisms in different ways. The thin layer of oil on water reduces the light penetration and exchange of oxygen and carbon dioxide across the air-sea interface and causing depletion of dissolved oxygen. It is reported that fish eggs and larvae are killed at a concentration ranging from 10-5 to 10-3 ml/L of oil (Texascenter, 1992).

2.3.1 Surrounding Land Uses

The study area is located starting from administrative area of Khulna City Corporation to Noapara. Some industrial setting, government office, Hat-Bazar is operating near the surrounding area. Agricultural activities are available at far and near of the study region.

2.3.2 Climate

Bangladesh has a tropical climate having three main seasons, the hot and humid summer, the rainy season and the mild and relatively dries winter. In the rainy season the river experienced high upstream flow. Spring and autumn are brief but can be distinguished by changes in vegetation. Winter shows its presence by falling temperature. However, the study area falls under the south-western climate zone of the different climate zone classified by Rashid (1997).

2.3.3 Temperature

Mean annual temperature of Khulna is about 26.3^0 C (79.3^0F) and monthly means varying between 12.4^0 C (54.3^0F) in January and 34.3^0 C (93.7^0F) in May.

2.3.4 Humidity

Khulna is humid during summer and pleasant in winter. The humidity of the area is higher throughout the year. Average annual relative humidity of Khulna is 76 percent. March and April are the least humid months over most south-western part of Bangladesh.

2.3.5 Rainfall

There are three main sources of rainfall in Bangladesh western depression in winter, early summer thunderstorms and the summer rains (monsoon).Average annual rainfall of Khulna is 1809.4 mm (71.24 inch). Approximate 87 percent of the annual average rainfall occurs between May and October.

2.4 River System

Khulna city area is bounded by the river of Bhairab on the northeast, Rupsha on the southeast and Pasur in further down south. The Atharobanki river meets with Rupsha and the Atai river meets with the Bhairab river on the central east and Mayuri river while Hatia river lie on the west. These rivers are virtually the distrubutaries of Ganges river which carry sediments from upstream. The rivers also experienced semi-diurnal floods tide from the Bay of Bengal. The Rupsha-Bhairab-Pasur are the active tidal rivers with strong current which carries coarser sediments from upstream and finer sediments mainly clay from downstream by flood tide. Semi-diurnal tides with a tidal period of about 12 hours 25 minutes are predominant in the Bay of Bengal. The tidal range at the coast is strong, ranging from 0.27 m at neap tide to 3.38 m at spring tide (BIWTA,2006) and influenced the estuary. The area is blessed with a warm tropical climate and sufficient rainfall which enable to support a wide biological diversity. The main river of the study area is Bhairab from Rupsha ghat to Noapara Ghat.

Bhairab (latitude N 23° 34' 27.804" and longitude E 88° 44' 36.744") River system flow the South of Bangladesh as shown in Figure 2.1. It originates from Tengamari border of Meherpur district and passes through Narail, Jessore town and Khulna area. After being finished long journey the Bhairab River falls Rupsha River at Jailkhana ghat Khulna town. The river is approximately 100 mile long in its tortuous course and 300 feet in wide including an average depth 4 to 5 feet with minimal water flow. It is tidal-influenced but a stable river. Bhairab River divided Khulna city into two parts. The towns of Khulna and Jessore are situated on the bank of this river. The development of their settlements and culture were influenced by the river (BIWTA, 2006).

Bhairab River is an important river in the moribund delta area. In the monsoon, the Ganges feeds it, but in the dry season it becomes dry. Its lower course remains navigable throughout the year and is influenced by tides.

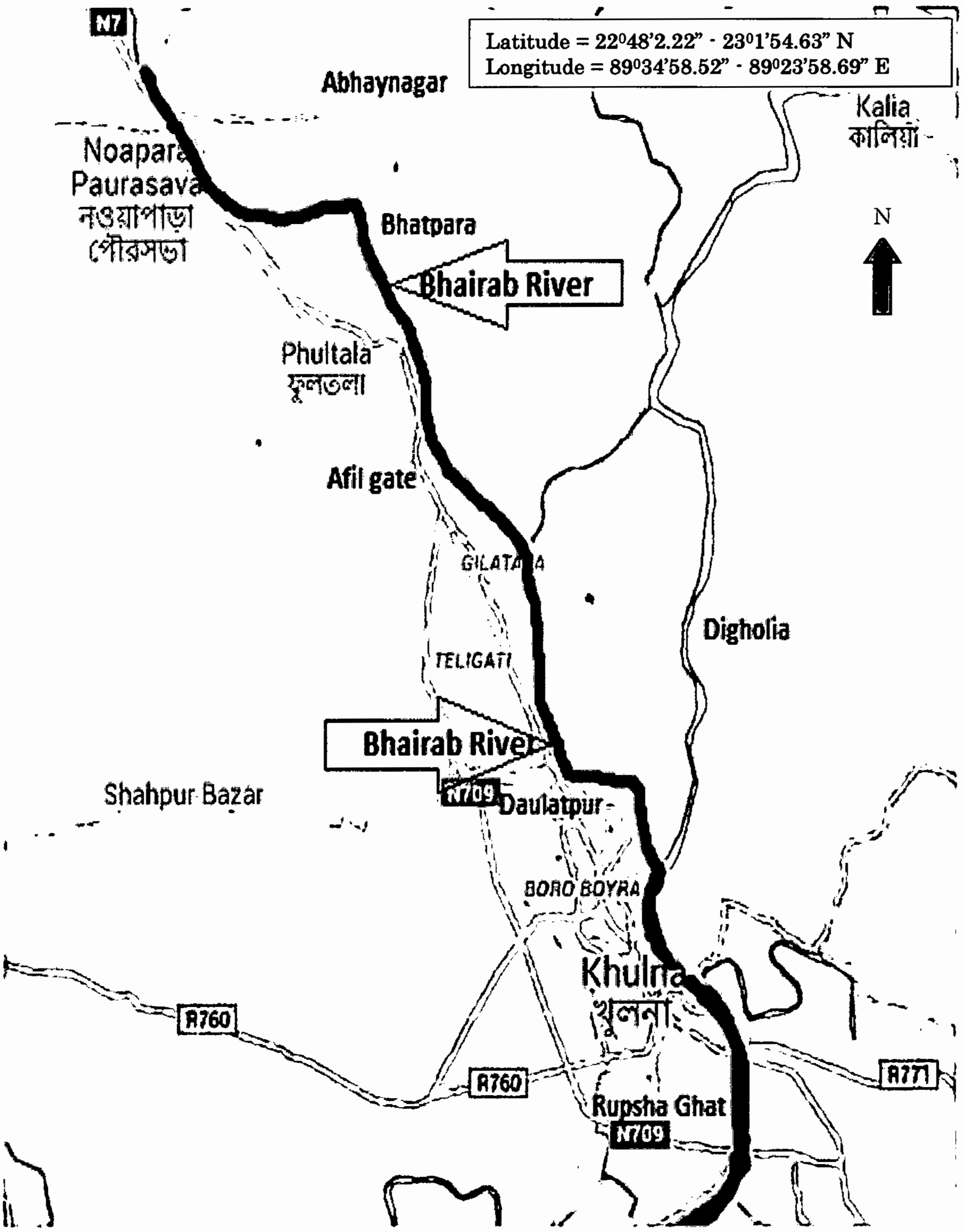

Figure 2.1 Geographical location of Bhairab River (Source: Google map)

2.5 Water Quality Parameters

Description of twenty water quality parameters includes definition, sources, factors affecting the parameter and its effect on surrounding.

2.5.1 Temperature

Temperature is an important part of a river's ecology that is relatively easy to measure and has a direct impact on the organism living in the water. Water temperature is a controlling factor for aquatic life. Water bodies will naturally show changes in temperature seasonally and daily even hourly. The temperature of a body of water influences its overall quality as it can harm aquatic organisms if it is beyond the normal range. Temperature changes could indicate thermal pollution. Shade is important to the health of the water body as it reduces the warming effect of direct sunlight. Deep water body usually is colder than shallow. Fish and most aquatic organisms are cold-blooded and require specific temperatures. Consequently, their metabolism increases as the water warms and decreases as it cools. Cold-blooded animals can't survive temperature below 0°C (32° F) and above 30°C; a suppression of all benthic organisms can be expected. Fish can sense very slight temperature differences. Fish migration often is linked to water temperature.

Warm water also makes some substances, such as cyanides, phenol, xylene and zinc, more toxic for aquatic life. If high water temperatures are combined with low dissolved oxygen levels, the toxicity is increased (WQ test summary, 1999).

Source: Industrial effluents, agriculture, forest harvesting, urban developments, mining.

Factors Affecting Water Temperature

- Air temperature
- Amount of shade
- Turbidity and storm water runoff.
- Water quantity and velocity of the stream.
- If any foreign materials is added to the water body.
- Thermal pollution

Effect of Water Temperature

- Solubility of dissolved oxygen and salinity in cold water is more than warm.
- Increased water temperature can cause increase in the photosynthesis rate of aquatic plants and algae which can lead to increase plant growth and algal blooms.
- Affect ability of fish to reproduce.
- It controls the rate of metabolic activities, reproductive activities and therefore, life cycles.
- If the water becomes too hot or too cold organisms become stressed, lowering their resistance to pollutants, diseases and parasites.

2.5.2 pH

The pH of natural water can provide important information about many chemical and biological processes provides indirect correlations with a number of different impairments. pH value of water is determined by the relative concentrations of H^+ ion and OH^- ion. Water with a pH of 7 has equal concentrations of H^+ ion and OH^- ion and is considered to be a neutral solution. pH is expressed in a scale with range from 1 to 14. A pH less than 7 is acidic and greater than 7 represents base saturation (WQ test summary, 1999).

Factors that Affect pH Level

- Acidic rainfall reduces pH value.
- Algal blooms generally cause water to be more basic.
- Level of hard water minerals
- Industrial process are released whether acids or bases
- Release of detergents into water.
- Carbonic acid from respiration or decomposition.
- Oxidation of sulphides in sediments is generally more acidic.

2.5.3 Turbidity

Turbidity is a measure of the optical property of a water sample that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. It is also a measure of water's lack of clarity and closely related to suspended sediment. Water the cloudier, higher the turbidity. Turbidity is measured in Nephelometric Turbidity Unit (NTU). Water is visibly turbid at levels above 5 NTU.

Causes of Turbidity

- Suspended particles can be clay, silt, finely divided organic and inorganic matter.
- Soil erosion, dredging and urban runoff
- Disposal of industrial waste
- Organic matter such as microorganism, phytoplankton, algae, decaying plants and animals.

Effect of Turbidity

- Reduce water clarity
- Aesthetically unpleasant
- Decreases rate of photosynthesis
- Increase water temperature
- Clog the gills of fish and shellfish.
- Lower dissolved oxygen

Turbidity Effect on Fish and Aquatic Life

Water plants need light for photosynthesis. If suspended particles block out light, photosynthesis and production of oxygen for fish and aquatic life will be reduced. If light levels get too low, photosynthesis may stop altogether and algae will die. It is important to realize that reduce photosynthesis in plant results in lower oxygen concentrations and large carbon dioxide concentrations. Large amount of suspended matter may clog the gills of fish and shellfish and kill them directly. Suspended particles may provide a place for harmful microorganisms to lodge. Fish can't see very well in turbid water and so may have difficulty finding food. Plankton density is a function of water turbidity. Turbidity in pristine water apparently comes from the healthy plankton population itself, an excellent food source for many fish (WQ test summary, 1999).

2.5.4 Conductivity

Solids can be found in nature in a dissolved form. Salts that dissolve in water break in positively and negatively charged ions. Conductivity is the ability of water to conduct an electrical current, and the dissolved ions are the conductors. Conductivity is a measure of how well water can pass an electrical current. It is an indirect measure of the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, iron and aluminum. The presence of these substances increases the conductivity of a water body. It is also measure of Total Dissolved Solids (TDS) or salinity. The salinity is quantified as the total concentration of soluble salts and is expressed in terms of electrical conductivity. Like other many parameters, electrical conductivity is highly temperature dependent, and also has a negative effect on dissolved oxygen concentrations available for aquatic life. Significant increases in conductivity may be an indicator that polluting discharges have entered the water. Unit of electrical conductivity is microsiemens per centimeter (μS/cm). For stream range 50 to 1500 μS/cm. Distilled water conductivity is zero.

Sources:

- Majorly Intrusion of sea water
- Fertilizer run-off
- Minerals and salts from urban rain water runoff
- Local geology and soils
- Municipal waste water
- Industrial discharge

Effect of Water Conductivity

- Concentration of dissolved salts that are outside the normal parameters can stress or cause die of aquatic life.
- Affect used for irrigation or drinking
- Specific conductivity may be used to estimate the total ion concentration of the water.

2.5.5 Color

Color is vital as most water users, be domestic or industrial. True color is caused by materials in solution or a colloidal state and should be distinguished from turbidity (apparent color caused by turbidity). Apparent color is the color of whole water sample, and consists of color from both dissolved and suspended components. True color is measured after filtering the water sample to remove all suspended materials.

Source/Causes of Color

- Dyes derived from decomposing vegetation, other organic waste and highly colored industrial process.
- Suspended materials affect the color of water in seas lakes and rivers.
- Green algae in rivers and stream often lend a blue-green color to the water.
- Iron and manganese can also impart color. Reddish tints from iron and blackish tints from manganese are natural and harmless.
- A yellowish tint to the water potentially dangerous. Yellow tea color water is indicative of organic material in the water.
- Pink water comes from potassium permanganate ($KMnO_4$).

Effect of Water Color

- Appearance/aesthetic
- Discolor clothing
- Affect industrial process.

2.5.6Alkalinity

Alkalinity is not a pollutant. It is a total measure of substances in water that have acid neutralizing ability. On the other words alkalinity is a measure of the resistance of water to a change in pH. Alkalinity indicates a solution's power to react with acid and "buffer" its pH. Alkalinity is important for fish and aquatic life because it protects or buffers against pH change. Alkalinity is typically reported as mg/L as $CaCO_3$. Total alkalinity is defined as the equivalent sum of the bases that are titrationble with strong acid.

Sources:

- The sources of natural alkalinity are rocks, which contain carbonate, bicarbonate and hydroxide compounds. Borate, silicates and phosphate may also contribute to alkalinity.

Effect of Alkalinity

- Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater.
- It is one of the best measures of the sensitivity of the stream to acid inputs.

2.5.7 Hardness

The hardness of a water is govern by the content of calcium and magnesium salt. Total hardness is the sum of calcium and magnesium hardness. On average, magnesium hardness representing about 1/3 of total hardness and calcium hardness represents about 2/3 of total hardness. Total hardness is express as equivalent $CaCO_3$.

Temporary Hardness

Temporary hardness is caused by the presence of dissolved calcium and magnesium bicarbonate minerals. These minerals yield Ca^{2+}, Mg^{2+} cations and CO_3^{2-}, HCO_3^- anions. The presence of metal cations makes the water hard. Temporary hardness can be reduced by boiling.

Permanent Hardness

Presence of calcium sulfate and/or magnesium sulfate in the water causes permanent hardness. Ions causing permanent hardness of water can't be removed by boiling.

Calcium Hardness ($CaCO_3$)

- Soft 0-20 mg/L
- Moderately soft 20-40 mg/L
- Moderately hard 40-80 mg/L
- Hard 80-120 mg/L
- Very hard >120 mg/L

Problems of Hard Water

- Hard water is soap-consuming and causes soap curd
- It form scale in hot water tanks, kettles, piping systems etc.
- Reduce heating efficiency of boilers by forming of insoluble encrustation.
- Leads to galvanic corrosion.
- It can also foul some water treatment system such as distillers and reverse osmosis.

2.5.8 Total Solids

Total solids are dissolved solids plus suspended and settleable solids in water. In stream water, dissolved solids consist of calcium, chlorides, nitrate, phosphorus, iron, sulfur, and other ions particles that will pass through a filter with pores of around 2 microns (0.002 cm) in size. Suspended solids include silt and clay particles, plankton, algae, fine organic debris, and other particulate matter. These are particles that will not pass through a 2 microns filter. Settleable solids refer to material of any size that will not remain suspended or dissolved in a holding tank. Total solids are related to both conductivity and turbidity. Total solids are measured in milligrams per liter (mg/L).

Sources:

- There are six major types of total solids; silt, clay, soil runoff, plankton, industrial waste and sewage.

Effect of Total Solids in Water

- Total solids also affect water clarity. Higher solids decrease the passage of light through water, thereby slowing photosynthesis by aquatic plants. Water will heat up more rapidly and hold more heat; this, in turn, might adversely affect aquatic life that has adapted to a lower temperature regime
- The concentration of total dissolved solids affects the water balance in the cells of aquatic organisms
- A high concentration of total solids will make drinking water unpalatable and might have an adverse effect on people who are not used to drinking such water. Levels of total solids that are too high or too low can also reduce the efficiency of wastewater treatment plants, as well as the operation of industrial processes that use raw water

2.5.9 Total Dissolved Solids (TDS)

Total dissolved solids is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular suspended form. Generally the operational definition is that the solids must be small enough to survive filtration through a filter with two-micrometer pores. Dissolved solids in freshwater include soluble salts that yield ions such as Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, or Cl^-. Total dissolved solids are sometimes used as a "watchdog" environmental test. Most aquatic ecosystems involving mixed fish fauna can tolerate TDS levels of 1000 mg/L (WQ test summary, 1999).

Sources

- Hard water ions - Ca^{2+}, Mg^{2+}, HCO_3^-
- Fertilizer in agricultural runoff - NH_4^+, NO_3^-, PO_4^{3-}, SO_4^{2-}
- Urban runoff - Na^+, Cl^-
- Salinity from minerals or returned water from irrigation - Na^+, K^+, Cl^-
- Acidic rainfall – H^+, NO_3^-, SO_3^{2-}, SO_4^{2-}

Effect of Total Solids in Water

- If TDS levels are high, especially due to dissolved salts, many forms of aquatic life are affected. The salt acts to dehydrate the skin of animals and high concentrations of dissolved solids can add a laxative effect to water or cause water to have an unpleasant mineral taste.
- High TDS level generally indicate hard water, which can cause scale buildup in pipes, valves, and filters reducing performance and adding to system performance costs.
- Spawning fishes and juveniles appear to be more sensitive to high TDS levels.

2.5.10 Suspended Solids

Suspended solids refer to small solid particles which remain in suspension in water as a colloid or due to the motion of the water. Suspended solids include silt and clay particles, plankton, algae, fine organic debris, and other particulate matter. These are particles that will not pass through a 2-micron filter. Suspended solids are important as pollutants and pathogens are carried on the surface of particles. The smaller the particle size, the greater the total surface area per unit mass of particle, and so the higher the pollutant load that is likely to be carried out.

Causes

- Silt, clay, soil runoff, zooplankton, plankton, industrial waste and sewage.
- Sediment which is generally negatively charged attracts positively charged molecules. Some of these molecules (phosphorus, heavy metals, and pesticides) are pollutants.

Effect of Suspended Solids in Water

- Large volume suspended reduces photosynthesis activity of phytoplankton, algae, and macrophytes. This leads fewer food sources for many invertebrates and decrease fish population.
- Some zooplankton suffer decline due to clogged feeding mechanisms. Likewise, fish may suffer clogging and abrasive damage to gills and other respiratory surfaces.
- The setting of suspended solids from turbid waters threatens benthic aquatic communities.
- Sediment deposition may also affect the physical characteristics of the stream bed.
- Increased sediment may impact plant communities because of less light penetration, abrasion, scouring and burial.
- Suspended solids are important as pollutants and pathogens are carried on the surface of particles. The smaller the particle size, the greater the total surface area per unit mass of particle, and so the higher the pollutant load that is likely to be carried.

2.5.11 Phosphate

A small amount of phosphorus is an essential nutrient for all aquatic plants and algae but in high levels, phosphorus can be considered a pollutant. Phosphorus concentration determines the level of eutrophication. Phosphorus in surface water is in the form of phosphates. Phosphate that is bound to plant or animal tissue is known as organic phosphate. Phosphate that is not associated with organic material is known as inorganic phosphate. Inorganic phosphate is often referred as orthophosphate or reactive phosphorus. It is the form most readily available to plants, and thus may be the most useful indicator of immediate potential problems with excessive plant and algal growth. Plant growth can be stimulated by levels above 0.1 mg/L (WQ test summary).

Most Common Source of Phosphorus

- Human and animal waste- from detergent, sewage and excrement from animals. (Organic phosphate)
- Industrial waste- condensed phosphate
- Agricultural waste- fertilizer contain high level of phosphate
- Human disturbance of land- clearing or disturbing of land vegetation increases erosion on more phosphates being washed out of the soil.

High Levels of Phosphates Results in

- Eutrophication
- Increase algal bloom thus increased BOD.
- Decreased dissolved oxygen.

2.5.12 Nitrite

Nitrite is extremely toxic to aquatic life, however, is usually present only in trace amounts in most natural freshwater systems because it is rapidly oxidized to nitrate by bacteria. Nitrite is usually indicator of direct contamination by sewage or manure because nitrites are unstable and quickly be transformed into nitrates suggesting that a current an ongoing source of fecal contamination is present. Nitrates and nitrites are considered together in water analysis interpretation.

Source

- Nitrite and nitrate are forms of the element nitrogen.

Effect of Nitrite in Water:

- Nitrites produce a serious illness (brown blood diseases) in fish even though they don't exist for very long in the environment.
- Nitrites also react directly with hemoglobin in human blood to produce methemoglobin, which destroys the ability of blood cells to transport oxygen especially babies. It is known as "blue baby disease".

2.5.13 Nitrate

Nitrates are an important protein source of nitrogen necessary for plants and animals to synthesize amino acids and proteins. Nitrogen is abundant on earth, making up about 80% of our air as N_2 gas. Most plants cannot use it in this form. However, blue-green algae and legumes have the ability to convert N_2 gas into nitrate (NO_3^-), which can be used by plants. Plants use nitrate to build protein, and animals that eat plants also use organic nitrogen to build protein. When plants and animals die or excrete waste, this nitrogen is released into the environment as NH_4^+ (ammonium). This ammonia is eventually oxidized by bacteria into nitrite (NO_2^-) and then into nitrate. In this form it is relatively common in freshwater aquatic ecosystems. Nitrate thus enters streams from natural sources like decomposing plants and animals waste as well as human sources like sewage or fertilizer. Natural levels of nitrate are usually less than 1.0 mg/L. Nitrite and ammonia are far more toxic than nitrate to aquatic life. Nitrates are a less serious environmental problem (WQ test summary).

Sources of Nitrate Ions

- Agricultural runoff
- Urban runoff
- Animal feedlots and stock yards
- Municipal and industrial wastewater
- Automobile and industrial emissions.
- Decomposition of plants and animals.

Effect of Nitrate in Water

- Nitrate levels above 10 mg/L in drinking water can cause potentially fatal disease in infants called blue baby syndrome.
- High nitrate concentration contributes to eutrophication.
- Unpleasant odor and taste of water.
- Algal bloom can occur with as little as 0.5 mg/L NO_3-N.

2.5.14 Chloride

Chloride, in the form of the Cl^- ion is one of the major inorganic anion in saltwater and freshwater. In drinking water salty taste produced by chloride depends on the concentration of the chloride ion. Water containing 250 mg/L of chloride may have a detectable salty taste if the chloride can form sodium chloride. The word chloride can also form part of the name of chemical compounds in which one or more chlorine atoms are covalently bonded. Chloride can be oxidized but not reduced.

Chloride is also a useful and reliable chemical indicator of river/groundwater fecal contamination, as chloride is non-reactive solute and ubiquitous to sewage and potable water. Many water regulating companies around the world utilize chloride to check the contamination levels of the rivers and potable water sources (WQ test summary, 1999).

Sources of Chloride Ions

- River or lake beds with salt-containing minerals
- Irrigation water returned to lakes /rivers
- Mixing of seawater with freshwater
- Chlorinated drinking water–often increases chloride levels
- Water softener regeneration-often increases chloride levels

Effect of Chloride in Water

- Saltwater organisms can survive in salinity levels up to 40000 ppm but many freshwater organisms cannot live in salinity level above 1000 ppm.
- The presence of chloride significantly aggravates the condition for pitting corrosion of most metals.
- Less water can be absorbed by the plant, causing stunted growth and reduced yields.

Salinity:

Salinity is the measure of total concentration, comprising mostly of Na^+ and Cl^- ions as well as small quantities of other ions (Mg_2^+, K^+ or SO_4^{2-}). It is the total of all non-carbonate salts dissolved in water. Conductivity is highly influenced by salinity.

The salinity of seawater is fairly constant, at about 35000 ppm.

- Highly saline water ranges from 10000 - 35000 ppm.
- Moderately saline water ranges from 3000 - 10000 ppm
- Slightly saline water ranges from 1000 - 3000 ppm
- Freshwater is less than 1000 ppm.

2.5.15 Dissolved Oxygen (DO)

Dissolved oxygen is essential to all forms of aquatic life including the organisms that break down man-made pollutants. Fish and aquatic animal cannot split oxygen from water but oxygen itself solutes in water and equilibrate with the oxygen in atmosphere. Virtually all the oxygen we breathe is manufactured by green plants. A total of three-fourths of the earth's oxygen supply is produced by phytoplankton in the oceans. Aquatic organisms have different DO requirements. Dissolved oxygen concentration can range from 0 to 15 mg/L based on the condition. Dissolved oxygen of freshwater at sea level will range from 15 mg/L at 0°C to 8 mg/L at 25°C. Concentration of unpolluted freshwater will be close to 10 mg/L at 15°C. Usually stream with high dissolved oxygen concentration (greater than 8 mg/L) are considered healthy streams (WQ test summary).

Sources of Dissolved Oxygen are

- Diffusion from the atmosphere and water at the surface.
- Aeration as water flows over rocks and uneven surface.
- Aeration through churning action of wind and waves.
- Photosynthesis from aquatic plants.

Concentration of DO is affected by

- Plant activity- DO level increase at day time when photosynthesis happens and decrease when photosynthesis ceases.
- Temperature- Cooler water has a greater capacity to dissolve oxygen than warmer one.
- Decaying organic matter in water- Decomposition releases heat, warming water decreases dissolved oxygen capacity.
- Stream flow- Faster the water moves and churns, the greater the amount of oxygen is dissolved.
- Atmospheric pressure- High altitudes and atmospheric pressure reduced DO capacity.
- Human activities-Removal of shade and releases of warm industrial water increase water temperature thus reduce dissolved oxygen.

Effect Dissolved Oxygen in Water

- DO level less than 3 mg/L are stressful to most aquatic organisms while most fish die at 1-2 mg/L.
- Fish can away from low DO areas.
- When the algae die, the organic matter is decomposed by bacteria. Bacterial decomposition consumes a great deal of oxygen.
- Water salinity also has an effect on dissolved oxygen levels, with higher saline reducing the availability of oxygen in the water.

2.5.16 Biochemical Oxygen Demand (BOD)

There is a significant relationship among organic matter, microbial population and finally with the dissolved oxygen content in water. Aerobic microbes need oxygen for their metabolism. They use dissolved oxygen and convert organic matter into energy. They utilize the provided energy from organic food, for their further metabolic reactions and especially for their reproduction. The population density is increasing with respect to the gained energy. But it depends on the available food content. This metabolic requirements for the newly created population, again creates a demand for the dissolved oxygen, which is proportional to the available food.

Therefore, the biochemical oxygen demand can be defined as the amount of dissolved oxygen required by aerobic organisms, to breakdown organic materials, in order to obtain energy for their metabolism. This value should be tested under given temperature for a given period of time, and will be depend on the nutrient concentration and enzymatic reactions too. High BOD is an indicator of poor quality.

Unpolluted, natural waters should have a BOD of 5 mg/L or less. Raw sewage may have BOD levels ranging from 150-300 mg/L (1991, Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods).

Sources of BOD

- Increased BOD can be resulted due to domestic sewage, petroleum residues and wastes of animal and crops.

Importance of BOD:

- BOD can be used as a gauge of the effectiveness wastewater treatment plant.
- It directly measures the pollution loading of wastewater and water.

2.5.17 Chemical Oxygen Demand (COD)

Chemical oxygen demand is the total measurement of all chemicals in the water that can be oxidized by strong chemical oxidant. Generally potassium dichromate ($K_2Cr_2O_7$) is used as oxidant. It includes both organic and inorganic substances. Ammonia will not be oxidized as COD.

COD is usually measured and the test is simple and easy to perform with the right equipment and can be done in two hours.

Sources of COD:

- Increased COD can be resulted due to domestic sewage, petroleum residues and wastes of animal, industrial effluent and crops.

Importance of COD:

- Generally, COD is preferred to BOD for process control measurements because results are more reproducible and are available in just two hours rather than five days.
- COD is a quick and easy measurement to get a snap in time picture of what is going on.
- For industrial samples, COD may the only feasible test because of the presence of bacterial inhibitors or other chemical interferences.

2.5.18 Manganese

Manganese is a naturally occurring element that can be found ubiquitously in the air, soil, and water. Manganese is an essential nutrient for humans and animals. Adverse health effects can be caused by inadequate intake or over exposure. Manganese deficiency in humans is thought to be rare because manganese is present in many common foods. Manganese compounds are less toxic than those of other widespread metals, such as nickel and copper. The greatest exposure to manganese is usually from food. Adults consume between 0.7and 10.9 mg/day in the diet, with even higher intakes being associated with vegetarian diets (Freeland-Graves *et al.*, 1987; Greger, 1999; Schroeder *et al.*, 1966).

Sources of Manganese

- Manganese is almost entirely excreted in the feces
- Air, soil and water.
- Manganese makes up about 1000 ppm (0.1%) of earth's crust, making it the 12th most abundant element there.

Effect of Manganese

- Although manganese is an essential nutrient at low doses, chronic exposure to high doses may be harmful.
- Manganese poisoning has been linked to impaired motor skills and cognitive disorders.
- Waterborne manganese has a greater bio-availability than dietary manganese.
- Higher level of exposure to manganese in drinking water are associated with increased intellectual impairment and reduced intelligence quotients in school-aged children

2.5.19 Fecal Coliform (FC)

Coliform are defined as rod shaped gram-negative non-spore forming bacteria which can ferment lactose with the production of acid and gas when incubated at 35-37°C.

Fecal coliform are a subset of the coliform group that are found in the intestinal tract of humans and other warm-blooded animals. The origins of fecal coliform are more specific than the origin of the more general total coliform group of bacteria, fecal coliform are considered a more accurate indication of animal or human waste than the total coliform. Fecal coliform bacteria are 6 species that are found in animal wastes and human sewage. Fecal coliform analysis is the best practical indicator of the presence and/or absence of pathogenic organisms. Coliform are a reasonably good indicator of pathogen.

Escherichia Coli (E-Coli)

Presence of E-coli indicates that the water has been exposed to feces and an immediate risk to human health exists. E-coli is a species of coliforms bacteria that is directly linked to fecal contamination by the wastes of warm-blooded animals including humans. The presence of E-coli in water is a strong indication of recent sewage animal waste contamination. E-coli and fecal coliform are not usually pathogenic, but their presence can indicate sewage contamination, perhaps accompanied by disease-causing pathogens (virus, protozoa). E-coli is regarded as the best biological drinking water indicator.

Sources of Coliform

- Lower intestine of warm blooded animal, including wildlife, farm animals, pets, and human and are excreted in their feces.
- Wastewater, sludge, septage or biosolids.

Problems

- Pathogen can cause disease such as gastroenteritis, ear infection, typhoid, dysentery, hepatitis A, and cholera.

2.5.20 Total Coliform (TC)

Total coliform including Escherichia coli are used world-wide as an indicator for fecal pollution. Total coliform bacteria are 16 species that are found in soil, vegetation, animal waste and human sewage. Total coliform bacteria consist of environmental and fecal types. TC has limited use as indicator of fecal pollution because TC may multiply in warm tropical climate. Total coliform is the sum of non-fecal and fecal coliform.

Sources of Total Coliform:

- Lower intestine of warm blooded animal, including wildlife, farm animals, pets, and human and are excreted in their feces.
- Wastewater, sludge, septage or biosolids.
- Non-fecal coliform comes from soil and vegetation.

Effect of Total Coliform:

- Pathogen can cause disease such as gastroenteritis, ear infection, typhoid, dysentery, hepatitis A, and cholera.

2.6 Some Important Correlation among Water Quality Parameters.

Water quality parameters correlate due to their own physical, chemical and biological properties. But the correlation coefficient and causes of correlation are different. Some important water quality parameter pairs are discussed here.

2.6.1 Temperature with Conductivity

Electrical conductivity of the water depends on the temperature of water and their correlation is generally nonlinear. (Millero, 2001, p.303). However, the degree of nonlinearity is relatively small in a temperature range 0-30 ^{0}C. They are positively correlated with each other. The higher the temperature, the higher the electrical conductivity would be. The electrical conductivity of water increases by 2% for an increase of 1 degree Celsius of water temperature (Masaki, 2003).

2.6.2 Total Dissolved Solids with Electrical Conductivity (EC)

The relationship between electrical conductivity and total dissolved solids is complex depending on the chemical composition and ionic strength (Masaki, 2003). Conductivity is open used as an estimate of total dissolved solids content of water samples. Sodium chloride dissociated as ions in water that ions worked as a conductor. For this reason, TDS correlates with conductivity. Generally TDS (mg/L) = 0.67 x EC (μS/cm) but the coefficient varies from 0.55 to 0.90.

2.6.3 Temperature with Total Dissolved Solids

Temperature shows positively correlation with TDS. Temperature increases solubility of water up to a certain limit. Thus warmer the water increases total dissolved solids. (WQ test summary, 1999).

2.6.4 Temperature with Dissolved Oxygen

The solubility of oxygen decreases as water temperature increases. The maximum solubility of oxygen in water range 15 mg/L at 0^0 C to 8mg/L at 30^0 C. So, temperature and dissolved oxygen are negatively correlated with each other (WQ test summary, 1999).

2.6.5 TDS with chloride

Chloride goes on water in dissolved forms. As the temperature rise in water raises solubility up to a saturated limit. Thus chloride positively correlates with total dissolved solids in a strong manner. In the coastal river water contains high chloride that results excessive TDS in water.

2.6.6 Turbidity with Suspended Solids

Turbidity is directly correlated with suspended solids in water. Floating or suspended particles are the key causes of turbidity. Turbidity is positive and strongly correlated with suspended solids. As suspended solids increase linearly increase turbidity (WQ test summary, 1999).

2.7 Surface Water Pollution

Water pollution is the pollution or contamination of natural water bodies like lakes, rivers, streams, oceans, and groundwater due to inflow or deposition of pollutants directly or indirectly into water systems. Water pollution very often caused by human activities. Any modifications or change in the chemical, physical and biological properties of water that can cause any harmful consequences on living things in the environment is known as water pollution.

Sources of water pollution, particularly surface water pollution are group under two categories based on the origin of the pollutant.

2.7.1 Point Source Pollution

Water pollution caused by point sources refers to the contaminants that enter the water body from a single, identifiable source like pipe or ditch. Point source pollutants can be discharges from sewage treatment plant, factories or a city storm drain.

2.7.2 Non-point Source Pollution

Pollution caused by non-point sources refers to the contamination that does not originate from a single source. Non-point source pollution is the cumulative effect of small contaminants gathered in large area. Leaching of nitrogen compounds from agricultural land, storm water runoff over an agricultural land or a forest are examples of non-point source pollution.

2.7.3 Pollutants

A substances or condition that contaminates air, water or soil. Pollutants can be artificial substances such as pesticides and PCBs or naturally occurring substances, such as oil or carbon dioxide that occur in harmful concentrations in a given environment. Heat transmitted to natural waterways through warm-water discharge from power plants and uncontained radioactivities from nuclear wastes are also considered pollutants (Water pollutants, Buriganga, 2013).

Table 2.1 Major Water Pollutions, Pollutants, Sources and their Effects.

Sl no	Types of Pollution	Pollutants	Sources	Effects
1	**Industrial waste:** Industries produce huge amount of waste which contains toxic chemicals and other pollutants and damage our environment. Many industries do not have proper waste management system and it drains the waste into rivers, canals and finally in sea.	Lead, mercury, sulpher, asbestos, nitrates, petrochemicals.	Different types of small and large industries as well as factories.	-Contain toxic chemicals - Increase minerals -Causes eutrophication -Raise temperature -Hazard for water organisms. -Discoloration of water
2	**Sewage and wastewater:** The sewage and wastewater that is produced by each household. The sewage water carries harmful bacteria and chemicals that can cause serious health problems. Pathogens are known as a common water pollutant.	Virus, protozoa, parasites, Malaria/ germs, nutrient substances.	Household, factories, commercial institutions.	-Causes pathogenic diseases - Serious health problem -Hazard for water organisms.
3	**Mining activities:** Mining is the process of crushing the rock and extracting coal and other minerals from underground. These elements when extracted in the raw form contain harmful chemicals and can increase the amount of toxic elements when mixed up with water.	Coal, minerals, sulphides.	From underground mines.	-Raw extraction contains harmful chemicals and can increase toxic elements. - Mining activities emit metal wastes.
4	**Marine dumping:** The garbage produces by each household in the form of paper, aluminium, rubber, glass and plastic. These items take from two weeks to two hundred years to decompose.	Paper, aluminium, rubber, glass, plastics.	Household, ship industries.	-It takes long time to decompose. -Harmful for sea animals
5	**Accidental Oil leakage:** Oil spill pose a huge concern as large amount of oil enters into the sea and does not dissolve with water. A ship carrying large quantity of oil may spill oil if met with an accident and can cause varying damage to species in the ocean depending on the quantity of oil spill, size of ocean and toxicity of pollutant.	Grease, oil, petrol, diesel, kerosene.	Submerge of oil tanker, road runoff, leaking oil pipelines.	-It does not dissolve in water. -Oil products tend to accumulate at the surface of water and cause problem for fish, birds and sea otters. - Some oil could be irritants to the skin.
6	**Burning of fossil fuels:** Fossil fuels like coal and oil when burnt produce substantial amount of ash in the atmosphere. The particles which contain toxic chemicals when mixed with water vapor result in acid rain.	Carbon, coal, petroleum, natural gas. and also nitrogen oxides,	Fossil fuels are continually being formed in natural processes	-Form acid rain -CO_2 is released from burning of fossil fuels which result in global warming. -Increase greenhouse gas.

Sl no	Types of Pollution	Pollutants	Sources	Effects
		sulfur dioxide, heavy metals etc.		
7	**Chemical fertilizers and pesticides:** Chemical fertilizers and pesticides are used by farmers to protect crops from insects and bacteria. They are useful for the plants growth. When it rains, the chemicals mixes up with rainwater and flow down into ponds, canals and rivers.	Fertilizer, pesticides, herbicides, plant debris.	Farms, crops land, stockpiling, animal feedlots.	-Encourage algal bloom known as eutrophication. -Reduce dissolved oxygen -Serious damage of aquatic animals.
8	**Leakage from sewer lines:** A small leakage from the sewer lines can contaminate the underground water, when not repaired on time; the leaking water can come on to the surface and become a breeding ground for insects and mosquitoes.	Virus, protozoa, parasites, Malaria	Broken or damaged sewer pipes, defective pipe joint.	- Contaminate both ground and surface water -Causes pathogenic diseases - Serious health problem -Hazard for water organisms
9	**Global warming:** An increase in earth's temperature due to greenhouse effect results in global warming. It increases the water temperature and result in death of aquatic animals and marine species which later results in water pollution.	Water vapor, carbon dioxide, methane, nitrous oxide, ozone, CFCs etc.	Emission of greenhouse gas from industries, burning fossil fuels.	-Increasing temperature -Death of aquatic animal and marine species. -Sea water level rising for melting ice cores.
10	**Radioactive wastes** - Mining and ores processing, power plants, and weapons production rise to radioactive pollution like that of uranium, thorium, cesium, iodine and radon. Nuclear energy is produced using nuclear fission or fusion.	Uranium, thorium, cesium, radon.	Nuclear and coal-burning power plant, mining, ores possessing, nuclear weapon production.	-At high enough concentrations it can kill, in lower concentration it can cause cancers and other illness. -Genetic mutations. -Birth defects.
11	**Urban development:** As population has grown, so has the demand for housing, food and clothes. More demand and waste are resulting from there and deteriorating environment and water quality.	Industrial and urban expansion related pollutants.	Industrial, Infra-structural	-Deforestation affects consuming CO_2. -more garbage produced, increase construction activities -Direct threat to high value ecology and reduce biodiversity.

Sl no	Types of Pollution	Pollutants	Sources	Effects
12	**Leakage from the landfills:** Landfills are nothing but huge pile of garbage that produces awful smell and can be seen across the city. When it rains, the landfills may leak and the leaking landfills can pollute the underground and surface water with large variety of contaminants.	Cardboard, plastics, glass, polythene Styrofoam, aluminium, tin and household waste etc.	Stockpile of household, institutional and industrial garbage.	-Direct streams of leachate severely diminish bio-diversity and greatly reduce populations of sensitive species. - Pathogenic microorganisms and toxic substance might be present.
13	**Animal waste:** The waste produce by animals is washed away into the rivers when it rains. It gets mixed up with other harmful chemicals and causes various water borne diseases.	Nitrogen and phosphorus	Household cattle, animal farm, cattle Hat-Bazar.	-It causes various water borne diseases. -It contains ammonia which is highly toxic to fish at low levels - Damage aquatic food chain
14	**Underground storage leakage:** Transportation of coal and other petroleum products through underground pipes is well known. Accidentals leakage may happen anytime and may cause damage to environment.	Coal, petroleum products such as kerosene, lubricant, mobil, gasoline.	Damage or broken underground oil storage, conveying leakage pipes.	-It does not dissolve with water. - It pollutes both surface and groundwater. - Some oil could be irritants to the skin
15	**Plastics.** They are a waste from industries, household and farms. They trigger organic pollution and are harmful to health.	Polythene, plastic bottle, gasoline, Synthetic compound.	Industrial effluent, Household cleaners, Hat-Bazar, farms.	Not biodegradable
16	**Alien species:** Alien species are animals or plants from one region that have been introduced into a different ecosystem where they do not belong. They have no natural predators, so they rapidly run wild, crowing out the usual animals or plants that thrive there.	Floating water hyacinth, dead animals.	Mostly non-native	-Hyacinth affects dissolved oxygen and water transparency. -Organic pollution. -Emit odor.
17	**Thermal pollution:** Thermal water pollution is the rise or fall in water temperatures. Some industries use water as cooling agent, the heated water is let-off directly into the natural environment at a higher temperature. Cold water pollution happens when cold water is released into the water bodies. Aquatic organisms like fish are vulnerable to slight changes in the temperature.	Hot water, Cold water.	Industrial effluent, water cooling from power plant, agriculture, mining etc.	-Rising temperature and reduce Dissolved oxygen (DO). -Reduced DO causes killing fish and other organism. - Control metabolic and reproductive activities. -Affect ability of fish to reproduce.

Sl no	Types of Pollution	Pollutants	Sources	Effects
18	**Suspended matter:** Substances, particles and chemicals do not dissolve in water easily. This kind of material is called particulate matter. Some suspended pollutants later settle under the water body. This can harm and even kill aquatic life that lives at the floor of the water bodies.	Silt, clay, soil, sediment, plankton, algae, organic matter, microorganism.	From urban runoff, industrial waste, land erosion, decaying plants and animals.	-Causes turbidity and decrease photosynthesis. - It can block the gills of fish, effectively suffocating them. -Increases water temperature. -Clog filters - Lower dissolved oxygen -Carry pesticides, bacteria and other harmful substances.
19	**Excessive nutrients:** Wastewater, fertilizers and sewage contain high levels of nutrients. The two most common nutrients are nitrogen and phosphorus	Nitrogen, phosphorus ammonium ions.	Sewage treatment plant, septic tank, runs off of fertilizer.	-It makes the water undrinkable - Grow too much algae -Depletion of oxygen -Microorganism dies out of oxygen starvation.
20	**PCBs:** PCBs or polychlorinated biphenyls are chemicals that used to be found in manufactured products such as inks, dyes, cooling electrical equipments. PCBs have long been suspected of causing severe life threatening illness.	Inks, dyes, plastics, pesticides.	Manufactured industry, leaking landfills, improper dumping.	-It poses severe life threatening illness such as cancer, liver damage and respiratory problems.

Sources: Water quality control handbook and others.

2.8 Ecology

Ecology is the scientific analysis and study of interactions among organisms and their environment. It is an interdisciplinary field that includes biology and earth science. It is the science of the relationships between organisms and their physical and chemical environments. By ecology, we mean the whole science of the relations of the organism to the environment including, in the broad sense, all the "conditions of existence." Ecology includes the study of plant and animal populations, plant and animal communities and ecosystems.

Although it includes the study of environmental problems such as pollution, the science of ecology mainly involves research on the natural world from many viewpoints, using many techniques. Modern ecology relies heavily on experiments, both in laboratory and in field settings. These techniques have proved useful in testing ecological theories, and in arriving at practical decisions concerning the management of natural resources.

An understanding of ecology is essential for the survival of the human species. Our populations are increasing rapidly, all around the world, and we are in danger of outstripping the earth's ability to supply the resources that we need for our long-term survival. Furthermore, social, economic and political factors often influence the short-term distribution of resources needed by a specific human population. An understanding of ecological principles can help us understand the global and regional consequences of competition among humans for the scarce natural resources that support us.

Ecology is a human science as well. There are many practical applications of ecology in conservation biology, wetland management, natural resource management (agro-ecology, agriculture, forestry, agroforestry, fisheries), city planning (urban ecology), community health, economics, basic and applied science, and human social interaction . Ecosystems sustain life-supporting functions and produce natural capital like biomass production (food, fuel, fiber and medicine), the regulation of climate, global biogeochemical cycles, water filtration, soil formation, erosion control, flood protection and many other natural features of scientific, historical, economic, or intrinsic value.

2.9 Human Ecology

The history of life on earth has been a history of interaction between living things and their surroundings. To a large extent, the physical form and the habits of the earth's vegetation and its animal life have been molded by the environment. Considering the whole span of earthly time, the opposite effect, in which life actually modifies its surroundings, has been relatively slight. Only within the moment of time represented by the present century has one species man acquired significant power to alter the nature of his world.

Ecology is as much a biological science as it is a human science. Human ecology is an interdisciplinary investigation into the ecology of our species. "Human ecology may be defined: (i) from a bio-ecological standpoint as the study of man as the ecological dominant in plant and animal communities (ii) from a bio-ecological standpoint as simply another animal affecting and being affected by his physical environment; and (iii) as a human being, somehow different from animal life in general, interacting with physical and modified environments in a distinctive and creative way. A truly interdisciplinary human ecology will most likely address itself to all three.

2.10 Physical Environment

Physical environment include water, gravity, pressure, wind and turbulence, fire, soils, biochemistry and climate.

2.10.1 Water

Diffusion of carbon dioxide and oxygen is approximately 10,000 times slower in water than in air. Aquatic plants exhibit a wide variety of morphological and physiological adaptations that allow them to survive, compete and diversify in the environments. Salt water plants have additional specialized adaptations. The activity of soil microorganisms and the chemistry of the water reduce the oxidation-reduction potentials of the water. Their gills form electrochemical gradients that mediate salt excretion in saltwater and uptake in freshwater.

2.10.2 Wind and Turbulence

Turbulent forces in air and water affect the environment and ecosystem distribution, form and dynamics. On a planetary scale, ecosystems are affected by circulation patterns in the global trade winds. Wind power and the turbulent forces it creates can influence heat, nutrient, and biochemical profiles of ecosystems. Wind speed and turbulence also influence evapotranspiration rates and energy budgets in plants and animals. Wind speed, temperature and moisture content can vary as winds travel across different land features and elevations.

2.10.3 Fire

Forest fires modify the land by leaving behind an environmental mosaic that diversifies the landscape into different stages and habitats of varied quality. Plants convert carbon dioxide into biomass and emit oxygen into the atmosphere. Fire releases CO_2 and converts fuel into ash and tar. Fire is a significant ecological parameter that raises many issues pertaining to its control and suppression.

2.10.4 Soil

Soil is the living top layer of mineral and organic dirt that covers the surface of the planet. It is the chief organizing center of most ecosystem functions, and it is of critical importance in agricultural science and ecology. The decomposition of dead organic matter, results in soils containing minerals and nutrients that feed into plant production. The whole of the planet's soil ecosystems is called the pedosphere. Tree roots, fungi, bacteria, worms, ants, beetles, centipedes, spiders, mammals, birds, reptiles, amphibians and other less familiar creatures all work to create the trophic web of life in soil ecosystems.

2.10.5 Biochemistry and climate

Ecologists' study and measure nutrient budgets to understand how these materials are regulated, flow, and recycled through the environment. This research has led to an understanding that there is global feedback between ecosystems and the physical parameters of this planet, including minerals, soil, pH, ions, water and atmospheric gases. Six major elements (hydrogen, carbon, nitrogen, oxygen, sulfur, and phosphorus; H, C, N, O, S, and P) form the constitution of all biological macromolecules and feed into the earth's geochemical processes.

2.11 River Ecology

Water flow is the key factor in influencing their river ecology. The strength of water flow can vary between systems, ranging from torrential rapids to slow backwaters. The speed of the water flow can also vary within a system and is subject to chaotic turbulence. This turbulence results in divergences of flow from the mean down slope flow vector as typified by eddy currents. The mean flow rate is based on variability of friction with the bottom or sides of the channel, obstructions, and the incline gradient.

2.11.1 Light

Light provides the energy necessary to drive primary production via photosynthesis, and can also provide refuge for prey species in shadows it casts. The amount of light that a system receives can be related to a combination of internal and external stream variables. Seasonal and diurnal factors might also play a role in light availability because the angle of incidence, the angle at which light strikes water can lead to light lost from reflection. Additional influences on light availability include cloud cover, altitude, and geographic position (Brown 1987).

2.11.2 Temperature

Most lotic species are whose internal temperature varies with their environment, thus temperature is a key abiotic factor for them. Water can be heated or cooled through radiation at the surface and conduction to or from the air and surrounding substrate. Shallow streams are typically well mixed and maintain a relatively uniform temperature within an area. In deeper, slower moving water systems, however, a strong difference between the bottom and surface temperatures may develop. The amount of shading, climate and elevation can also influence the temperature of lotic.

2.11.3 Chemistry

Water chemistry between systems varies tremendously. The chemistry is foremost determined by inputs from the geology of its watershed, or catchment area, but can also be influenced by precipitation and the addition of pollutants from human sources. In larger river systems the concentrations of most nutrients, dissolved salts, and pH decrease as distance increases from the river's source.

Oxygen is likely the most important chemical constituent of lotic systems, as all aerobic organisms require it for survival. It enters the water mostly via diffusion at the water-air interface. Oxygen's solubility in water decreases as water pH and temperature increases. Oxygen is a byproduct of photosynthesis, so systems with a high abundance of aquatic algae and plants may also have high concentrations of oxygen during the day. Oxygen can be limiting if circulation between the surface and deeper layers is poor.

2.11.4 Substrate

The inorganic substrate of river systems is composed of the geologic material present in the catchment that is eroded, transported, sorted, and deposited by the current. Typically, particle size decreases downstream because the higher gradients of mountain streams facilitate a faster flow, moving smaller substrate materials further downstream for deposition. Substrate can also be organic and may include fine particles, autumn shed leaves, submerged wood, moss, and more evolved plants.

2.11.5 Bacteria

Bacteria are present in large numbers in lotic waters. Free-living forms are associated with decomposing organic material, biofilm on the surfaces of rocks and vegetation, in between particles that compose the substrate, and suspended in the water column. Other forms are also associated with the guts of lotic organisms as parasites. Bacteria play a large role in energy recycling.

2.11.6 Primary producers

Algae, consisting of phytoplankton and periphyton, are the most significant sources of primary production in most streams and rivers. Phytoplankton floats freely in the water column and thus is unable to maintain populations in fast flowing streams. Plants exhibit limited adaptations to fast flow and are most successful in reduced currents. Rooted plants usually occur in areas of slackened current where fine-grained soils are found (Brown 1987).

2.11.7 Insects and other Invertebrates

Up to 90% of invertebrates in some lotic systems are insects. These species exhibit tremendous diversity and can be found occupying almost every available habitat, including the surfaces of stones, below the substratum and in the surface film. Some avoid high current areas, inhabiting the substratum or the sheltered side of rocks. Additional invertebrate common to flowing waters such as snails, limpets, clams, mussels, as well as crustaceans like crayfish and crabs.

CHAPTER THREE

METHODOLOGY

3.1General

This chapter describes the research strategy, baseline survey, selection of sampling stations, collection of water sample, laboratory test procedure with apparatus and water quality index calculation procedure etc.

3.2 Research Strategy

The chronological activities of this study are outlined below:

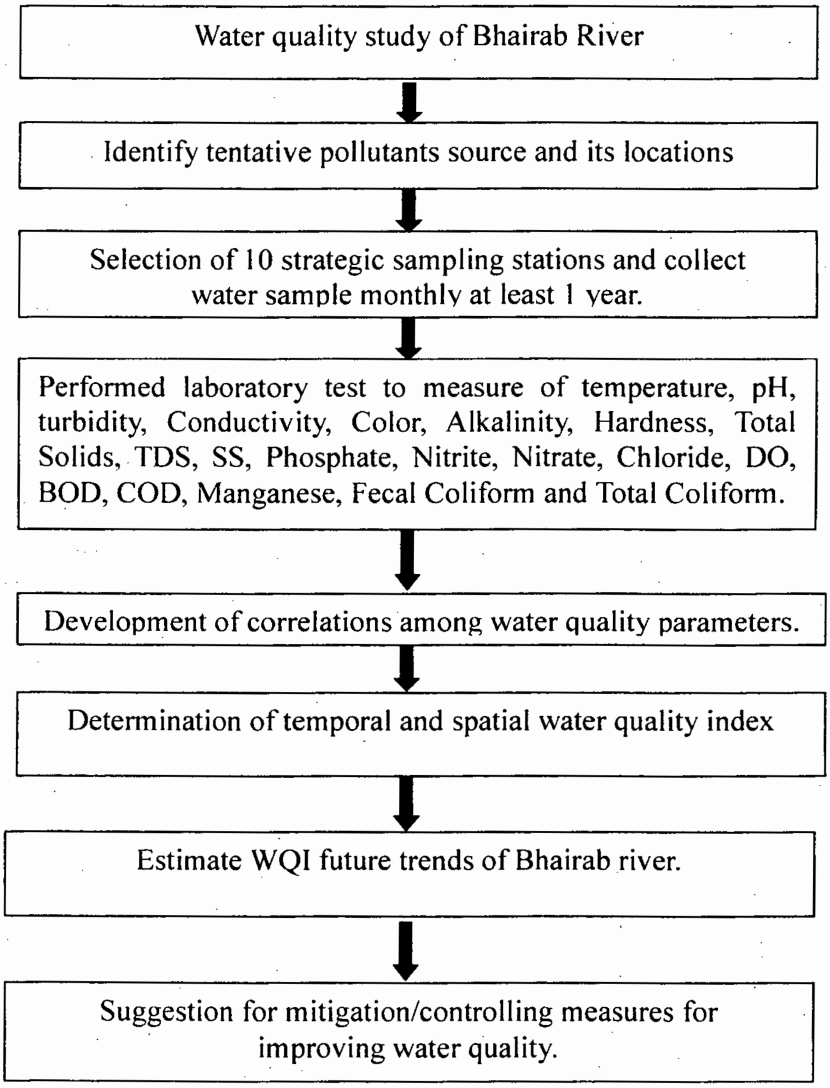

Figure 3.1: Flow chart sequence of the research works.

3.3 Baseline Survey

At first, a baseline survey has carried out to investigate the existing source of pollution that is directly or indirectly weighing contamination of river. The baseline survey includes primary data collection through reconnaissance survey, direct observation, stakeholder and community consultation and key informant interviews. A questionnaire has been prepared incorporating various information such as types of pollution sources (industrial, domestic, agriculture or others), probable causes of pollution and also modes of pollutants irrespective of temporal and spatial manner. Type of water uses along the river consumers is important information for the study. The aim of this survey is to find out the various types of sources and information that helps to perform the study towards optimum goal.

3.4 Selection of Strategic Water Sampling Stations

Total ten sampling stations have been selected primarily considering easy access and relatively equal interval. On which seven from Rupsha ferry ghat to Fultala Bazar ghat and remaining three stations from Fultala to Noapara Bazar ghat. Sampling station's ID were termed as S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9 and S_{10} is provided in Table 3.1. The length of the study area along Bhairab River is nearly 36.98 km. Ten water sampling stations are Rupsha ferry ghat (S_1), Khulna BIWTA launch terminal (S_2), Charerhat Kheya ghat (S_3), Daulatpur Bazar ghat (S_4), Cable factory ghat (S_5), Afil Jute mills Kheya ghat (S_6), Fultala Bazar ghat (S_7), Bhatpara ferry ghat (S_8), Raj ghat Kheya ghat (S_9) and Noapara Bazar ghat (S_{10}) as shown in Figure-3.1. In each point latitude and longitude has been recorded by GPS in order to collect the sample from the same point on the next sampling date.

Table 3.1: Global Position of Ten Sampling Station of Bhairab River, Khulna.

Station ID	Sampling Stations	Latitude	Longitude	Chainage (Km)	Relative Distance (Km)	Remarks
S_1	Rupsha Ferry ghat	22⁰48'2.22" N	89⁰34'58.52" E	0.0	0.0	Water collecting stations has been selected considering sense of easy access and relatively equal interval.
S_2	Khulna BIWTA launch terminal	22⁰49'27.39" N	89⁰33'36.08" E	3.82	3.82	
S_3	Charerhat Kheya Ghat	22⁰51'17.80" N	89⁰33'12.87" E	7.67	3.85	
S_4	Daulatpur Bazar ghat	22⁰52'13.36" N	89⁰31'39.78" E	11.70	4.03	
S_5	Cable Factory ghat	22⁰54'30.34" N	89⁰31'8.28" E	16.10	4.40	
S_6	Afil Jute mills ghat	22⁰56'26.43" N	89⁰29'43.51" E	20.68	4.58	
S_7	Fultala Bazar Ghat	22⁰58'30.41" N	89⁰28'42.77" E	25.09	4.41	
S_8	Bhatpara Ferry Ghat	23⁰0'34.14" N	89⁰27'33.21" E	29.49	4.40	
S_9	Raj ghat Kheya ghat	23⁰0'28.01" N	89⁰25'24.84" E	33.28	3.79	
S_{10}	Noapara Bazar ghat	23⁰1'54.63" N	89⁰23'58.69" E	36.98	3.70	

Note: Latitude, Longitude and chainage has been taken by Google Earth.

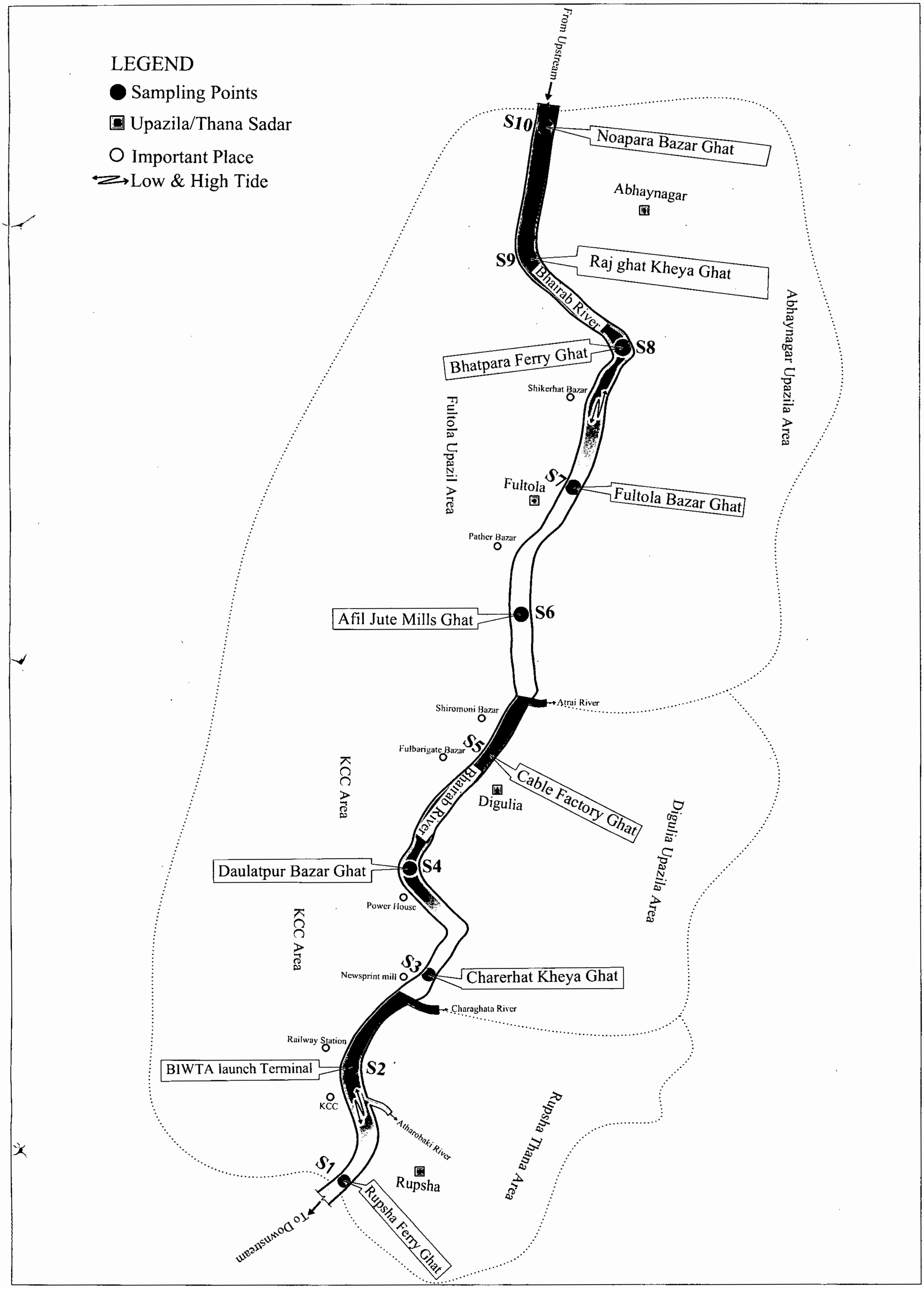

Figure 3.2 Selected water sampling stations of Bhairab River, Khulna

3.5 Collection of Water Samples

Samples were collected from the defined sampling stations shown in Figure 3.2 at every month throughout the year 2014. Samples were taken with carefully and at optimum time associated with environmental situation. 1.5 liter polypropylene bottles were used for water sample collection. Prior to sample collection, all bottles were washed with dilute alcohol followed by hot distilled water and were dried up in oven. Each water sample was collected firstly from three different places and make mixture homogeneously with them. The required amount was taken for experiment from this mixture. All the samples were preserved into the environmental engineering laboratory, KUET and tested them with appropriate strength and opportunity.

3.6 Water Sampling Depth

Water sample were collected at the station from a depth of 0.30 m - 0.45 m from the surface of water.

3.7 Labeling of Water Samples

Labeling is very essential for testing of samples. The test result is influenced by time. Each container clearly labeled with the following sequence:

- Date and time
- Sample number
- Sampling stations

3.8 Water Sample Preservation

We used plastic bottles for collection of sample. The sample was bottled carefully so that no air bubble is entrained in the bottle. Also the samples were preserved in ice box during collection specially in hot season.

3.9 Laboratory Tests of Parameters

To analyze the water quality of the Bhairab River samples were collected. Experiments were carried on the collected water sample to determine the physical, chemical and biological aspects of the water. Physical examination was conducted to find out Temperature, pH, Turbidity, Conductivity, Color, Alkalinity, Hardness, Total Solids (TS), Total Dissolved Solids (TDS), Suspended Solids (SS). Chemical examination revealed the Phosphate, Nitrite, Nitrate, Chloride, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Manganese of the water. While biological examination determined Fecal Coliform (FC) and Total Coliform (TC) of the water. The methods outlined in the Standard Methods for the Examination of Water and Wastewater (APHA. 2005) was followed for the analysis of all the physico-chemical parameters. Entire lab test has been performed in KUET environmental lab. Analytical apparatus reference model used in laboratory test are described in Table 3.2.

Table 3.2 Measurement of Parameters and Analytical Method

Parameters	Unit	Analytical Apparatus Reference Model
Temperature	^{o}C	Digital Thermometer with probe
pH	-	pH meter, HACH multi-meter, Model no-sensION156
Turbidity	NTU	Turbidimeter, Partech model, DR LANGE
Conductivity	µS/cm	Conductivity meter, HACH multi-meter, Model no-sensION156
Color (Pt-Co)	Pt-Co	Spectrophotometer, Model HACH DR/2500
Alkalinity	mg/L	Titration with stand, burette, pipette, beaker, conical flask, wash bottle, dropper, measuring cylinder etc.
Hardness	mg/L	Titration with stand, burette, pipette, beaker, conical flask, wash bottle, dropper, measuring cylinder etc.
Total solids	mg/L	0.70 µm pore size filter paper, Stand, funnel, beaker, woven, digital balance, measuring cylinder etc.
Total Dissolved Solids	mg/L	0.70 µm pore size filter paper, Stand, funnel, beaker, woven, digital balance, measuring cylinder etc.
Suspended Solids	mg/L	0.70 µm pore size filter paper, Stand, funnel, beaker, woven, digital balance, measuring cylinder etc.
Phosphate	mg/L	Spectrophotometer, Model HACH DR/2500
Nitrite	mg/L	Spectrophotometer, Model HACH DR/2500
Nitrate	mg/L	Spectrophotometer, Model HACH DR/2500
Chloride	mg/L	Titration with stand, burette, pipette, beaker, conical flask, wash bottle, dropper, measuring cylinder etc.
Dissolved Oxygen	mg/L	DO meter with probe, HACH Model HQ40d,
BOD	mg/L	DO meter, HACH Model HQ40d, BOD incubator, BOD bottle.
COD	mg/L	Titration with stand, burette, pipette, beaker, conical flask, wash bottle, dropper, measuring cylinder etc.
Manganese	mg/L	Spectrophotometer, Model HACH DR/2500
Fecal Coliform	N/100ml	Filtration unit, incubator, beaker, 0.45µm pore size filter paper.
Total Coliform	N/100ml	Filtration unit, incubator, beaker, 0.45µm pore size filter paper.

3.10 Calculation of NSF Water Quality Index

The National Sanitation Foundation (NSF) created and designed a standard index called the Water Quality Index (WQI). The WQI is one of the most widely used of all existing water quality procedures. The overall results of nine separate tests can be used to determine of a particular stretch of river.

The water quality index (WQI) consists of nine important parameters

Dissolved Oxygen
Fecal Coliform
pH
Biochemical Oxygen Demand (BOD)
Change temperature
Total phosphate
Nitrates
Turbidity
Total Solids

An equation of NSF water quality index by using weighted factor of individual parameter and sub-index of each water quality parameter based on their respective testing values which can be found by water quality index calculator or water quality index curve of respective parameters as shown in Figure 3.22, 3.23, 3.24, 3.25, 3.26, 3.27, 3.28, 3.29 and 3.30.

The water quality index of the individual parameter was calculated here by using water quality index calculator exercised by Environmental Engineering and Earth Sciences (EEES) Center of Environmental Quality, Wilkes University.

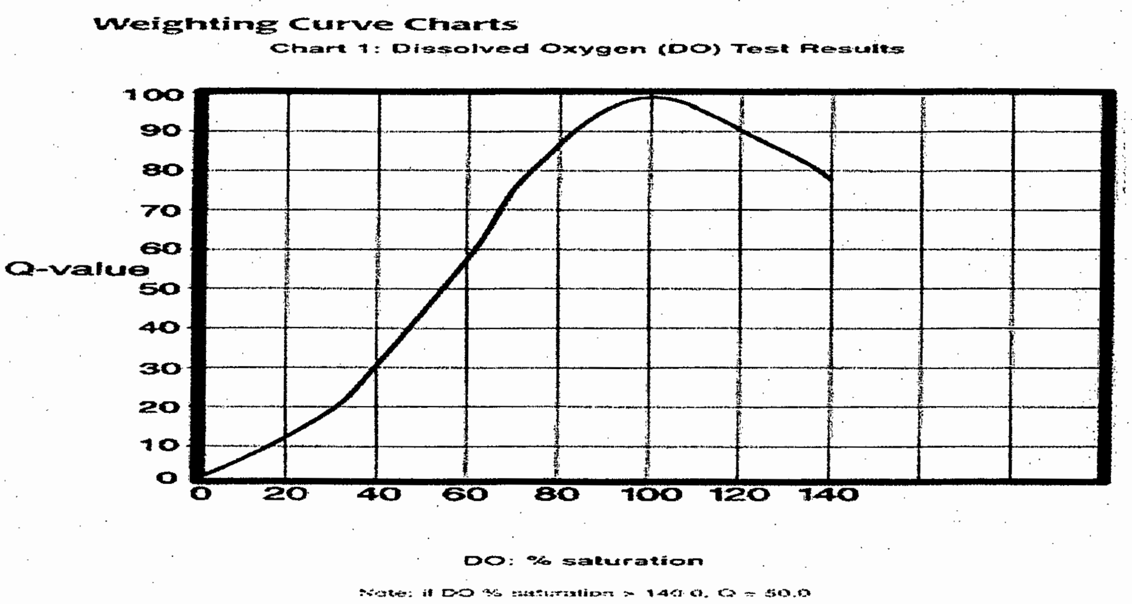

Figure 3.3 Average sub-index curve of DO

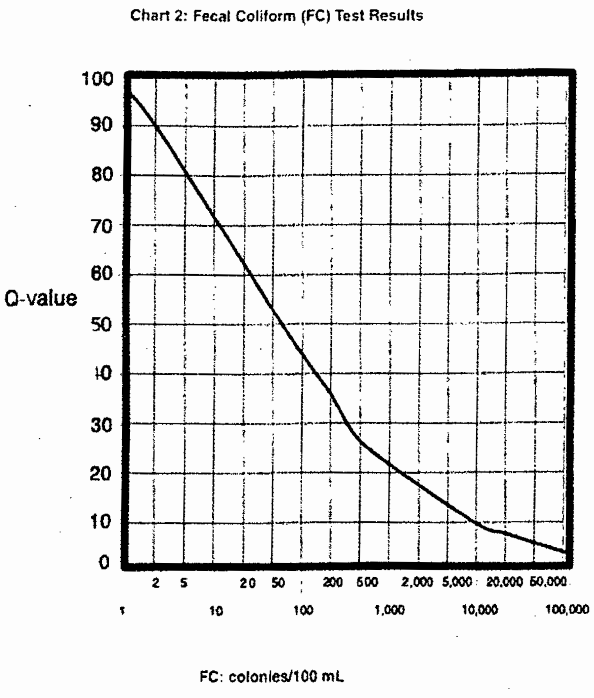

Figure 3.4 Average sub-index curve of FC

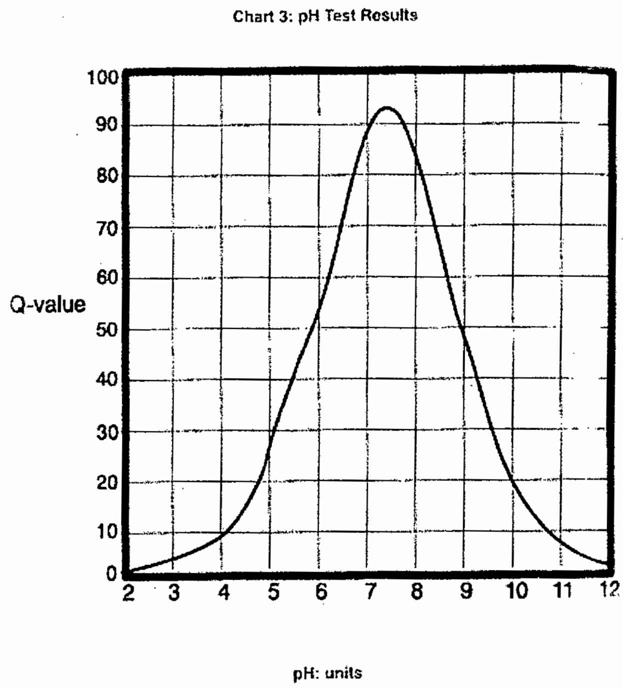

Figure 3.5 Average sub-index curve of pH

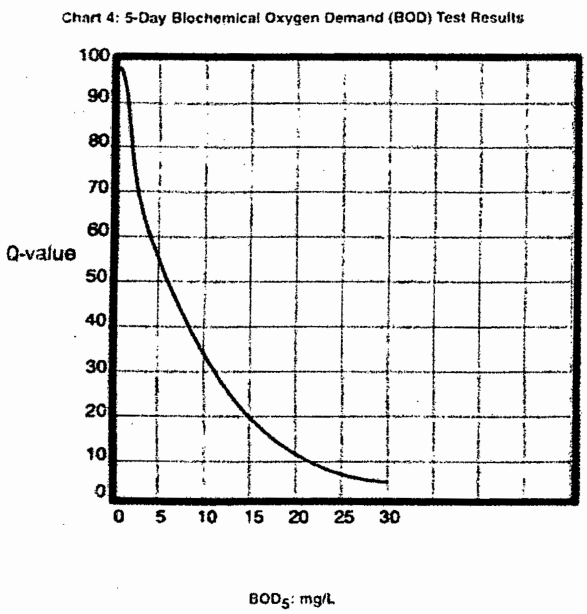

Figure 3.6 Average sub-index curve of BOD

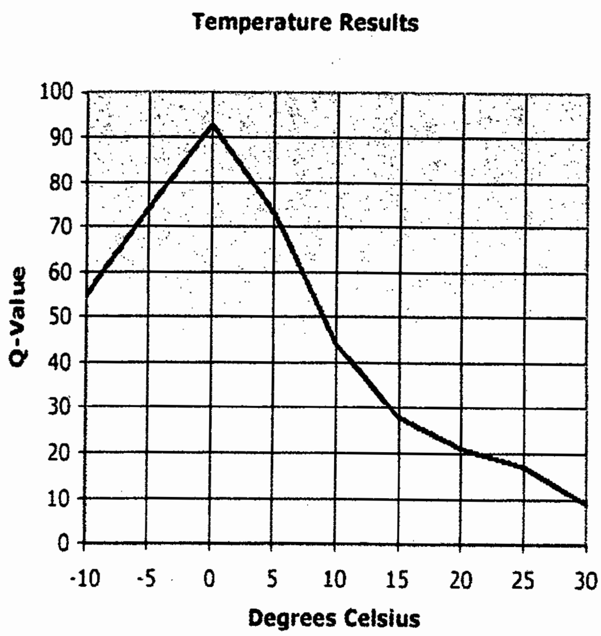

Figure 3.7 Average sub-index curve of Temperature

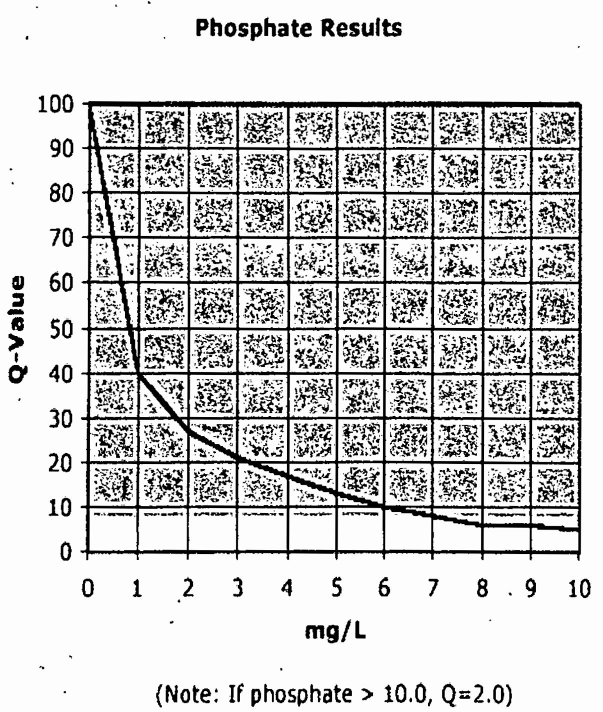

Figure 3.8 Average sub-index curve of Phosphate

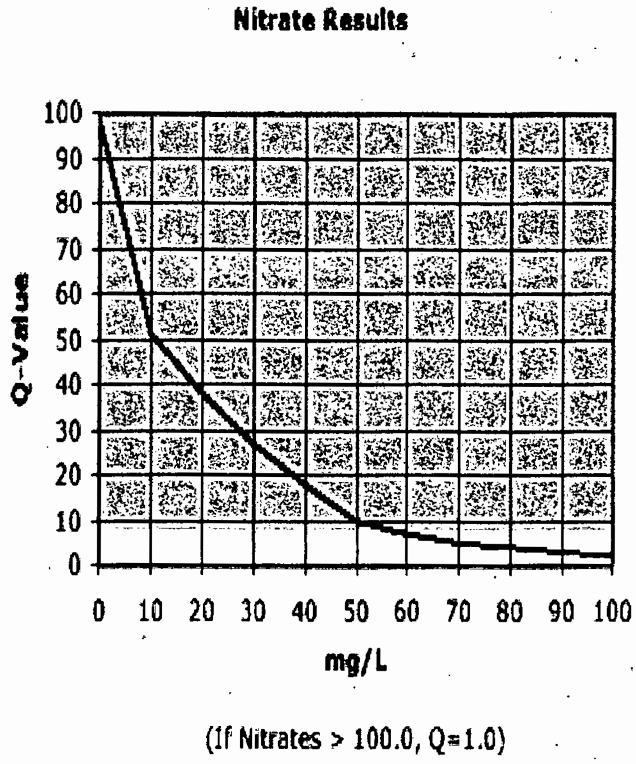

Figure 3.9 Average sub-index curve of Nitrate

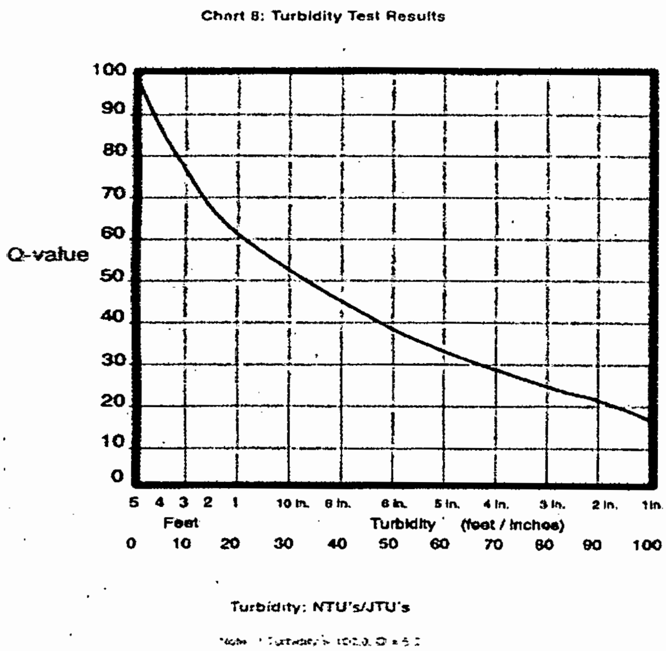

Figure 3.10: Average sub-index curve for Turbidity

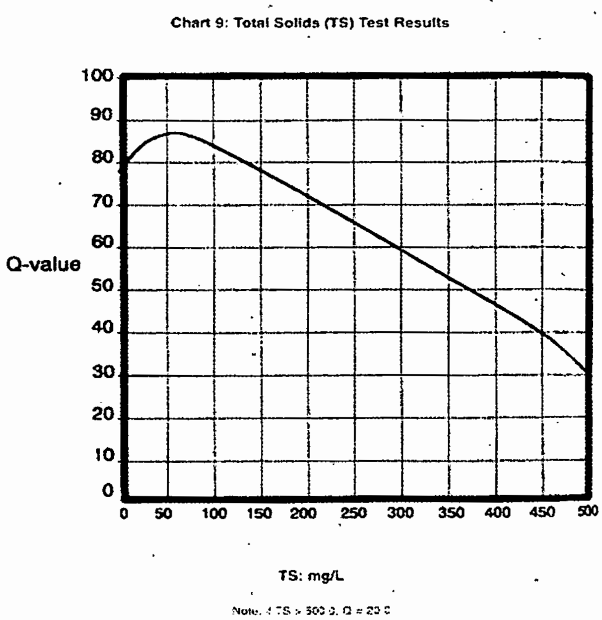

Figure 3.11: Average sub-index curve for Total Solids

According to National Sanitary Foundation (NSF) overall water quality index, WQI can be calculated by the following equation, Eq. (3.1) used by (EEES). The highest score a body of water can receive is 100.

$$WQI=0.17I_{DO} + 0.16I_{FC} + 0.11(I_{pH} + I_{BOD}) + 0.10(I_{\Delta T} + I_{PO_4} + I_{NO_3}) + 0.08I_T + 0.07I_{TS} \dots (3.1)$$

Where I is the Individual water quality sub-index and co-efficient are weighting factor of the individual parameter. Overall water quality index has been calculated by using equation (3.1) If less than nine parameters are performed, the overall WQI can be estimated by adding the results and then adjusting for the number of tests. For example, BOD and temperature are not available; the seven remaining sub-totals are added and the seven weighting factors are also added. Then former is then divided by the latter, to obtain a required WQI i.e. WQI= Sum of the individual water quality index/Sum of the weight factors.

Water Quality Index provides a single number that expresses overall water quality at a certain location on several water quality parameters and turns complex water quality data into information that is understandable and useable by the general people (Rumman *et al.*2012).

Water quality index is a mathematical instrument used to transform large quantities of water quality data into a single number which represents the water quality level while eliminating the subjective assessments of water quality and biases of individual water quality experts. Basically a WQI attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining certain level of water quality (Miller *et al.* 1986).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 General

This is the most important chapter of the research. The chapter aims to present and analyze water quality of Bhairab River in many ways and means. The main tasks include assessment of the river water quality with graphical representation, Calculation of temporal and spatial water quality index, determination of overall water quality index (WQI) by National Sanitary Foundation (NSF) method, calculation of projected trend of WQI and future chloride movement on the course of time. Development of correlation among water quality parameters. Numerous primary, secondary data, their formulation, calculation and discussion are interpreted here.

4.2 Experimental Results

Water quality test results of Bhairab River are shown in Table 4.1 for the year 2014. Monthly average values are calculated from the investigational values. Thirteen average values found beyond the BDS permissible limit out of twenty parameters while seven are within admissible limit. Turbidity, conductivity, total dissolved solids, suspended solids, chloride, fecal coliform and total coliform are much higher than its permissible value. The standard values for drinking purposes are compared with the experimental values. Turbidity, Conductivity, Color, TDS, SS, Chloride, COD, Manganese, FC and TC are too high than the permissible drinking limit. Total dissolved solids and chloride start increasing from February and attains peak in June and then gradually declined.

Table 4.2 shows comparison of water quality of Bhairab River with other secondary data. Comparison was made with DoE and others two researches named X and Y. Temperature, Turbidity, pH, Alkalinity, suspended solids, Dissolved Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand, Fecal Coliform and Total Coliform data are more or less similar compared with secondary data. There is no abrupt variation among these records. Here all data has used average value except Y value. All Y value are parameterwise tested only a single or specific date. Variation of concentration differs due to several causes like sample collection time, location, low and high tide, temporal and spatial effect, types of equipments used, collection and preservation system of sample. Hardness variation is remarkable with Y because being it as a single data. Chloride variation is remarkable because test has been done at different times. Nitrate variation is very close to DoE but too differ with Y, because Y is single test value.
Temperature, pH, Total Dissolved Solids, Phosphate, Nitrate, Dissolved Oxygen, Biochemical Oxygen Demand and Fecal Coliform are very likely compared with DoE data. Others data differs with it.

Table 4.3 shows the highest and lowest values of tested water quality parameters with their locations and month. Fifteen highest values have exceeded BDS permissible drinking limit while the only five are within admissible boundary. Ten lowest values also above the permissible limit whereas remaining values are inside the permissible values. So the water quality of Bhairab River is not fit for nearly all the purposes. Chloride highest concentration is 166 times greater than lowest. Highest deliberation of Turbidity, Conductivity, Hardness, TS, TDS, SS, Phosphate, COD, Manganese and FC are over ten times greater than its lowest one. Most of the highest value observed near downstream while lowest value experienced in upstream area. Highest values generally found in dry (Nov-Jun) and lowest ones are in rainy season (July-Oct).

Table 4.4 shows the surface water quality standards for different purposes like drinking, recreation, water supply after treatment, fisheries, industrial use and irrigation according to the source Environmental Conservation Rules (ECR, 1997). Four most important parameters pH, Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO) and Total Coliforms (TC) range are described for typical best practice. This table can be used a guidelines in compared with individual water quality parameter and thus specified appropriateness of uses. Here pointed out that pH, BOD, DO and TC only four parameters surface water quality are provided here. So others parameters surface water quality can't be possible to compare.

Table 4.1 Water Quality Test Result of Bhairab River in the Year 2014

Sl No.	Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year Avg.	BDS (ECR'97)	WHO
1	Temperature (^0C)	18.17	22.38	32.02	36.38	37.32	30.69	29.25	28.44	27.64	27.33	21.76	16.89	27.36	20-30	-
2	pH	7.88	7.86	7.65	7.67	7.634	7.60	7.59	7.827	7.02	7.02	7.41	7.90	7.59	6.5-8.5	-
3	**Turbidity (NTU)**	528	1087	991	532	346	310	258	316	151	265	336	450	**464**	10	5
4	**Conductivity (µS/cm)**	1457	1966	6070	6838	5979	2072	395	191	141	260	74	989	**2203**	500-700	-
5	**Color (Pt-Co)**	301	386	129	157	153	106	108	92	99	74	199	176	**165**	15	15
6	**Alkalinity (mg/L)**	132	118	138	129	118	76	81	83	99	102	138	103	**110**	100	-
7	Hardness (mg/L)	318	231	279	291	226	303	258	234	175	141	210	281	246	200-500	-
8	**Total Solids (mg/L)**	1312	2074	4677	4814	4217	1622	424	377	206	346	327	884	**1773**		-
9	**TDS (mg/L)**	996	1323	3950	4490	3945	1355	272	120	88	182	47	614	**1449**	1000	1000
10	**SS (mg/L)**	316	751	726	324	272	267	153	257	118	164	280	270	**325**	10	-
11	Phosphate (mg/L)	0.35	0.35	0.56	1.05	1.07	1.62	0.93	1.45	1.4	1.38	0.36	0.37	0.91	6	6
12	Nitrite (mg/L)	0.04	0.04	0.05	0.04	0.03	0.03	0.04	0.02	0.03	0.05	0.03	0.06	0.04	<1	3
13	Nitrate (mg/L)	2.31	2.73	2.89	4.14	3.09	1.55	2.09	1.97	2.87	3.33	2.66	2.82	2.70	10	50
14	**Chloride (mg/L)**	559	733	2284	2518	2210	726	153	66	48	102	24	346	**814**	150-600	250
15	DO (mg/L)	7.21	7.01	6.42	6.40	6.35	6.58	6.63	6.9	7.0	7.07	7.05	7.25	6.82	6	-
16	**BOD (mg/L)**	0.79	1.02	1.12	0.48	1.01	0.69	0.63	0.51	1.34	1.22	1.13	0.95	**0.91**	0.20	-
17	**COD (mg/L)**	96	143	138	131	186	234	154	115	106	138	205	93	**145**	4	-
18	Manganese (mg/L)	0.06	0.07	0.07	0.07	0.06	0.07	0.04	0.03	0.04	0.03	0.04	0.07	0.05	0.1	0.1
19	**FC (N/100ml)**	360	369	345	344	360	443	319	1154	1005	430	255	338	**477**	0	0
20	**TC (N/100ml)**	985	1156	2269	2940	768	1455	975	2457	2515	716	1796	991	**1585**	0	0

Notes: Twelve parameters beyond the BDS permissible limit are bolded in the Table 4.1

Table 4.2 Comparison of Water Quality of Bhairab River with Secondary data.

Sl No.	Parameters	Experimental Value, 2014 (Average)	X Value (2013)	Y Value (14.4.2014)	DoE (2013)	Remarks
1	Temperature (^{0}C)	27.36	-	31.56	27.62	Experimental value is average. So differs with Y value but similar with DoE value.
2	pH	7.59	7.61	7.80	6.85	Variation of pH is not too far from each. All values are within acceptable limit.
3	**Turbidity (NTU)**	**464**	154.49	-	275	Turbidity variation is not too remarkable.
4	**Conductivity (µS/cm)**	**2203**	-	-	6711	Conductivity variation is too remarkable. Result differs as sample has been collected at different times, spaces and situation.
5	**Color (Pt-Co)**	**165**	-	532.50	-	Experimental value is average, so differs from Y.
6	**Alkalinity (mg/L)**	**110**	76.50	117.60	33.80	Alkalinity variation is negligible. All concentration are more or less nearby.
7	Hardness (mg/L)	246	207.97	4679.5	1048	Y value found too high because it is a single value rather than average. Fluctuation of four values is too high.
8	**Total Solids (mg/L)**	**1773**	138.0	12490	12750	Total solids variation is remarkable. DoE and Y value is too high.
9	**TDS (mg/L)**	**1449**	-	11660	3355	TDS variation is remarkable. Y value is high for being a single value.
10	**SS (mg/L)**	**325**	-	830	125	SS variation is not too remarkable. Most of the values are nearly close.
11	Phosphate (mg/L)	0.91	0.28	3.96	1.01	Variation is remarkable but all data are within BDS limit. Y values are too high for being a single one.
12	Nitrite (mg/L)	0.04	-	-	-	No secondary data found.
13	Nitrate (mg/L)	2.70	-	6.66	2.84	Nitrate variation is not too remarkable. Concentrations are more or less closes.
14	**Chloride (mg/L)**	**814**	130	9970	2410	Chloride variation is remarkable because test has been done at different times and place.
15	DO (mg/L)	6.82	6.20	8.15	6.68	Variation is remarkable. Experimental and secondary data are very closes.
16	**BOD (mg/L)**	**0.91**	1.02	0.70	1.05	Variation is not so remarkable. Most of the concentration is more or less closes.
17	**COD (mg/L)**	**145**	-	204.40	72.66	COD variation is not too remarkable. All data are more or less alike.
18	**Manganese (mg/L)**	**0.05**	-	4.38	-	Variation is very remarkable. Y value is single one, so differs.
19	**FC (N/100ml)**	**477**	-	500	380	FC variation is negligible. Experimental and secondary data are very closes.
20	**TC (N/100ml)**	**1585**	-	1090	-	Variation is not too remarkable.

X (Jabed Iqbal): Seasonal variation and water quality assessment of Bhairab River in Khulna, Bangladesh. Y (Omor Faruk): Assessment of water quality of Bhairab River using NSF water quality index.

Table 4.3 Highest and Lowest Water Quality Value of Bhairab River, 2014.

Sl	Parameters	Year highest			Year lowest		
		Highest Value	Stations	Month	Lowest Value	Stations	Month
1	Temperature (°C)	**37.50**	Noapara	May	**16.80**	Afilgate	Dec
2	pH	**8.30**	Rupsha ghat	Aug	**6.97**	Rajghat	Sep
3	Turbidity (NTU)	**1468**	Charerhat	Feb	**89**	Rajghat	Sep
4	Conductivity (μS/cm)	**8127**	Rupsha ghat	Apr	**55**	Kh. BIWTA	Nov
5	Color (Pt-Co)	**460**	C. Factory	Jan	**60**	Fultala	Oct
6	Alkalinity (mg/L)	**175**	C. Factory	Apr	**55**	C. Factory	Jun
7	Hardness (mg/L)	**1667**	Kh. BIWTA	Feb	**89**	Rupsha ghat	Nov
8	Total Solids (mg/L)	**5718**	Rupsha ghat	Apr	**179**	Charerhat	Sep
9	TDS (mg/L)	**5378**	Rupsha ghat	Apr	**35**	Kh. BIWTA	Nov
10	Suspended (mg/L)	**1100**	C. Factory	Mar	**109**	Bhatpara	Sep
11	Phosphate (mg/L)	**2.24**	Noapara	Jun	**0.18**	C. Factory	Feb
12	Nitrite (mg/L)	**0.63**	Kh. BIWTA	Mar	**0.00**	Daulatpur	Nov
13	Nitrate (mg/L)	**6.60**	Kh. BIWTA	Apr	**0.80**	Afilgate	Aug
14	Chloride (mg/L)	**2982**	Rupsha ghat	Apr	**18**	Kh. BIWTA	Nov
15	DO (mg/L)	**8.09**	Kh. BIWTA	Dec	**5.73**	Noapara	Apr
16	BOD (mg/L)	**1.90**	C. Factory	Mar	**0.20**	Daulatpur	Apr
17	COD (mg/L)	**448**	Charerhat	Jun	**32**	Fultala	Sep
18	Manganese (mg/L)	**0.09**	Kh. BIWTA	Mar	**0.00**	Bhatpara	Oct
19	FC (N/100ml)	**1800**	C. Factory	Sep	**180**	C. Factory	Nov
20	TC (N/100ml)	**3400**	Kh. BIWTA	Apr	**500**	Fultala	Jul

Table 4.4 Standard Value for Surface Water Quality

Best Practice based classification	pH	BOD mg/L	DO mg/L	TC N/100ml
a. Source of drinking water for supply only after disinfecting	6.5-8.5	2 or less	6 or above	50 or less
b. Water usable for recreational activity	6.5–8.5	3 or less	5 of more	200 or less
c. Source of drinking water for supply after conventional treatment	6.5–8.5	6 or less	6 or more	5000 or less
d. Water usable by fisheries	6.5–8.5	6 or less	5 or more	---
e. Water usable by various process and cooling industries	6.5–8.5	10or less	5 or more	5000 or less
f. Water usable for irrigation	6.5–8.5	10or less	5 or more	1000 or less
Notes: 1. In water used for pisiculture, maximum limit of presence of ammonia as Nitrogen is 1.2 mg/L. 2. Electrical conductivity for irrigation water – 2250 μmhoms/cm (at a temperature of 25°C); Sodium less than 26%; boron less than 0.2%.				

Source: Environment Conservation Rules (ECR, 1997)

4.3 Assessment of Water Quality

Assessments of the river water quality parameters are performed by comparing experimental values with standard values for drinking (Table 4.1), recreation, irrigation and other purposes (Table 4.4). A total number of twenty water quality parameters' assessments are described here.

4.3.1 Temperature

Figure 4.1 shows the temporal variation of average monthly temperature of the selected ten sampling stations (S_1, S_2 ...S_{10}) of the Bhairab River water. The lowest temperature was recorded 16.8 °C in December and the highest was 37.5°C in the month of May. Both the values exceed the upper and lower limits of the Bangladesh standard (ECR,'97).Therefore, the Bhairab River water cannot be used for drinking during May and December for higher temperature. For other months the temperature is within the limit for drinking purpose. However, it may be used for recreation, irrigation and other purposes.

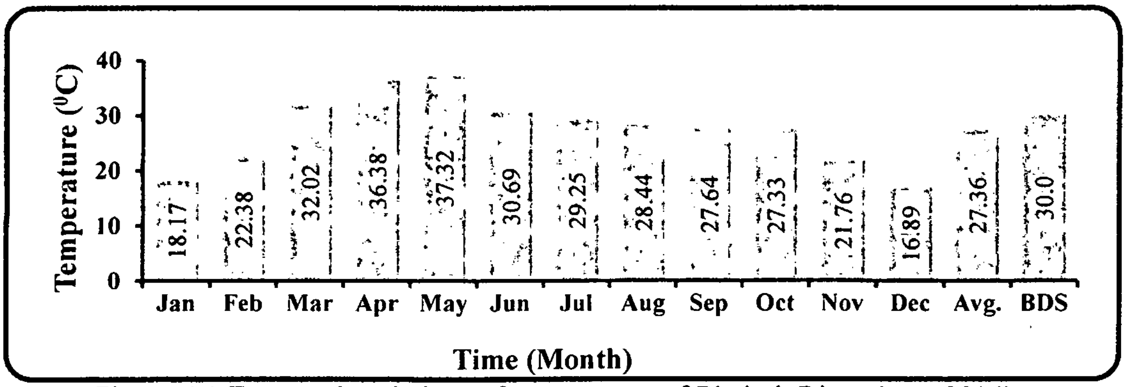

Figure 4.1 Temporal variations of temperature of Bhairab River (year 2014)

4.3.2 pH

Figure 4.2 shows the temporal variation of average monthly pH of the selected ten sampling stations of the Bhairab River. Highest value 8.30 recorded in August while the lowest found 6.97 in September. Monthly variation of pH is minor and close to each other. Highest and lowest values are within BDS permissible limit for drinking purpose. Standard value for surface water quality for pH 6.5-8.5 according to ECR,'97.So the Bhairab River water can be used for drinking as well as for recreation, irrigation and other purposes based on pH.

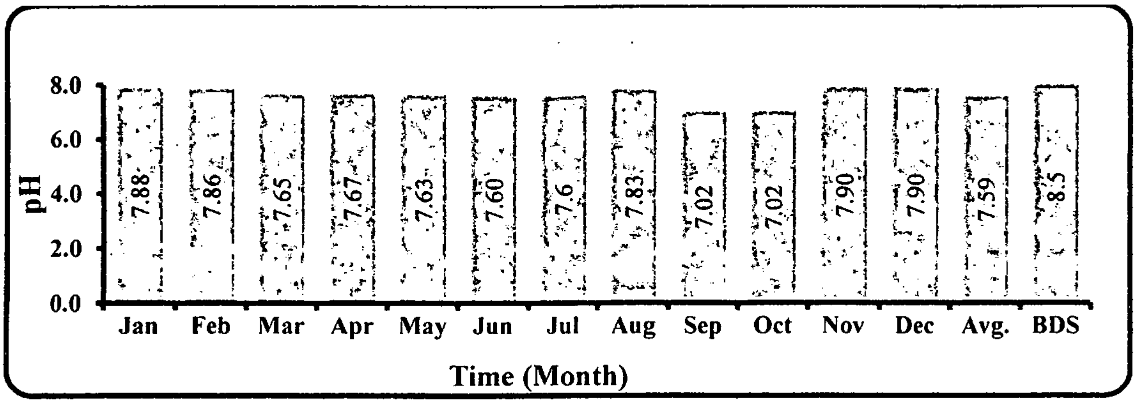

Figure 4.2 Temporal variations of pH of Bhairab River (year 2014)

4.3.3 Turbidity

In the Figure 4.3.monthly average turbidity found 464 NTU. Year highest turbidity was recorded 1468 NTU in February while the lowest was 89 NTU in September. The monthly variation of the turbidity was too high. BDS for drinking water is 10 NTU and there is no standard limit for recreation, irrigation. Maximum and minimum both values are exceeded allowable drinking limit. So the Bhairab River water cannot be used for drinking but may be used for recreation, irrigation and fisheries purposes based on concentration of turbidity.

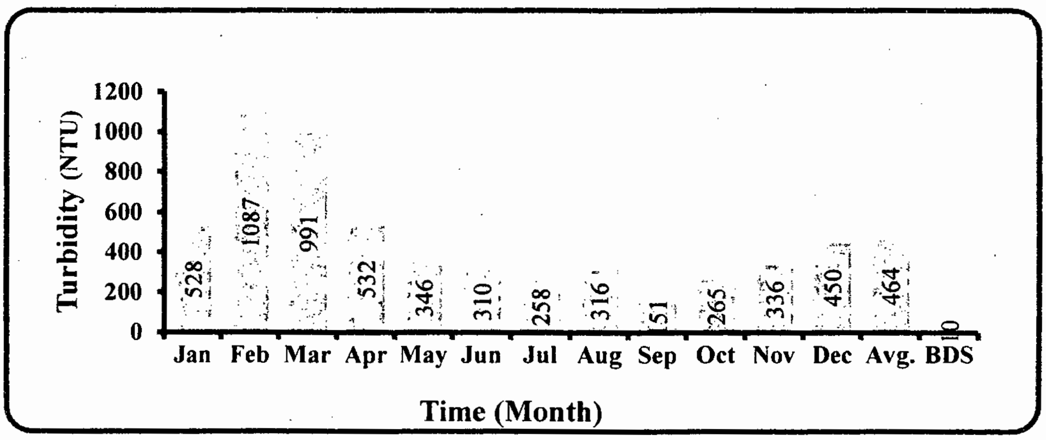

Figure 4.3 Temporal variations of turbidity of Bhairab River (year 2014)

4.3.4 Conductivity

In the Figure 4.4 monthly conductivity throughout the year 2014 are shown where the highest value was recorded 8127 μS/cm in April and the lowest was 55μS/cm in November. The monthly variation of the conductivity was too high specially for the month of January to April. Permissible value for BDS of conductivity is 500-700 μS/cm for drinking water. Highest and average value exceeded BDS permissible value while the lowest value remains within it and there is no standard limit for recreation and irrigation. So the Bhairab River water can be used for drinking except dry season but it may be used for recreation, irrigation and other purposes based on of conductivity.

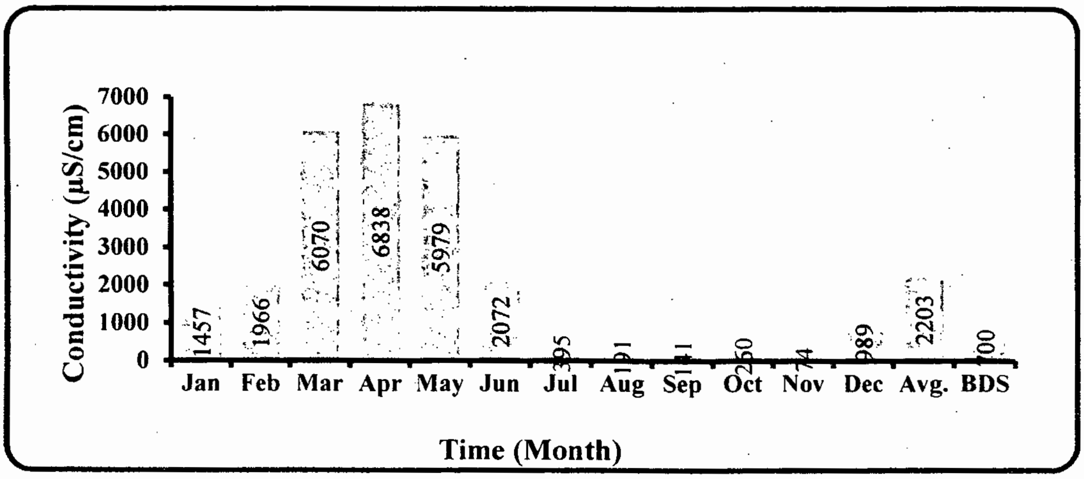

Figure 4.4 Temporal variations of conductivity of Bhairab River (year 2014)

4.3.5 Color

In the study period monthly average colors were recorded and shown in Figure 4.5. Monthly highest was found 460 Pt-Coin January while the lowest was 60 Pt-Co in October. The monthly variation of color concentration was high. Monthly highest, average and lowest values exceeded BDS Permissible value for drinking water. Color concentration according to Bangladesh water quality standard for drinking is 15 Pt-Co and there is no standard limit for recreation, irrigation, industrial use. So the Bhairab River water cannot be used for drinking but may be used for recreation, irrigation and industrial purposes based on color concentration.

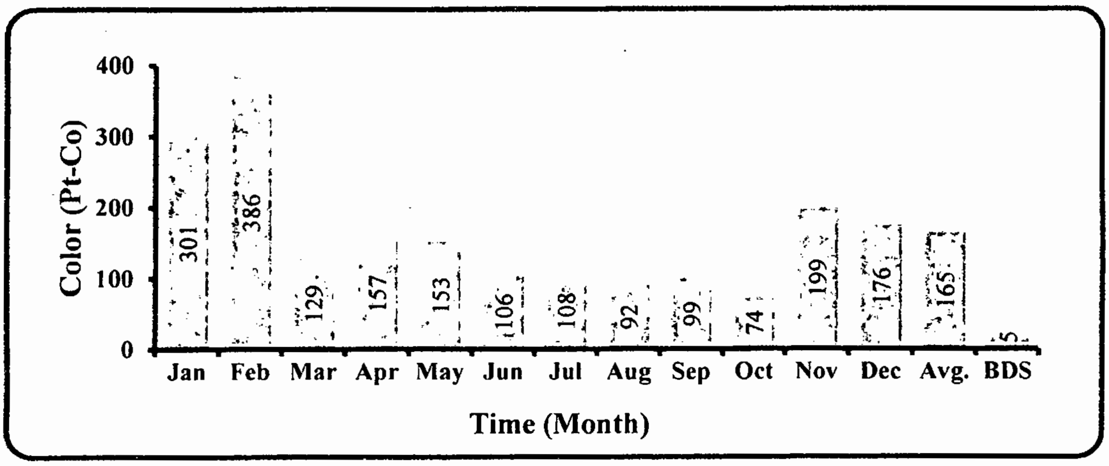

Figure 4.5 Temporal variations of color of Bhairab River (year 2014)

4.3.6 Alkalinity

In the Figure 4.6 monthly average of alkalinity of Bhairab River throughout the year 2014 is shown. Monthly average value was noted 110 mg/L which is close to allowable drinking level. Year highest alkalinity was 175 mg/L in April while the lowest was 55 mg/L in June. The monthly variation of the alkalinity was negligible. Highest value exceeded permissible limit but the lowest one was within drinking limit. On the basis of average value Bhairab River water may be used for drinking as well as for recreation and irrigation purposes based on concentration of alkalinity.

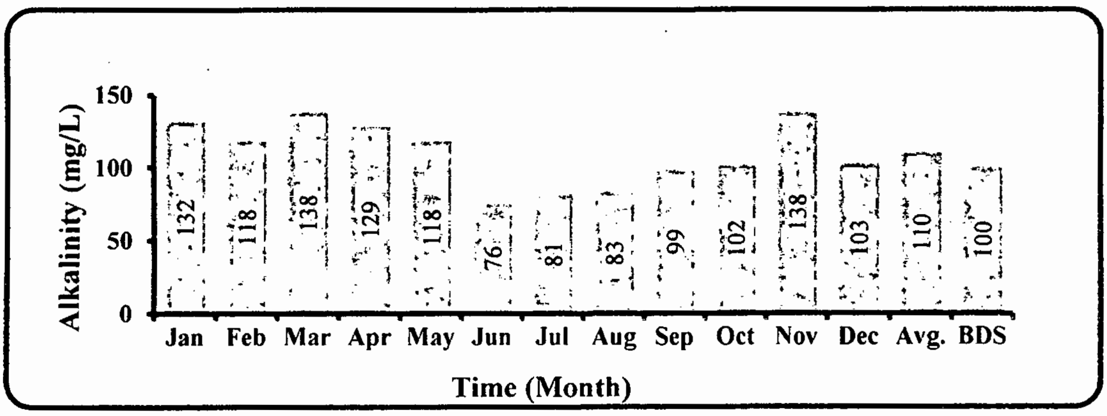

Figure 4.6 Temporal variations of alkalinity of Bhairab River (year 2014)

4.3.7 Hardness

In the study period monthly hardness is shown in Figure 4.7. Highest value of hardness was recorded 1667 mg/L in February while the lowest was 89 mg/L in November. Both highest and lowest values are within the BDS drinking water limit. The monthly variation of hardness over the year was negligible. Bangladesh drinking water quality standard for hardness is 200-500 mg/L. All of the hardness value of different stations and months are within BDS limit, so the Bhairab River water can be used for drinking and other purposes based on hardness concentration.

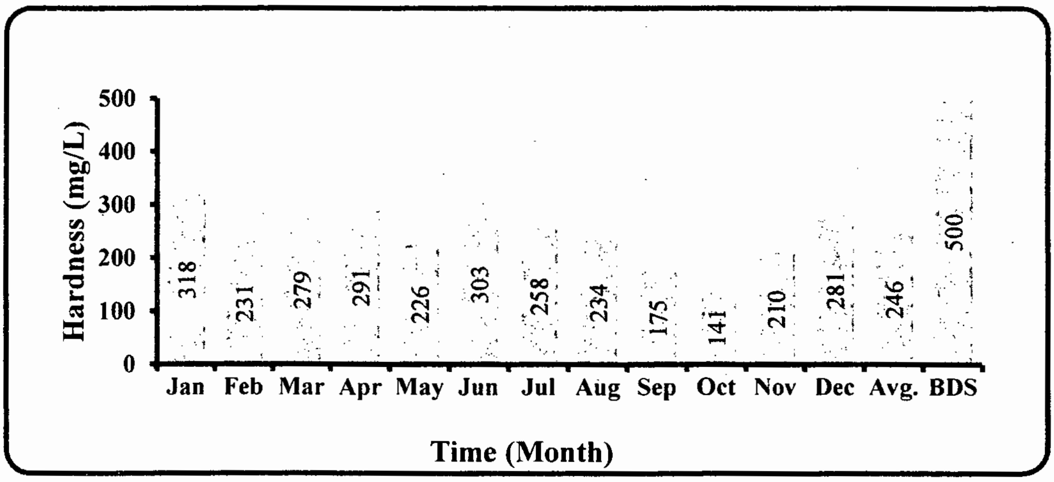

Figure 4.7 Temporal variations of hardness of Bhairab River (year 2014)

4.3.8 Total Solids (TS)

Monthly average total solids of the studied river are shown in the Figure 4.8.Year highest TS was 5718 mg/L in April while the lowest was 179 mg/L in September. Monthly fluctuation of total solids was remarkable throughout the year. In the study it starts up from February and reaches optimum in April and then sharply declines due to cause high variability of salinity in water. There is no TS standard limit for drinking water.

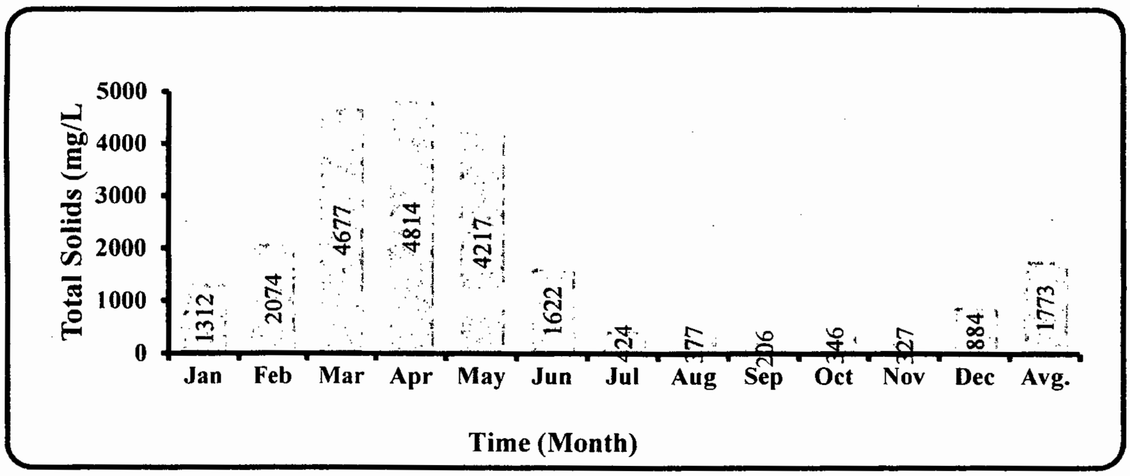

Figure 4.8 Temporal variations of total solids of Bhairab River (year 2014)

4.3.9 Total Dissolved Solids (TDS)

Throughout the year 2014 monthly average TDS is shown in Figure 4.9. Year highest TDS was 5378 mg/L in April while the lowest was 35 mg/L in November. The monthly fluctuation of the TDS was significant. TDS concentration starts rising from March and drastically reached high concentration (3101 mg/L) in April due to mounting chloride content in water. Bangladesh drinking standard is 1000 mg/L and there is no standard limit for recreation, irrigation and industrial use. So Bhairab River is usable for drinking purpose except February to June.

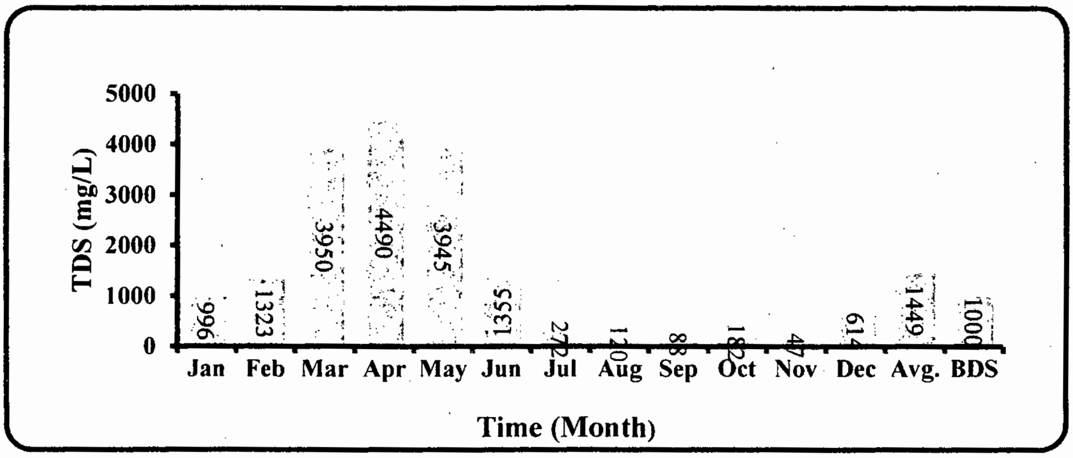

Figure 4.9 Temporal variations of TDS of Bhairab River (year 2014)

4.3.10 Suspended Solids (SS)

In the Figure 4.10 monthly average suspended solids is shown where highest value found 1100 mg/L in March and the lowest was recorded 109 mg/L in September. The monthly fluctuation of SS in some cases was remarkable. Bangladesh drinking standard limit for suspended solids is 10 mg/L. Highest and lowest both values exceeded BDS drinking limit. Comparing SS with BDS it cannot be used for drinking purpose but can be used for recreation, irrigation and fisheries.

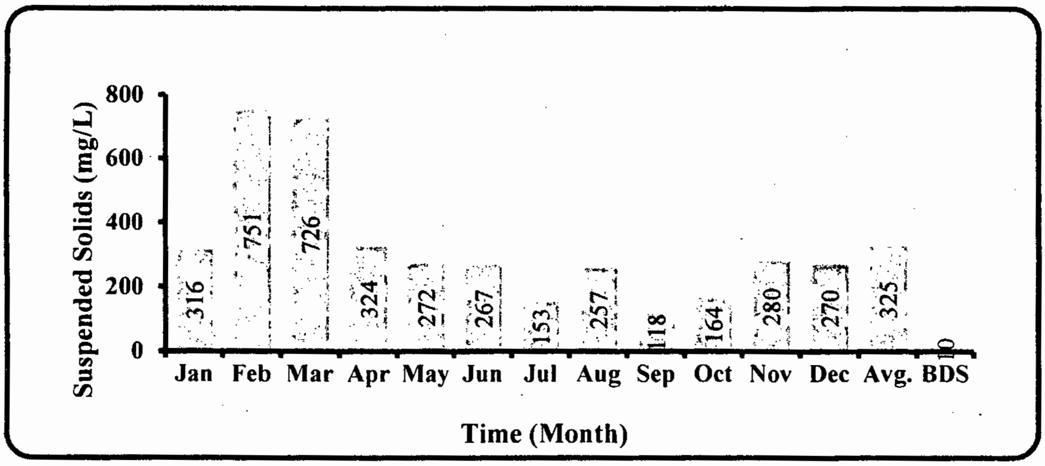

Figure 4.10 Temporal variations of suspended solids of Bhairab River (year 2014)

4.3.11 Phosphate

Monthly average phosphate is shown in the Figure 4.11.Highest phosphate concentration was found 2.24 mg/L in June while the lowest was 0.18 mg/L in February. The value of phosphate according to Bangladesh water quality standard drinking is 6 mg/L. In all ten sampling stations monthly phosphate was always less than the permissible limit, and there is no standard limit for recreation, irrigation. So the Bhairab River water can be used in all-purpose based on phosphate concentration.

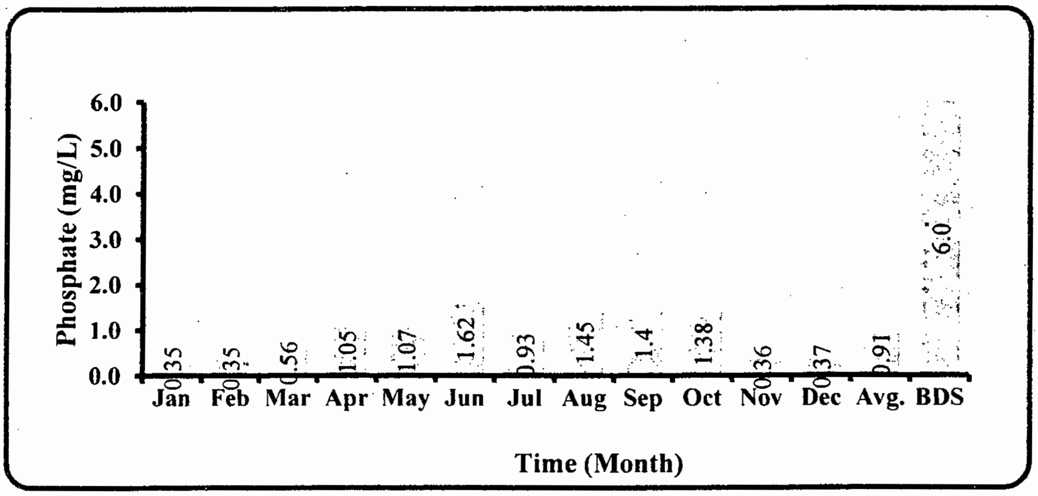

Figure 4.11 Temporal variations of phosphate of Bhairab River (year 2014)

4.3.12 Nitrite

Monthly nitrite concentration is compiled very negligible as compared with Bangladesh standard in Figure 4.12.Highest and lowest nitrite concentration was 0.63 mg/L and 0.0 mg/L respectively are within the permissible limit. Allowable drinking water limit for nitrite is 1.0 mg/L. So the Bhairab River water can be used easily in all-purpose based on nitrite concentration.

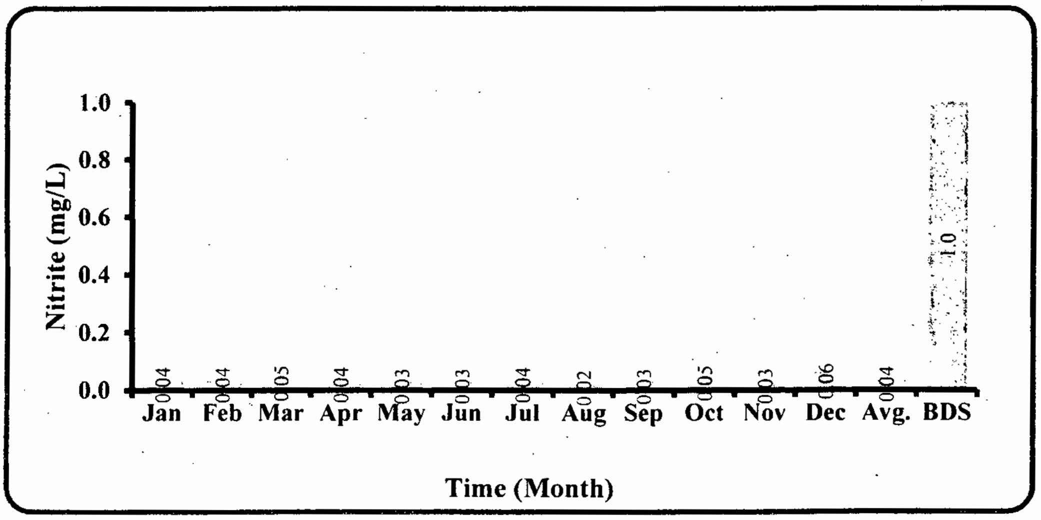

Figure 4.12 Temporal variations of nitrite of Bhairab River (year 2014)

4.3.13 Nitrate

In the Figure 4.13monthly average nitrate concentration is shown for the year 2014. Highest nitrate value was recorded in 6.60 mg/L in April while the lowest was 0.80 mg/L in August. Its BDS drinking water permissible value is 10 mg/L. Both highest and lowest values are enough safe side than the permissible limit. Monthly fluctuation was negligible. There is no standard limit for recreation, irrigation. So the Bhairab River water can be used for drinking and other purposes based on nitrate concentration.

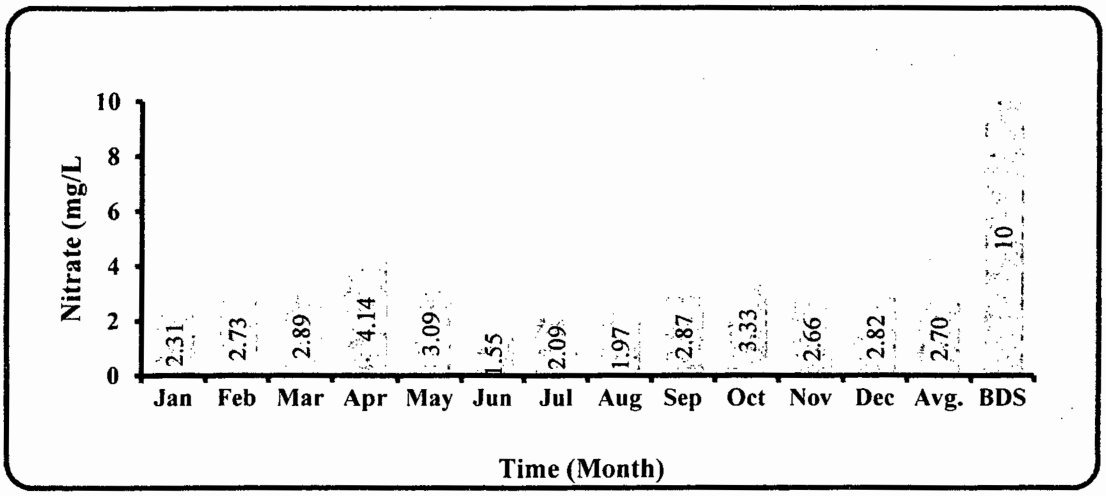

Figure 4.13 Temporal variation of nitrate of Bhairab River (year 2014)

4.3.14 Chloride

Monthly average chloride content of Study River is shown in the Figure 4.14. Highest chloride was recorded 2982 mg/L in April and the lowest one was 18 mg/L in November. From the Figure 4.14 it is observed that chloride content rises from March and get peak in June. In this dry period Bhairab River water remains high salinity. Bangladesh water quality standard for drinking is 1000 mg/L for coastal area and150-600 mg/L for other area and there is no standard limit for recreation, irrigation and pisciculture. So the Bhairab River water can be used for drinking purpose except March to June.

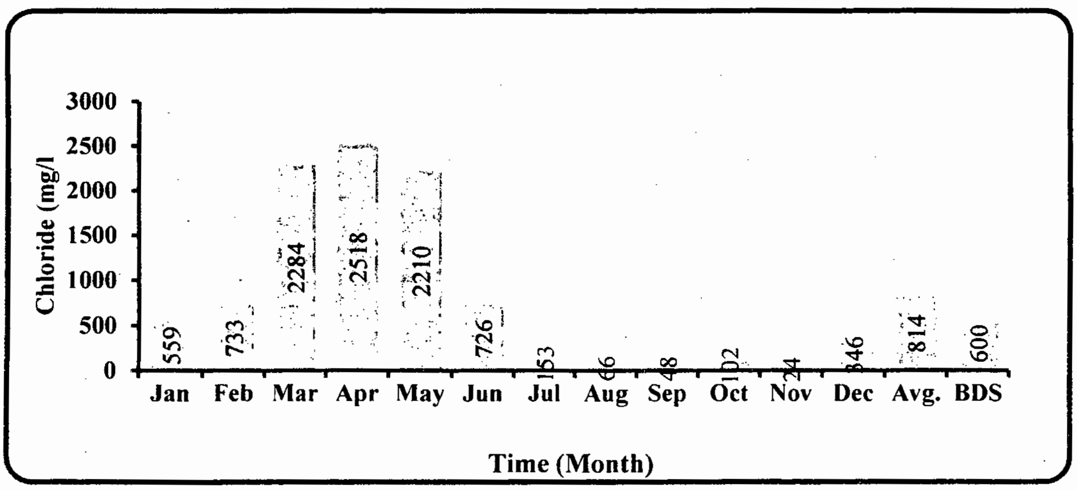

Figure 4.14 Temporal variations of chloride of Bhairab River (year 2014)

4.3.15 Dissolved Oxygen (DO)

DO is the best parameter to assess water quality. Monthly average DO is shown in Figure 4.15 during the study period. Highest DO was 8.09 mg/Lin December while the lowest was 5.73 mg/L in April. DO limit according to Bangladesh drinking standard is 6.0 or above mg/L and DO for fisheries, irrigation, industrial purpose is 5 or more mg/L. So the Bhairab River water is suitable for drinking and also usable for recreation and irrigation purposes based on concentration of dissolved oxygen.

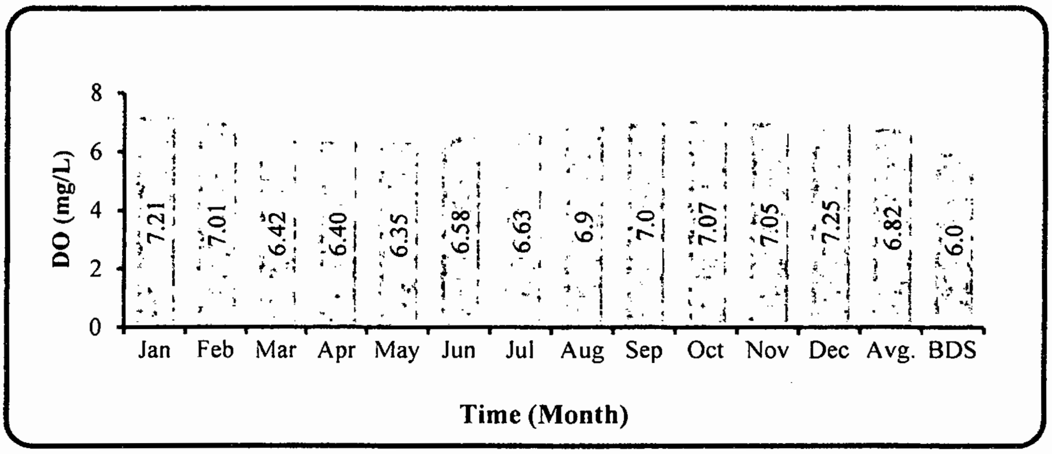

Figure 4.15 Temporal variations of dissolved oxygen of Bhairab River (year 2014)

4.3.16 Bio-Chemical Oxygen Demand (BOD)

In the study monthly average BOD concentrations is shown the Figure 4.16 during the study period. Highest BOD was 1.90 mg/L in March and the lowest one was 0.20 mg/L in April. BOD content was observed high in every month. High BOD indicates sewage pollution. Permissible value for BOD is 0.20 mg/L for drinking water. Hence the Bhairab River water is not suitable for drinking purpose based on BOD concentration.

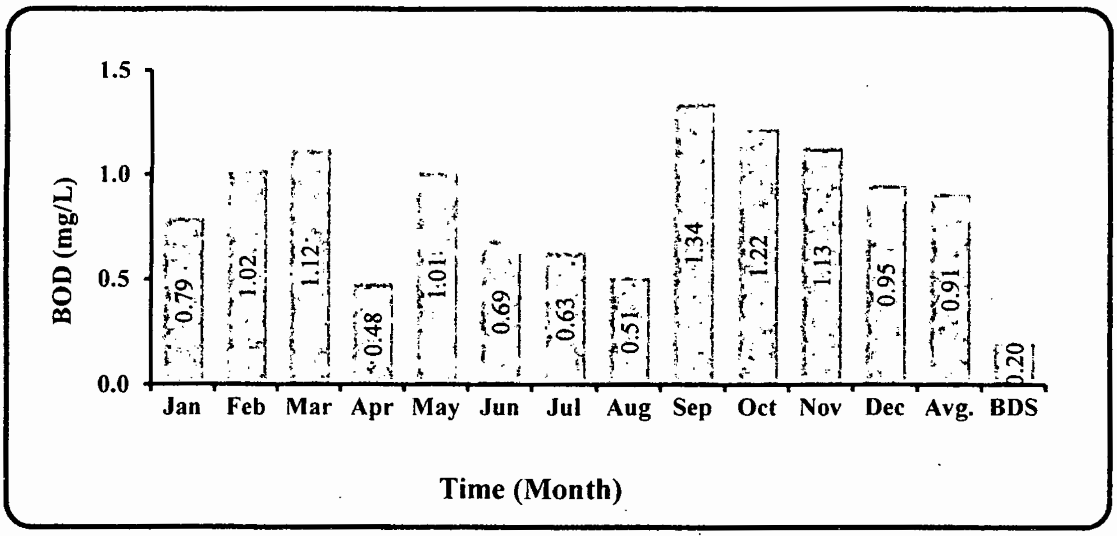

Figure 4.16 Temporal variation of BOD of Bhairab River (year 2014)

4.3.17 Chemical Oxygen Demand (COD)

In the test result monthly average COD were shown in the Figure 4.17. Monthly average, highest and lowest values were 145 mg/L, 448 mg/L and 32 mg/L respectively and all of those exceeded Bangladesh standard drinking water level 4.0 mg/L. Monthly fluctuation of COD was remarkable. COD concentration over the study period was too high in all sampling station. It indicates industrial pollution of water. So the Bhairab River water is not suitable for drinking but usable for other purpose based on COD.

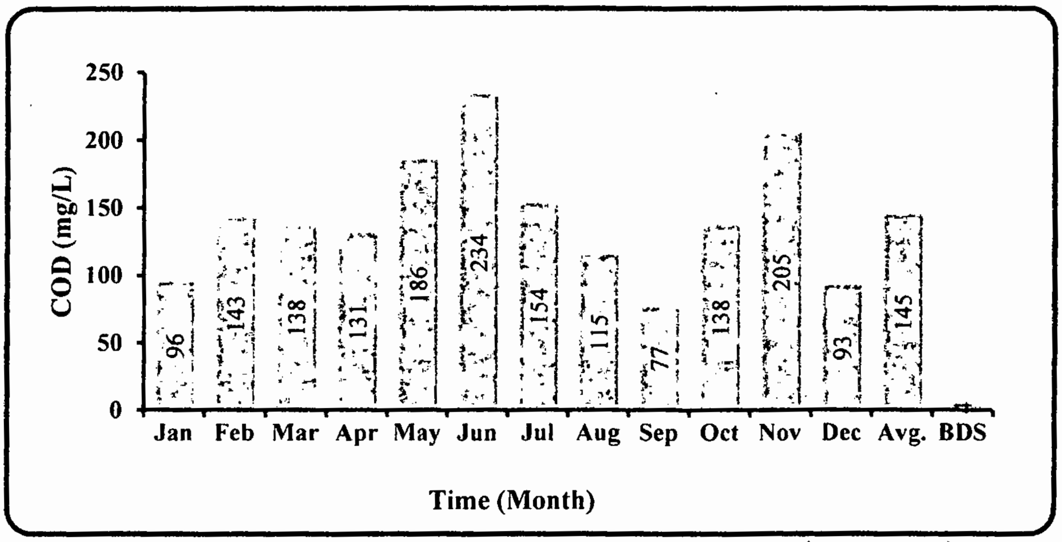

Figure 4.17 Temporal variations of COD of Bhairab River (year 2014)

4.3.18 Manganese

Manganese concentrations of the Bhairab River are shown in Figure 4.18 during the study period. Highest manganese was recorded 0.09 mg/L in March while the lowest was 0.00 mg/L in October. Bangladesh water quality standard for drinking is 0.10 mg/L and there is no standard limit for others. Highest and lowest both values are within the permissible BDS limit. So the Bhairab River water is suitable for all purposes based on manganese concentration.

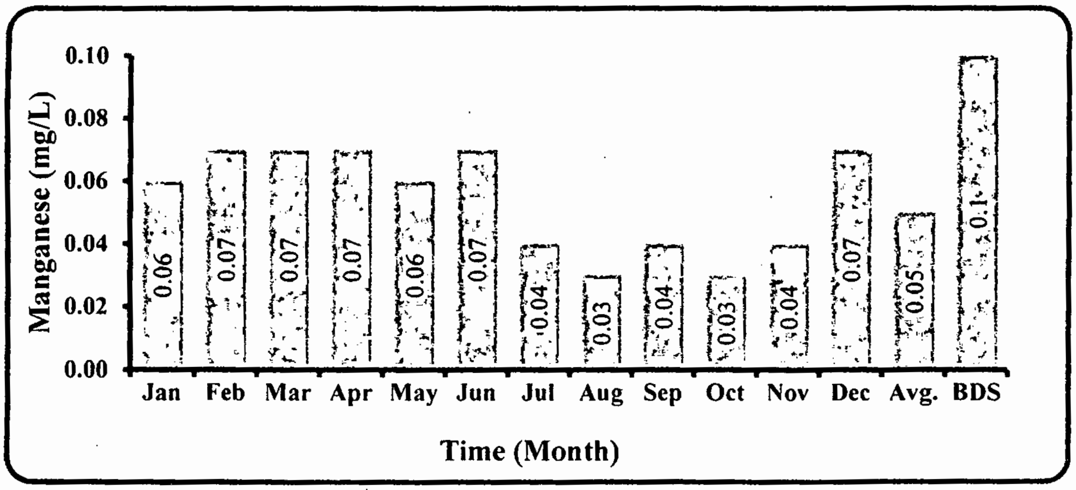

Figure 4.18 Temporal variations of manganese of Bhairab River (year 2014)

4.3.19 Fecal Coliform (FC)

For the study period 2014 average monthly FC is shown in Figure 4.19. Highest FC was recorded 1800 N/100ml in September while the lowest was 180 N/100ml in November. Bangladesh drinking water quality standard for FC is nil/100ml. Highest, average and lowest numbers are exceeded BDS permissible limit. High FC content in water indicates sewage pollution. The monthly variation of FC was remarkable and always too higher than the BDS limit. However the Bhairab River water is not suitable for drinking purposes but may be usable for recreation, irrigation based on fecal coliform.

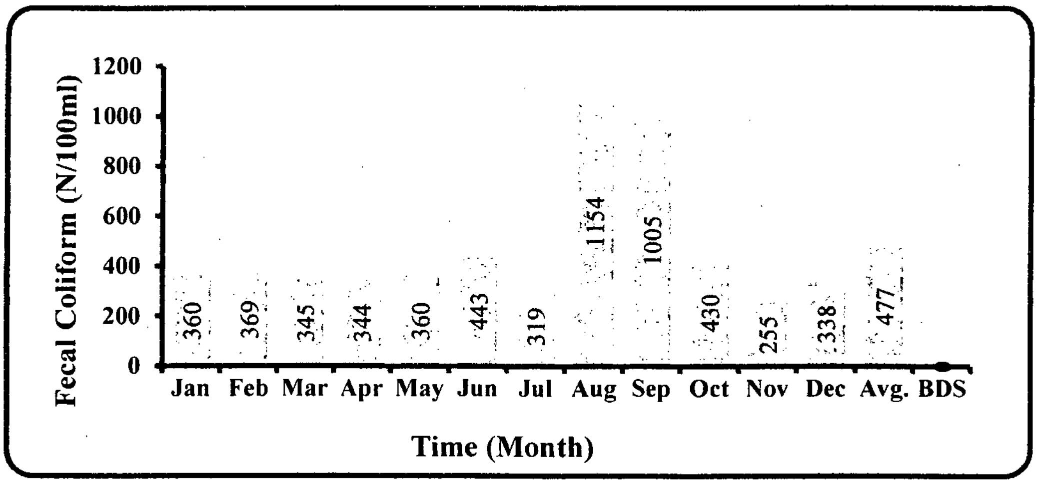

Figure 4.19 Temporal variations of Fecal Coliform of Bhairab River (year 2014)

4.3.20 Total Coliform (TC)

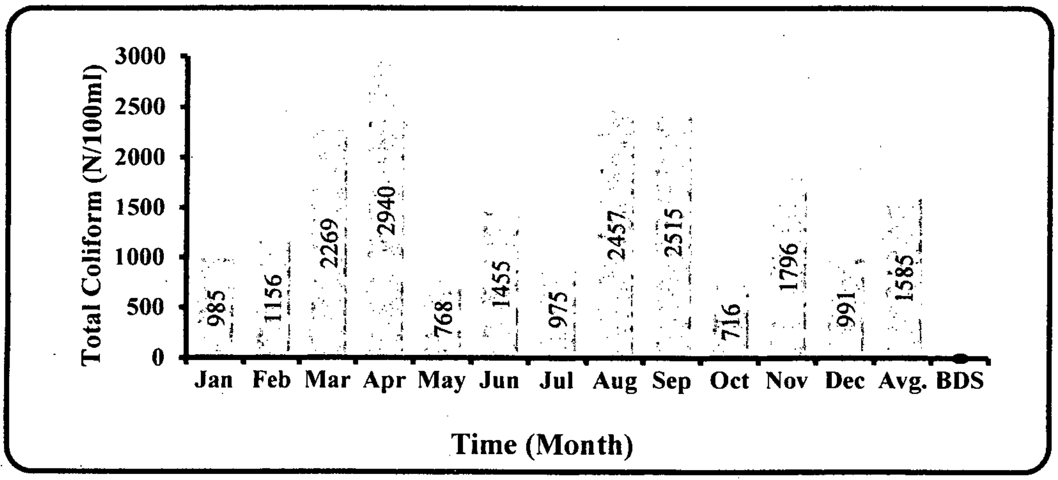

Figure 4.20 Temporal variations of Total Coliform of Bhairab River (year 2014)

Monthly average TC is shown in Figure 4.20 during the study period. As per BDS guideline number TC would be nil per 100ml. Highest TC was found 3400 N/100ml in April while the lowest was 500 N/100ml in July. In August and September of the study period TC increased enormously. Water in high TC content indicates sewage pollution. Throughout the study period total coliform content was high in all stations. So the Bhairab River water is not suitable for drinking without treatment but may be usable for recreation, irrigation purposes based on total coliform.

4.4 Comparison of Water Quality with Tidal Condition.

Some water quality variances were observed during low and high-tide samples are described here. Most cases difference is minor.

- ✓ Total coliforms and turbidity are comparatively high in low-tide than high-tide.
- ✓ pH and chloride found no remarkable variation in both low and high-tide.
- ✓ Dissolved oxygen condition observed better in high-tide.

4.5 Estimated NSF Water Quality Index for Bhairab River.

Water quality index is a dimensionless number that combines multiple water quality factors into a single number. In National Sanitary Foundation (NSF), nine important water quality parameters are used. To calculate WQI primarily individual WQI are determined by using individual water quality result then the overall WQI calculations are made.

4.5.1 Temporal Variation of WQI of Bhairab River

In the NSF water quality index procedure, generally nine parameters are used. The parameters are DO (% saturation), FC, pH, BOD, change in temperature (ΔT), phosphate, nitrate, turbidity and total solids. Among them two parameters DO (% saturation) and change in temperature (ΔT) value are used from Table 4.6 and remaining seven parameters value are from Table 4.1 for calculating WQI. In the Table 4.7 monthly Water Quality Index shown derived by using NSF water quality index equation (equation 3.1, Methodology) and found WQI 68, 66, 60, 56, 57, 57, 62, 60, 61, 61, 70 and 69 respectively from January to December 2014.Before this, Individual water quality index are calculated following Figure 3.22 - Figure 3.30 average sub-index curves. Monthly variation of water quality index is ignorable. Maximum WQI found 69 in December while the minimum was 56 in April. Overall WQI of the study period 2014 found 64.

Temporal variation of water quality index throughout the year 2014 is shown in bar graph in the Figure 4.21. Variation of monthly WQI also show in Figure 4.22 by line graph. In the Table 4.5 NSF water quality index range are shown.

Table 4.5 Water Quality Index ranges described by NSF

Range	0-25	25-50	50-70	70-90	90-100
WQI	Very Bad	Bad	Medium	Good	Excellent

Reference temperature has been considered the lowest temperature of the month. Temperature change (ΔT) has been calculated subtracting individual monthly temperature to the reference temperature. DO (percent saturation) is recorded from DO meter directly during the test. Here pointed out that DO (percent saturation) and DO mg/L reading can be read in the DO meter simultaneously. DO (percent saturation) record and temperature change (ΔT) calculation are shown in the Table 4.5.Comparing with water quality index range temporal water quality of Bhairab River is medium.

Table 4.6 Calculation of DO (% Saturation) and Temperature Change ^{0}C

Sl No.	Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1	DO (mg/L)	7.21	7.01	6.42	6.40	6.35	6.58	6.63	6.9	7.0	7.07	7.05	7.25	6.82
	DO (%Saturation)	**86.52**	**84.12**	**77.04**	**76.80**	**76.20**	**78.96**	**79.56**	**82.80**	**84.0**	**84.84**	**84.6**	**87.0**	**81.87**
2	Temperature (^{0}C)	18.17	22.38	32.02	36.38	37.32	30.69	29.25	28.44	27.64	27.33	21.76	16.89	27.36
	Temp. change (ΔT) ^{0}C	**1.28**	**5.49**	**15.13**	**19.49**	**20.43**	**13.80**	**12.36**	**11.55**	**10.75**	**10.44**	**4.87**	**0.0**	**3.42**

Table 4.7 Temporal Water Quality Index

Sl No.	Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1 year Overall
1	DO	92	90	84	83	83	86	86	89	90	91	91	93	88
2	FC	32	32	32	32	32	30	33	21	22	30	35	32	30
3	pH	88	88	92	91	92	92	92	89	88	88	87	87	90
4	BOD	96	95	94	98	95	97	97	98	92	93	94	95	95
5	Temperature	87	70	28	21	23	29	34	36	46	45	75	92	78
6	Phosphate	76	76	57	39	39	30	42	32	33	33	75	74	51
7	Nitrate	93	91	91	69	88	95	95	95	91	83	92	91	90
8	Turbidity	5	5	5	5	5	5	5	5	5	5	5	5	5
9	Total solids	20	20	20	20	20	20	43	49	72	64	54	20	38
	Monthly WQI	**68**	**66**	**60**	**56**	**57**	**57**	**62**	**60**	**61**	**61**	**70**	**69**	**65**

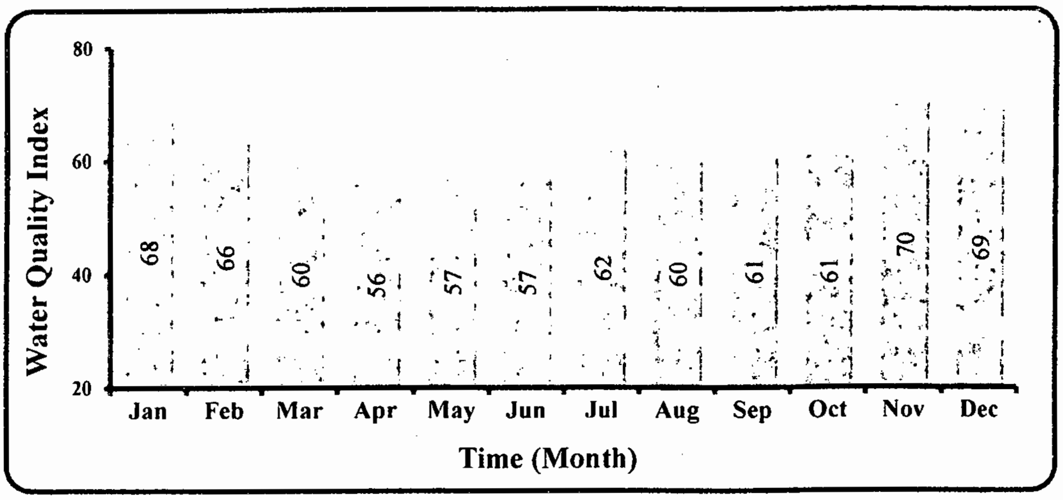

Figure 4.21 Temporal variation of WQI of Bhairab River, 2014 (by bar graph)

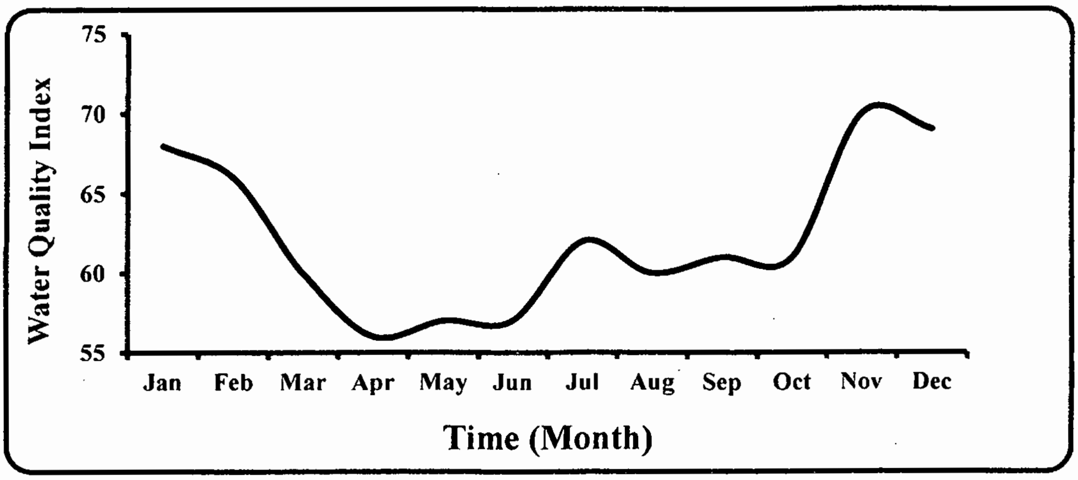

Figure 4.22 Temporal variation of WQI of Bhairab River, 2014 (by line graph)

4.5.2 Calculation of Spatial WQI

Stationwise WQI calculation is the same as monthly process. Here nine parameters experimental quality data are used from Table 4.8. Twelve month average data are used as each station water quality value. In the study stationwise (S_1, S_2...S_{10}) water quality index found 65, 65, 65, 65, 65, 65, 64, 65 and 64 respectively for the year 2014 are shown in Table 4.9.Stationwise no water quality index variations found except S_8 and S_{10}.Maximum WQI found 65 in January while the minimum was 64. Stationwise overall WQI of the study period were also found 65.

Temperature change (ΔT) has been calculated with a reference station. Here reference station is considered most upstream point S_{10} (Noapara, 27.41^{0}C). Change of temperature has been calculated subtracting respective individual temperature from reference temperature. Calculations are shown in Table 4.8.

4.5.3 Comparison between Temporal and Spatial WQI

Temporal WQI variation is more than the stationwise WQI variation. From the Figure 4.21 difference of temporal highest and lowest WQI is 12 while Figure 4.23 stationwise same difference found 1. So, it is clear that WQI temporal variation is much more than spatial variation.

Table 4.8 Test Data for Spatial WQI

Sl No.	Parameters	Station1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station10	Average
1	DO (%sat)	82.32	84.84	83.28	82.68	82.20	82.92	79.42	83.16	80.64	81.84	82.32
2	FC (N/100ml)	438	453	448	462	518	554	504	456	475	461	477
3	pH	7.63	7.59	7.59	7.62	7.53	7.55	7.60	7.57	7.61	7.60	7.59
4	BOD (mg/L)	0.90	0.89	0.73	0.98	0.93	0.64	0.92	1.06	1.05	0.95	0.91
5	**Temperature (^{0}C)**	27.30	27.33	27.37	27.35	27.34	27.40	27.38	27.37	27.31	27.41	27.36
	Temp. change (^{0}C)	**0.11**	**0.08**	**0.04**	**0.06**	**0.07**	**0.01**	**0.03**	**0.04**	**0.10**	**0.0**	**0.05**
6	Phosphate (mg/L)	1.16	0.94	0.90	0.95	0.87	0.82	0.86	0.84	0.88	0.84	0.91
7	Nitrate (mg/L)	2.39	2.61	2.97	3.02	2.75	2.35	2.25	3.29	2.27	3.14	2.70
8	Turbidity (NTU)	451	516	525	546	476	510	414	357	419	429	464
9	Total solids (mg/L)	1923	1777	1747	1811	1793	1764	1847	1779	1598	1696	1773

Table 4.9 Spatial Water Quality Index

Sl No.	Parameters	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station10	Over all WQI
1	DO	89	91	89	89	89	89	86	89	87	88	88.6
2	Fecal Coliform	30	30	30	29	28	28	29	30	29	29	29.2
3	pH	92	92	92	92	92	92	92	92	92	92	92
4	BOD	96	96	97	95	95	97	95	94	95	95	95.5
5	Temperature	93	93	93	93	93	93	93	93	93	93	93
6	Phosphate	37	42	43	42	44	46	45	45	44	45	43.30
7	Nitrate	93	92	90	90	91	93	94	84	94	87	90.80
8	Turbidity	5	5	5	5	5	5	5	5	5	5	5
9	Total solids	20	20	20	20	20	20	20	20	20	20	20
	Spatial WQI	**65**	**65**	**65**	**65**	**65**	**65**	**65**	**64**	**65**	**64**	**65**

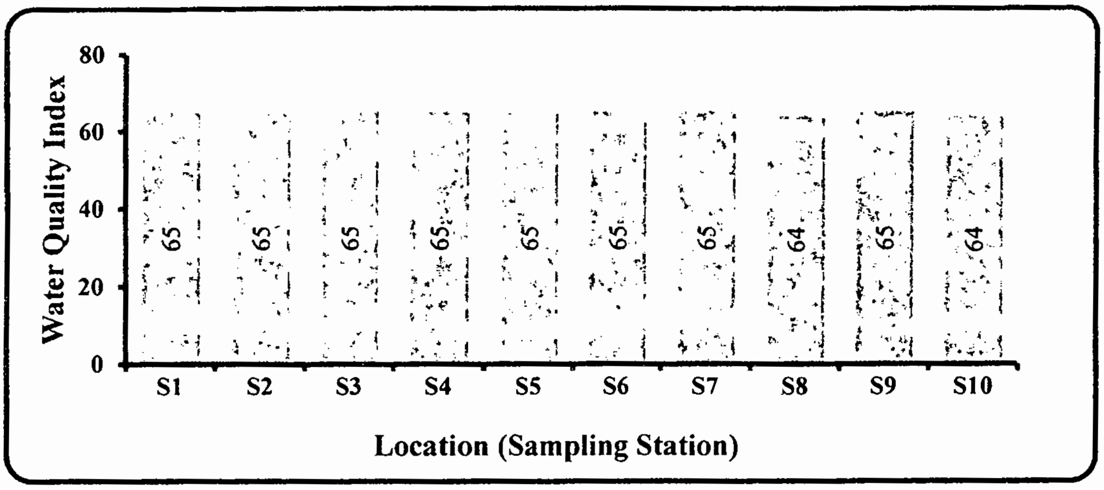

Figure 4.23 Spatial water quality index of Bhairab River

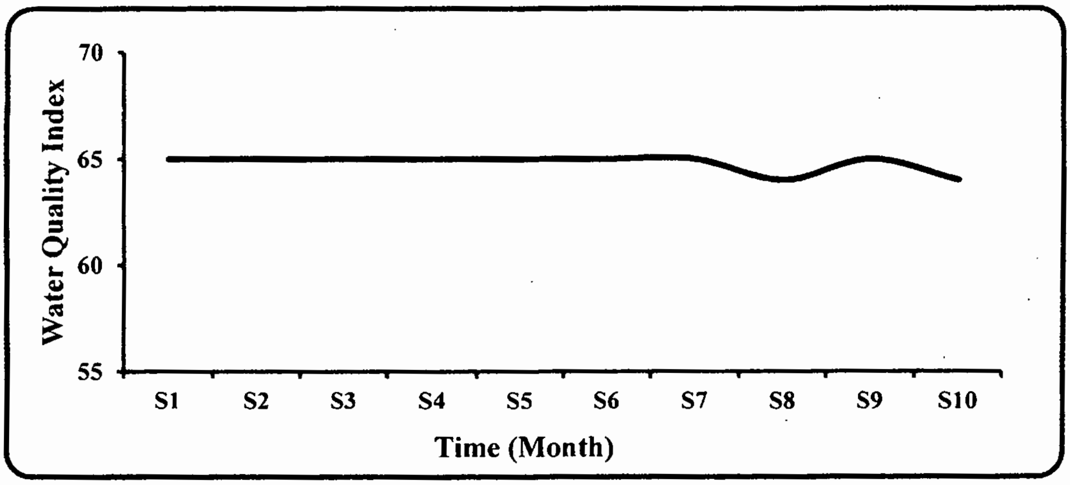

Figure 4.24 Spatial WQI variation of Bhairab River

4.5.4 Projected Trend of Water Quality Index (WQI).

In the study the main purpose is to determine trend of future water quality index so that we can predict far and near future water quality of Bhairab River. Taking water quality data from the Table 4.10 yearly water quality indices found 71, 69, 68, 66, 66, 65, 64, 63, 64 and 64 starting from 2005-2014 respectively and shown in Table 4.11.In the Figure 4.25 Bhairab River water quality index progressive curve has been plotted. It is found that water quality index has progressively decreasing with course of time. In the year 2005 water quality index observed 71 while in 2014 it reduced to 64. During the last ten years WQI decreased by 7 points, so the yearly average decreasing rate presumed 0.70 point per year. This is alarming for the environment. Water quality index is unitless, it is a pure number.

Water quality index is deteriorating day by day due to decline individual water quality with time. Multi-use of water and moreover improper management is the key causes for this. In addition, remarkable trim down of upstream flow influences degradation of water quality.

Table 4.10 Water Quality data of 2005 to 2014

Sl No.	Parameters	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	DO (mg/L)	7.10	7.07	7.17	7.01	6.78	7.12	6.86	6.77	6.68	6.82
	DO (% Saturation)	**85.20**	**84.75**	**86.0**	**84.10**	**81.32**	**85.40**	**82.30**	**81.20**	**80.15**	**81.87**
2	FC (N/100ml)	240	360	400	650	540	380	430	410	380	477
3	pH	7.65	7.65	7.73	7.72	7.67	7.2	7.1	6.95	6.85	7.63
4	BOD (mg/L)	0.74	0.73	0.86	0.84	0.78	1.0	1.4	0.95	1.05	0.91
5	Temperature (^{0}C)	27.28	27.63	27.68	27.55	27.59	27.57	27.84	27.91	27.62	27.36
	Temp. change (^{0}C)	**0.0**	**0.35**	**0.40**	**0.27**	**0.31**	**0.29**	**0.56**	**0.63**	**0.34**	**0.08**
6	Phosphate (mg/L)	0.26	0.41	0.47	0.54	0.63	0.79	0.87	0.94	1.01	0.91
7	Nitrate (mg/L)	1.83	0.96	1.80	1.57	0.97	3.3	3.10	3.63	2.84	2.70
8	Turbidity (NTU)	132	136	100	87	110	180	190	210	275	473
9	Total solids (mg/L)	1625	1763	2563	3653	3481	7174	9580	11060	12740	1773

Source: Department of Environment except BOD. BOD has taken from others.

Table 4.11 Water Quality Index from 2005 to 2014 (ten years).

Sl No.	Parameters	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	DO	91	91	92	90	88	91	89	88	87	88
2	FC	36	32	31	26	28	31	30	31	34	30
3	pH	92	92	91	91	91	92	90	87	84	90
4	BOD	97	97	96	96	96	95	91	95	95	95
5	Temperature	93	91	91	91	91	92	90	90	91	78
6	Phosphate	86	70	63	58	54	47	44	42	40	51
7	Nitrate	95	96	95	95	96	84	88	77	91	90
8	Turbidity	5	5	5	5	5	5	5	5	5	5
9	Total solids	20	20	20	20	20	20	20	20	20	20
	Yearly WQI	71	69	68	66	66	65	64	63	64	**64**

WQI trend equation obtains from the line is **Y= (-0.787X+1649)** .... (4.1)
Using this equation (4.1) water quality index assume to be 51.39 and 35.65 for the year 2025 and 2050 respectively. As per NSF water quality index range in 2025 Bhairab River water quality remains medium while in 2050 quality reduce medium to bad.

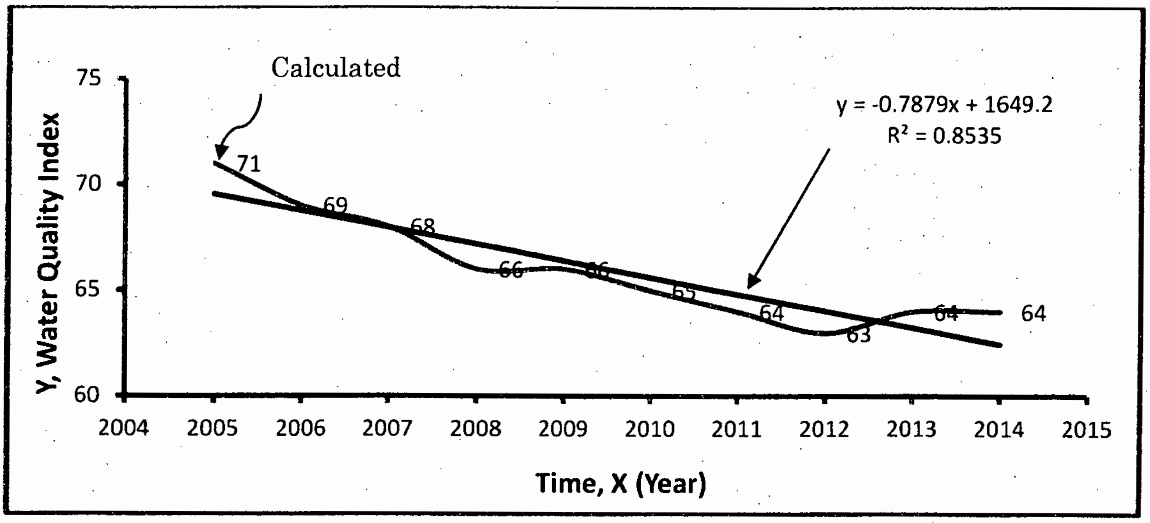

Figure 4.25 Temporal WQI trend of Bhairab River

4.6 Temporal Chloride Variation of Bhairab River

Bhairab River is situated in the coastal area of Bangladesh so its salinity is a very common event. Locals suffer huge for their everyday being activities due to low to high salinity. Chloride data is used from the Table 4.12 for showing temporal variations of chloride concentration of Bhairab River that is shown in Figure 4.26.Generally salinity starts up from February and begins decline May or June depends on intensity of rainfall at upstream.

Table 4.12 Average Chloride Concentration for the Year 2014

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chloride	559	733	2284	2518	2210	726	153	66	48	102	24	346

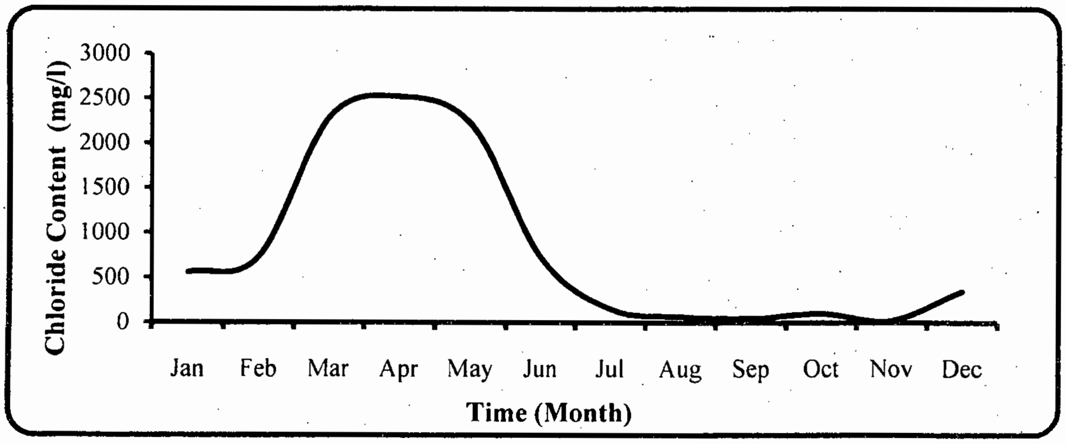

Figure 4.26 Temporal chloride variation of Bhairab River

4.7 Causes of Chloride Mounting

Key cause of gradual chloride mounting is reducing the upstream flow in dry season. In dry season Ganges River flows are controlled strictly and Bhairab River for being one of the tributaries of it reduces the upstream pressure and saline water can easily enter into the inward. Gradual rises of sea level also influencing salinity mounting with the course of time.

4.8. Development of Correlation among Parameters

The correlation can be established by determining correlation coefficient. It is a measure of the strength and direction of a linear relationship between a pair of variables. It is a mutual relationship. The correlation coefficient is denoted by r takes on values ranging between +1 and -1.

4.8.1 Important Guidelines for developing Correlations.

The following points are the accepted guidelines for interpreting the correlation coefficient.

- 0 indicates no linear relationship.
- +1 indicates a perfect positive linear relationship: as one variable increases in its values, the other variable also increases in its values.
- -1 indicates a perfect negative linear relationship: as one variable increases in its values, the other variable decreases in its values.
- Values between 0 and 0.3 (or 0 and -0.3) indicate a weak positive (or negative) linear relationship.
- Values between 0.3 and 0.7 (or -0.3 and -0.7) indicate a moderate positive (or negative) linear relationship.
- Values between 0.7 and 1.0 (or -0.7 and -1.0) indicate a strong positive (or negative) linear relationship.
- The correlation coefficient is a dimensionless quantity, implying that it is not expressed in any units of measurement (Pearson's correlation).

4.8.2 Linearity Assumption

The correlation coefficient requires that the underlying relationship between the two variables under consideration is linear. If the relationship is known to be linear, or the observed pattern between the two variables appears to be linear, then the correlation coefficient provides a reliable measure of the strength of the linear relationship. If the relationship is known to be nonlinear, or the observed pattern appears to be nonlinear, then the correlation coefficient is not useful, or at least questionable.

Table 4.14 Detailed calculation of correlation coefficient between turbidity and suspended solids pair has been interpreted here for clear understanding

Turbidity(x)	SS (y)	$(x-\bar{x})$	$(y-\bar{y})$	$(x-\bar{x})(y-\bar{y})$	$(x-\bar{x})2$	$(y-\bar{y})2$
336	280	-128.17	-44.83	5746	16428	2010
450	270	-14.17	-54.83	777	201	3006
528	316	63.83	-8.83	-564	4074	78
1087	751	622.83	426.17	265431	387917	181621
991	726	526.83	401.17	211348	277550	160937
532	324	67.83	-0.83	-56	4601	1
346	272	-118.17	-52.83	6243	13964	2791
310	267	-154.17	-57.83	8916	23768	3344
258	153	-206.17	-171.83	35426	42506	29526
316	257	-148.17	-67.83	10050	21954	4601
151	118	-313.17	-206.83	64773	98075	42779
265	164	-199.17	-160.83	32033	39669	25866
$\sum x$= 5570	**$\sum y$= 3897**	**$\sum$= 0**	**$\sum$= 0**	**640123**	**930708**	**456560**

Here n=12, Therefore degree of freedom N = n-1 =12-1= 11

$\bar{x}=\frac{\sum x}{n}= 464.17$, $\bar{y}=\frac{\sum y}{n}= 324.83$, where $\bar{x}$ = mean value of x and $\bar{y}$ = mean value of y.

Karl-Pearson Correlation Coefficient $r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})2\sum(y-\bar{y})2}} = \frac{640123}{\sqrt{(930708)(456560)}} = 0.982$

Correlation coefficient among other parameters has been calculated using same means and shown in Table 4.14.

The Correlation co-efficient r value 0.982 between turbidity and suspended solids means the pair is strong and positively correlated with each other i.e. if turbidity increases then suspended solids will increase simultaneously and vice-versa.

Table 4.15 Karl-Pearson's Correlation Matrix (CM) of Studied Water Quality Parameters.

Parameters	Tempt.	pH	Turbidity	Conductivity	Color	Alkalinity	Hardness	TS	TDS	SS	PO_4	NO_2	NO_3	Chloride	DO	BOD	COD	Mn	FC	TC
Temp.	1																			
pH	-0.20	1																		
Turbidity	-0.10	0.510	1																	
Conductivity	0.67	0.267	0.453	1																
Color	-0.51	0.533	0.654	0.041	1															
Alkalinity	-0.086	0.126	0.543	0.489	0.508	1														
Hardness	-0.055	0.774	0.329	0.695	0.284	0.118	1													
TS	0.628	0.306	0.540	0.995	0.113	0.522	0.702	1												
TDS	0.070	0.268	0.454	0.997	0.048	0.491	0.700	0.995	1											
SS	-0.036	0.469	0.982	0.403	0.593	0.518	0.285	0.541	0.453	1										
Phosphate	0.597	-0.491	-0.599	-0.063	-0.745	-0.689	-0.312	-0.121	-0.064	-0.533	1									
Nitrite	-0.331	0.092	0.368	0.389	0.127	0.248	0.142	0.422	0.383	0.152	-0.475	1								
Nitrate	0.295	-0.247	0.175	0.533	0.026	0.565	-0.257	0.515	0.534	0.099	-0.133	0.379	1							
Chloride	0.666	0.266	0.416	0.997	0.045	0.499	0.687	0.994	0.995	0.461	-0.072	0.40	0.535	1						
DO	-0.923	-0.046	-0.113	-0.784	0.346	-0.030	-0.244	-0.758	-0.783	-0.175	-0.341	0.213	-0.182	-0.781	1					
BOD	-0.225	-0.604	0.062	-0.176	0.043	0.309	-0.637	-0..156	-0.178	0.102	-0.181	0.249	0.231	-0.169	0.314	1				
COD	0.378	-0.148	-0.129	0.131	-0.135	-0.105	-0.003	0.124	0.132	-0.005	0.234	-0.391	-0.281	0.123	-0.462	-0.030	1			
Manganese	0.008	0.622	0.654	0.616	0.560	0.070	0.398	0.454	0.460	0.322	-0.023	0.001	0.012	0.460	-0.035	-0.006	0.001	1		
FC	0.087	-0.215	-0.356	-0.355	-0.377	-0.482	-0.335	-0.357	-0.206	-0.299	0.585	-0.558	-0.245	-0.356	0.157	-0.046	-0.340	-0.210	1	
TC	0.350	-0.092	0.049	0.263	-0.257	0.140	0.076	0.158	-0.093	0.093	0.241	-0.346	0.024	0.262	-0.290	0.224	-0.149	-0.007	0.487	1

Table 4.16 Calculation of Karl-Pearson's Correlation Coefficient r^2 Values

Parameters	Temp.	pH	Turb.	Cond.	Color	Alkali.	Hardn.	TS	TDS	SS	PO_4	NO_2	NO_3	Cl	DO	BOD	COD	Mn	FC	TC	Individual Parameter Correlations.			
																					N	W	M	S
Temperature	1																				8	5	5	1
pH	0.00	1																			7	9	3	0
Turbidity	0.00	0.25	1																		6	8	4	1
Conductivity	0.00	0.07	0.20	1																	5	8	3	3
Color	0.26	0.28	**0.43**	0.00	1																8	7	4	0
Alkalinity	0.00	0.00	**0.30**	0.24	0.26	1															8	8	3	0
Hardness	0.00	**0.60**	0.10	**0.48**	0.08	0.00	1														5	8	6	0
TS	**0.40**	0.10	0.30	***0.99***	0.00	0.28	**0.50**	1													5	7	4	3
TDS	**0.44**	0.07	0.20	***0.99***	0.00	0.24	**0.49**	***0.99***	1												5	7	4	3
SS	0.00	0.22	***0.96***	0.20	**0.35**	0.27	0.08	**0.30**	0.20	1											6	10	2	1
Phosphate	**0.36**	0.24	**0.36**	0.00	**0.56**	**0.47**	0.09	0.00	0.00	0.28	1										7	7	5	0
Nitrite	0.11	0.00	0.14	0..15	0.00	0.00	0.00	0.18	0.14	0.00	0.23	1									6	12	1	0
Nitrate	0.09	0.06	0.00	0.28	0.00	**0.32**	0.07	0.27	**0.30**	0.00	0.00	0.14	1								7	10	2	0
Chloride	**0.43**	0.07	0.21	***0.99***	0.00	0.25	**0.47**	***0.99***	**0.99**	0.21	0.00	0.16	0.29	1							4	9	3	3
DO	***0.85***	0.00	0.00	**0.61**	0.12	0.00	0.06	**0.58**	**0.61**	0.00	0.12	0.05	0.00	**0.60**	1						7	7	4	1
BOD	0.05	**0.36**	0.00	0.00	0.00	0.09	**0.40**	0.00	0.00	0.00	0.00	0.06	0.05	0.00	0.10	1					11	6	2	0
COD	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.15	0.08	0.00	0.22	0.00	1				13	6	0	0
Manganese	0.00	**0.39**	**0.41**	**0.38**	**0.31**	0.00	0.16	0.20	0.21	0.10	0.00	0.00	0.00	0.21	0.00	0.00	0.00	1			10	5	4	0
FC	0.00	0.00	0.13	0.13	0.14	0.23	0.12	0.14	0.13	0.09	**0.34**	**0.31**	0.06	0.13	0.00	0.00	0.12	0.00	1		6	11	2	0
TC	0.13	0.00	0.00	0.07	0.07	0.00	0.00	0.00	0.00	0.008	0.06	0.12	0.00	0.07	0.08	0.05	0.00	0.00	0.23	1	9	10	0	0

Note: Moderately correlated are indicated by bold while strongly correlated are indicated by bold and italic. N - No correlation, W - Weak correlation, M - Moderately correlation and S - Strong correlation.

In the Table 4.15 Correlation Matrix (CM) among 20 water quality parameters of Bhairab River has been developed. All the parameters are more or less correlated with each other. Total 190 correlation are developed among them 116 are positive and 74 are negatively correlated. Positive or negative correlation characterizes nature of the correlations. A positive correlation means one parameter increases the other parameter increases simultaneously. But in negative correlation one parameter increases, decreases the other one. Phosphate is the highest while pH is the lowest negatively correlated parameters. Correlation is calculated by following Karl-Pearson's correlation method.

In the Table 4.16 square value of correlation matrix (CM) among 20 water quality parameters of Bhairab River has been made. Square value was made for being identified correlation among parameters more efficiently. In the square value of correlation coefficient some correlation disappears and the real correlation come out. In the square magnitude we can't understand the nature of correlation.

4.9 Correlation Based on Strength

Among 190 squared calculated correlations in Table 4.16, 71 found no correlation among them while 81 weak, 30 medium and 8 got strong correlations. Individually parameterwise correlation are discussed here following Table 4.16.

4.9.1 No Correlation

Among 190 correlation 71 correlation value found 0.00 i.e. those correlation are ignorable which is 37.35%. From here it is clear that a considerable portion of correlation is non-influential. Most of the no correlation parameters are COD, BOD, Manganese, Color, Alkalinity, Dissolved oxygen etc. These parameters has been correlated least times with others.

4.9.2 Weak Correlation

Total 81weak correlation (Coefficient over zero-0.30) found which is 42.65% of total developed correlation of Bhairab River. Weak correlation denotes weak influence among parameters. Weak correlated parameters are identified as Fecal coliform, Total coliform, Nitrite, Suspended solids, pH etc.

4.9.3 Moderately Correlation

Total 30 moderately correlation (Coefficient 0.30-0.70) found which 15.78% of total developed correlation of Bhairab River. Moderately correlation is considerable because it influence other parameters remarkably. In Bhairab River correlation analysis many parameters demonstrate moderate correlation amongst them Hardness, Temperature, Phosphate, TS, TDS, Manganese, Conductivity are remarkable. Moderately correlated parameters are important to know the major influence of river water quality.

4.9.4 Strong Correlation

Only 8 strong correlation (Coefficient over 0.70) observed in Bhairab River correlation analysis which 4.22% of total developed correlation. Strong correlation denotes highly influence among water quality parameters. Most strong correlated parameters are identified as Temperature, Turbidity, Conductivity, Total solids, Total dissolved solids, Suspended solids, Chloride and dissolved oxygen. Some cases these parameters has made negative or positively strong correlation among them. These eight parameters are important to manage water quality of Bhairab River.

4.10 Final Remarks on the Water Quality of Bhairab River

From the Table 4.16 it is observed that total 190 correlation has been developed by using twenty water quality parameters. Amongst then 71 found no correlation, 81 weak, 30 moderately and 8 strong. Only moderate and strong correlation can influence remarkably with others parameters.

Bhairab River established that Temperature, Turbidity, Conductivity, Total solids, Total dissolved solids, Suspended solids, Chloride and dissolved oxygen these eight water quality parameters contribute enormously to form strong correlation with each other. Specially conductivity, TDS and chloride are strong and positively correlated. Precisely it can be said that when chloride remain under tolerance limit then Bhairab River water can be used in various ways and means except drinking.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

Bhairab River is the only perennial surface water source in the catchment which recharges the shallow aquifers being used for irrigation and domestic purposes. Some important water quality parameters like Temperature, pH, Turbidity, Conductivity, Color, Alkalinity, Hardness, TS, TDS, SS, Phosphate, Nitrite, Nitrate, Chloride, DO, BOD, COD, Manganese, TC and FC has been studied during the year 2014.

In the present study the indices values have been estimated at ten sampling locations along the stretch of the Bhairab River to ascertain the suitability of water for designated best use at particular location and time to determine the level of treatment required for the individual parameter and level of pollution. Correlation has been developed among parameters and finally, water quality index of this river was assessed by using national sanitary foundation water quality index method.

5.2 Conclusions

During the study following conclusions are drawn.

1. Total twenty water quality parameters were tested among them twelve parameters such as Turbidity, Conductivity, Color, Alkalinity, TS, TDS, SS, Chloride, BOD, COD, TC and FC were beyond BDS limit while the remaining eight parameters found within BDS limits are identified as Temperature, pH, Total hardness, DO, Phosphate, Nitrite, Manganese and Nitrate. If Bhairab river water would be used for drinking purposes then the water must be treated.

2. In the correlation study it shows that all the parameters are not correlated with each other. Total 190 correlations are developed among them 8 are strongly, 30 are moderately, 81 are weakly correlated. Remaining 71 did not happen any correlation. Chloride, TDS and conductivity are very strongly correlated with each others. If the water monitoring authority keeps under control those influencing parameters then the water management process will be easy and effective.

3. Water quality index trend observed downward on course of time. Water quality index found 71 in 2005 whereas 64 in 2014. So, last ten years it reduced by 7 points and average yearly decline results0.7 points. Projected WQI in 2030 and 2050 assumed to be 51.39 and 35.65 which will push water quality medium to bad.

4. Chloride trend moves upward. In dry season particularly January to May chloride content goes beyond the permissible limit. In this period Bhairab River water can't be used any domestic, agricultural and commercial purposes. Chloride concentration in the river mainly depends on amount of flow arrives from upstream.

5. Along the river bank there found some hanging latrine. People directly discharging their excretion in the river. Besides, huge cargo vessel move through Bhairab River and its crew also fall their feces directly in river. It increases BOD and bacterial pollution.

5.3 Recommendations

The following recommendations are suggested to improve the present condition and for future study.

1. The entire hanging latrine along the river especially in Hat-Bazar area to be removed or they should construct hygienic and environment friendly toilet.

2. Effluents of industries and urban sewage system must be treated and monitored sincerely before outfall.
3. Modern waste management methods should be applied. Private sector may be encouraged for introducing modern recycling process.

4. Mass media (Print & electronic) should come forward in publicity of showing causes and impacts of water pollution.

5. Fish is the indication to measure the level of river water pollution. So it is practical and significant to make further research on aquatic species for the safety of human health as well as river environment.

6. This study specifically deals with the water quality index and its trends in future of Bhairab River. However further investigation is recommended to know the heavy metals and its impact on water quality.

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ANNEXURE

Pollution Sources of Bhairab River

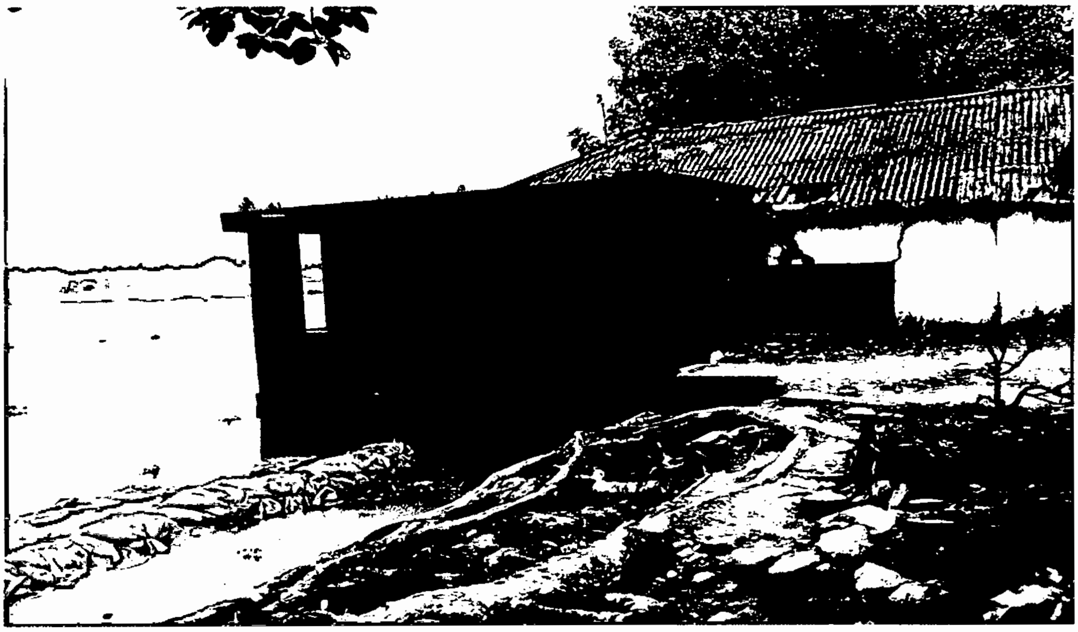

Figure A.1 Photograph of public toilet direct discharging sewage in Bhairab River.

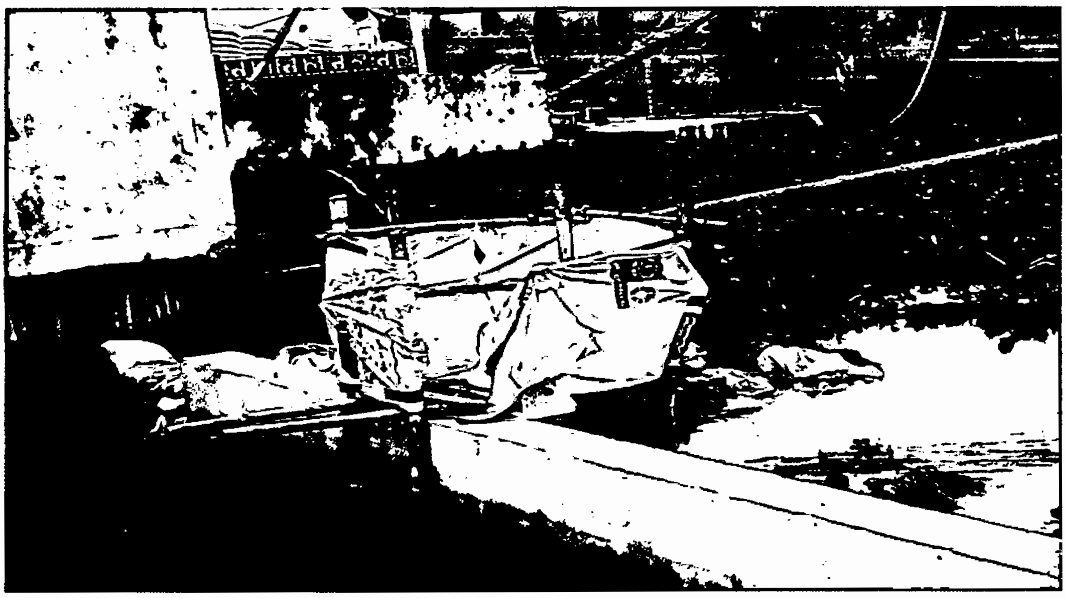

Figure A.2 Photograph of hanging latrine near 7 Rosevalt ghat, Khulna.

Figure A.3 Photograph of Solid waste of a printing and packaging company near Bhairab River at Rupsha.

Figure A.4 Photograph of wastewater outfall of Noapara Pourashava to Bhairab River

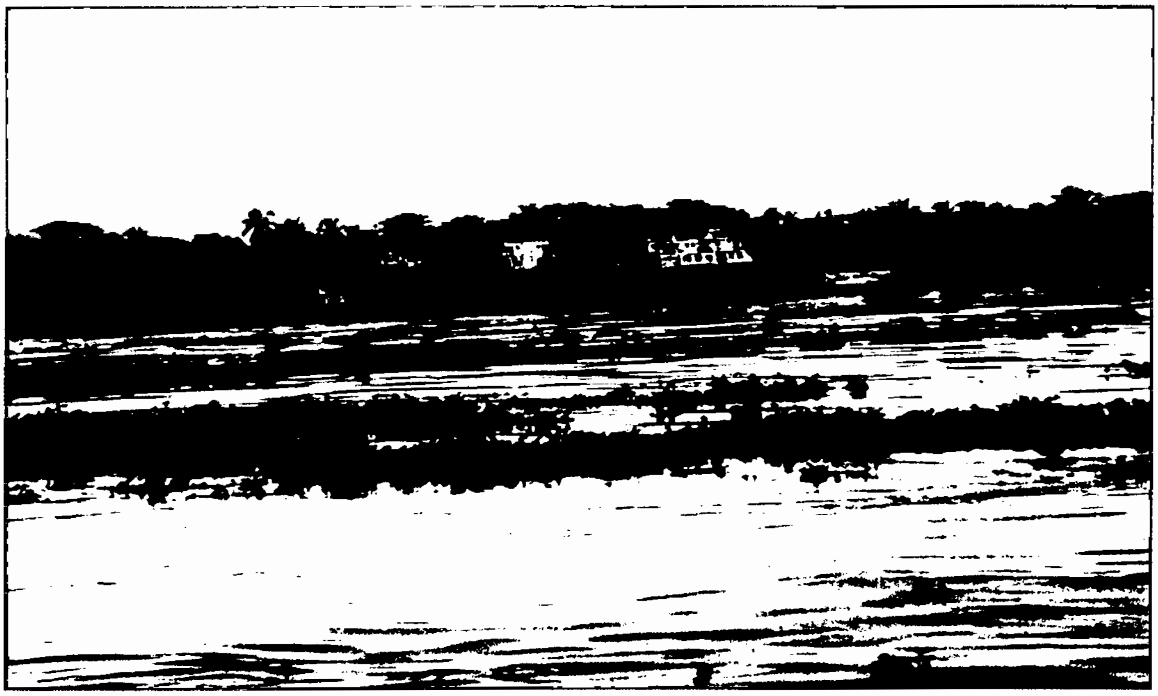

Figure A.5 Photograph of Hyacinthine Pollution of Bhairab River

Figure A.6 Photograph of Coal related pollution at Noapara