Assessment of Microbial Quality of Supply Water in Chittagong City, Bangladesh

A Master Thesis presented by

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Declaration

I herewith declare that I completed this document independently and did not use any other than the cited references and aids. I cited exact quotations and paraphrases as such, and I followed the rules of good scientific practice in the general regulations of the Karlsruhe Institute of Technology (KIT) (*Regeln zur Sicherung guter wissenschaftlicher Praxis im Karlsruher Institut für Technologie (KIT)*) in its most current edition. I did not submit this document to any other institution for the purpose of being awarded any other academic degree.

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Abstract

Chittagong is the second largest city in Bangladesh and its premier sea port and industrialized city. Due to its economic activity it has led to a large population influx. Chittagong Water and Sewerage Authority (CWASA) is the responsible authority for supplying water to the city dwellers, which is being use for drinking purpose also. But the kind of population and urban growth Chittagong is going through, presents tremendous challenges to the utility authority in providing utility services. The water supplied by the CWASA is being treated by Mohra Water treatment Plant and Kalurghat Iron removal Plant. But the problem of water shortage, compounded by pollution, is causing indisputable harm to the city by posing a serious risk of microbial contamination of drinking water.

The aim of the study was to reveal the present water quality, more importantly microbial water quality of the supplied water of CWASA, to assess the reasons or influencing factors and to discusses major deterioration mechanisms that may contribute to water quality failure. Samples of water from the raw water source, treated water before entering distribution network, from distribution network and consumers' reservoir were collected and tested for some microbial (total coliform, fecal coliform and Escherichia coliform) and chemical parameters. Some formal and informal discussion with CWASA employee and direct observation were also used for data collection during the field survey.

The results show that various parameters (Maximum values distribution network/ consumers' reservoirs: TC: 8/100ml / 4/100ml, FC: 3/100 ml / 3/100ml, EC: 1/100ml / 2/100ml, Turbidity: 41 NTU/ 15 NTU and Minimum Residual Chlorine: 0mg/l / 0 mg/l) analyzed in the samples exceeded the Bangladesh Environmental conservation Rule, 1997 and WHO Guideline for drinking water. About 17.5% samples were found to be microbial contaminated in the distribution network, but in reservoirs the contamination was 45%. It is not that the supplied water is always of poor quality, but due to longer retention time in users' reservoir the chance of contamination gets higher and the water deteriorate. Insufficient and centralized chlorination, pre chlorination, pipe leakage, damage and corrosion, absence of any sewer system in the city, pipe alignment close to sewage system or open drains, pressure fluctuation in net, lack of proper maintenance of distribution network and consumers' reservoirs, lack of public awareness, unplanned urbanization etc. have been found as the crucial role in water quality deterioration.

To improve the present water quality, increment of post chlorination dose, decentralized chlorination, use of biological filters for algae removal, appropriate maintenance of distribution network, regular sanitary inspection, regular assessment of water samples from the net, proper maintenance of consumers' reservoirs, involvement of local public in maintenance activity and lots of others measures have been proposed. But organizing public awareness and capacity building program along with above mentioned recommendation have been given a higher priority to confirm a secure investment in Safe Drinking Water and Health.

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Nomenclature

AC…………..... Asbestos Cement
AOC…………. Assimilable Organic Carbon
BBS………….. Bangladesh Bureau Statistics
BDOC……….. Biodegradable Dissolved Organic Carbons
BECR………... Bangladesh Environmental Conservation Rule
BOD………… Biological Oxygen Demand
BPS………….. Booster Pump Stations
CCC…………. Chittagong City Corporation
CDA…………. Chittagong Development Authority
COD…………. Chemical Oxygen Demand
CR…………… Consumers' Reservoir
CWASA……... Chittagong Water and Sewerage Authority
DI……………. Ductile Iron
DN…………... Distribution Network
DO…………... Dissolved Oxygen
DPHE………... Department of Public Health Engineering
DTW………… Deep tube wells
E…………….. East
E.Coli………... Escherichia coli
EPZ………….. Export Processing Zone
FC…………… Fecal Coliform
GoB…………. Government of Bangladesh
HWL………… Hydraulic Water Level
ID……………. Identity Number
JICA…………. Japan International Cooperation Organization
KIRP………… Kalurghat Iron Removal Plant
KOICA……… Korea International Cooperation Organization
LGD…………. Local Government Division
LGRD……….. Local Government and Rural Development

MOD…………	Maintenance Operation Distribution
MWTP……….	Mohra Water Treatment Plant
min…………..	Minimum
max………….	Maximum
N……………..	North
NPSWSS…….	National Policy for Safe Water Supply and Sanitation
NWMP……….	National Water Management Plan
NWP…………	National Water Policy
PVC………….	Polyvinyl Chloride
RDOC………..	Refractory Dissolved Organic Carbons
SS…………….	Suspended Solids
TC……………	Total Coliform
TDS………….	Total Dissolved Solids
UFW…………	Unaccounted-for -Water
USAID……….	United States Agency for International Development
WHO…………	World Health Organization

Measurement Units and Symbols

Measurement Units

#/ml	Number per milliliter
cm	centimeter
ft	Feet
ft^2	Square feet
gm	gram
gpm /ft^2	Gallon per minute per square feet
gpm	Gallon per minute
km	Kilometer
KW	Kilo Watt
lpm	Liter per minute
m/d.	Meter per day
m	Meter
m^2	Square meter
m^3	Cubic meter
$m^3/d/m^2$	Cubic meter per day per square meter
m^3/day	Cubic meter per day
$m^3/h/m^2$	Cubic meter per hour per square meter
m^3/min	Cubic meter per minute
mg/l	Milligram per liter
MGD	Million Gallon per day
ml	Milliliter
ML.	Million liter
MLD	Million liter per day
mm	millimeter
nm	Neno meter
NTU	Nephelometric Turbidity Units

ppm	Parts per million
sft	Square Feet
sq. km	Square Kilometer

Symbols

%	Percentage
~	Within the range
$<$	Smaller than
$>$	Greater than
$\geq$	Greater than or equal
°C	Degree Celsius
BOD_5	Biological Oxygen Demand of 5 days
Cl_2	Chlorine
$K_2 HgI_4$	Potassium Iodomercurate
N	Normal
NaOH	Sodium Hydroxide
NH_3-N	Ammonia Nitrogen
X°Y'Z"	Degree, minute and second
$ZnSO_4$	Zinc Sulfate

1 Introduction

1.1General

Water is one of the vital components of the physical environment. The quality of drinking water is closely associated with human health, and providing safe drinking water is one of important public health priorities. Affordable, abundant and clean water is essential for human well-being. There are clear linkages between access to potable water and health, nutrition levels and subsequently education achievement, labor productivity and economic growth. Worldwide in 1995, contaminated water and food caused more than 3 million deaths, of which more than 80% were among children under age five (WHO, 1996). Globally, the World Health Organization (WHO) estimates that 1.8 million people die each year from diarrheal diseases. Parveen *et al*, 2008, reported that at least one and a half thousand million people worldwide used polluted water. This problem is more acute in developing countries where higher incidence of water-borne diseases is reported. A recent estimate suggested that residents of developed countries experience 1 episode of diarrheal illness every 2 years, whilst residents of developing nations may experience between 5 and 20 episodes per year. With a current global population 6.5 billion individuals this adds up to 5-60 billion gastroenteritis cases annually (Nath *et al*, 2006).

Problems are acute, especially in the urban areas due to increased migration of rural people and increased economic growth as well. By 2020, half of the developing world's population will live in urban centers, including the mushrooming informal settlements that now account for 40% – 70% of the population in many cities in developing countries. In many cities demand for water, at current tariff levels, greatly outstrips supply, resulting in water management strategies that deliver water to households only for a few hours each day or for certain days of the week. As many as 500 million urban residents have inappropriate access to water services or experience water scarcity (USAID, 2006). They also acknowledge that many of the remaining 5.2 billion people who use an "improved" water source nevertheless drink water which is unsafe, following contamination at source, in the piped distribution system or as a result of unhygienic handling during transport or in the home. Consumption of unsafe water continues to be one of the major causes of diarrheal disease deaths (Nath *et al*, 2006).

The problem of water shortage, compounded by pollution, is causing indisputable harm in most poor countries of Asia and Africa. The population in poor countries like Bangladesh is growing so fast that improvements on water supply have failed to keep pace. As the demand for water increases, share of water per person will decrease, gradually it would result in greater demand for water. With about 250 rivers that once dotted the country, Bangladesh is now identified as a water-scarce country. Moreover, as much of the world becomes urbanized, its water crisis will deepen. Human activity is playing an ever greater role in creating water scarcity and "water stress" -- defined as the indication that there is not enough good quality water to meet human needs. Given the pressures of urban population growth, especially of low-income families that construct dwellings at the urban fringe far removed from main trunk lines, providing adequate supplies of safe water will remain one of the biggest urban challenges in coming decades.

Chittagong commercial capital of Bangladesh is one of the densely populated urban areas which has been suffering from inadequate supply of drinking water often associated with water quality problems too. This city is also witness of major population growth over the last three decades, mainly due to migration from the villages and other part of the country. The population of the city was 0.5 million in 1971, which has grown to more than 3.6 million in 2004 (Amin, 2006). The total area of Chittagong and suburban areas is around 270 sq-km. Between 1974 (77 sq. km.) to 2007, the built-up area has increased by around 250% (CWASA, 2009). Chittagong Water and Sewerage Authority (CWASA) is supplying water to the city dwellers. Although some private and community tube wells are found in the city, a large fraction of the people directly depend on CWASA’s supply water. This kind of growth presents tremendous challenges to the utility authorities in providing utility services.

1.2 Problem Statement

The scarcity of adequate and safe drinking water has posed a serious threat to city dwellers in recent days. CWASA is supplying water to the city dwellers by its limited distribution network system as the only 7.5% of the estimated households in the Chittagong City Corporation (CCC) area is connected to the treated pipe water (World Bank, 2010). Moreover CWASA can meet only one-fourth of the total demand of the port city and the water supply is not regular but intermittent (Amin, 2006). The insufficient amount of water supplied by WASA means that half or more of the city’s needs are supplied by other wells or surface water whose quality is not known. The main sources of CWASA’s supply water are surface water from Halda River and groundwater from deep tube wells (400-1000 ft) at different locations of the city. Surface water extracted from the above source is being supplied to the distribution network after treatment at Mohra Water Treatment Plant whereas groundwater is being treated at Kalurghat Treatment Plant. But the city dwellers are not only suffering from inadequate water supply but they also are posed to serious threat due to the scarcity of safe water.

A fourfold variation in deaths due to diarrhea was revealed between the five divisions assessed in Bangladesh in a Demographic and Health survey carried out in 2004. Diarrhea proportional mortality under 5-s ranged from 2.1% to 8.5% showing the maximum in Chittagong. Poor access to water, sanitation and hygiene, poor housing, crowding and limited or no access to care were considered to be some of the main risk factors for the development of diarrheal disease (Boschi-

Pinto *et al*, 2009). So this indicates the quality of drinking water in Chittagong is at high risk. In another research done by Zuthi *et al*, 2009, water quality test results of random samples collected from different routes of CWASA's distribution system revealed that the microbial water quality deteriorated during its flow from treatment plant through the distribution system though the water leaving the Mohra treatment plant and Kalurghat Iron Removal Plant contained neither total coliform nor fecal coliform.

Although some communities may have access to piped water at home, it may be contaminated by defects in the distribution system. Many communities have access to water that is microbiologically safe when collected or when it leaves a treatment plant. However, substandard water distribution systems, intermittent water pressure often lead to the introduction of fecal contamination resulting in microbiologically contaminated water at the consumer's tap or collection point, even though the water may have been obtained from a high quality, protected and centrally treated source. Therefore, water supply in those areas may not be safe for drinking purpose and domestic use considering the microbiological water quality standard. Only a group of fortunate people are capable of buying drinking water from private owned company. Rests of the dwellers have to rely on CWASA water for drinking which often pose a potential source of health risk. CWASA is striving hard to keep pace with the city development. In this backdrop the question of water quality is beyond imagination for the dwellers as well as for CWASA also. Therefore the people of Chittagong city are at high risk due to microbial contamination of drinking water.

1.3 Objectives of the Study:

The deterioration of water quality can adversely affect consumers' health as well as the aesthetic properties of water (taste, odor, color). One of the primary drinking water quality concerns in the distribution system is the presence of microorganisms. The public health impacts of bacteria growth in the distribution system have been explored and well-documented. Distribution system conditions conducive to bacterial growth can result in a loss of disinfectant residual, violation of drinking water regulations focusing on microbial water quality in the distribution system and growth of opportunistic pathogens. So the major focus of this Master Thesis was to reveal present water quality of the supply water by Chittagong WASA.

The first goal of this Thesis is to provide the quality, mainly microbial water quality, of water supplied by CWASA. The thesis hereby attempts to give an overview on the present water supply and quality within the city. In order to identify such water quality, water samples from intake points of surface and ground water, different locations of the distribution network of CWASA and right after the treatment were analyzed in this study. Microbial water quality parameters and some physical and chemical parameters were examined. The results are compared with the Bangladesh guidelines and WHO guidelines for drinking water to give a better understanding of the quality of drinking water the city people are consuming.

To date, little consideration has been given to the impact of deteriorating (ageing) water mains on water quality as a major decision driver for the renewal/ rehabilitation of water mains. The second goal was to assess the reasons or influencing factors which are responsible to deteriorate the quality of the supply water. Numerous factors can affect water quality in the distribution network like effects of urbanization and anthropogenic activities, long retention time, condition of storage tanks, different problems in distribution network, fault in the treatment plant or environmental factor etc. This thesis discusses major deterioration mechanisms that may contribute to water quality failure.

Finally some recommendations and ideas are developed to improve the present water quality situation. These recommendations can be taken as suggestion by CWASA to improve the present situation and to ensure a more sustainable water supply system. Specific main purposes of this Master's Thesis and research is to

1. Assess the present microbial quality of water supplied by CWASA.
2. Find out what are the reasons or influencing factors responsible for the water quality.
3. Develop ideas and recommend measures can be taken to improve the situation.

1.4 Scope of the Study:

Among waterborne diseases of bacterial origin typhoid, bacillary dysentery and diarrhoea are common in Bangladesh. Although a substantial amount of work has been carried out on common water borne pathogens in Bangladesh, unfortunately a little information is available (Parveen *et al*, 2008). Observed the significance of monitoring supply water quality, a study on drinking water quality in the distribution network was done in Khulna city corporation area of Bangladesh. No further study was conducted in other urban areas of Bangladesh (Zuthi *et al*, 2009). Though Chittagong is the second largest city of the country, the quality of the supply water has not yet been given the priority as it was supposed to be. So this study was conducted to determine the microbial quality of the water distributed by the CWASA.

High risks are associated with the ingestion of water that is contaminated with human and animal excreta. The microbiological quality indicator is concentration of fecal coliform (FC) bacteria in the water samples. The detection of *Escherichia coli* (*E. coli*) provides definite evidence of fecal pollution. If drinking water is fecally contaminated, bacterial pathogens are likely to be widely and rapidly dispersed. Both WHO guideline and Bangladesh standard values for bacteriological quality for drinking water suggested that FC must not be detectable ('nil') in any 100 ml sample (Hoque *et al*, 2006). The microbial contamination of drinking water will result in the contamination of food, an increased number of carriers and cases, the re-contamination of drinking water, and the vicious circle of disease spreading and death will thus be completed. Since contaminated water can pose a potential source of health risk to Chittagong city dwellers, it is pertinent to ascertain the quality of water from production to consumers end with an objective to assess important water quality parameters of the CWASA's supply water. Study in this respect is also to warn the city dwellers against the quality of water they are using and waterborne pathogens.

Chlorine is by far the most commonly used disinfectant in developing countries and without exception in Chittagong also. Several factors influence the efficiency of disinfection with chlorine. These include the pH and turbidity of the water and, of course, the concentration of chlorine and contact time. Thus, this study analyzes the effectiveness of water treatment plant and the faults in the distribution system, hence assesses the mechanism of water quality failure. The data presented here may serve as a baseline, and can be compared in any future research work.

Finally the Thesis also recommends some solutions to improve the present condition of the water supply system which is must for safe water supply. CWASA may consider some of these recommendations to have a better water quality. As safe water supply has a direct on the livelihood of the poor people by improving health and saving lots of time, this study was also an effort to make a progress towards Millennium Development Goal and reducing poverty in the country.

2. Literature Review

2.1 Legislation in Bangladesh Concerning Water Supply and Safe Drinking Water

2.1.1 The Water Supply and Sewerage Ordinance 1963

The 'WASA Ordinance, 1963' giving Government of Bangladesh (GoB) power to establish WASAs and permitting them to do any work relating to water supply, sewerage systems, solid waste management and drainage. The 1963 ordinance presently regulates Chittagong WASA (LGD, 2004). To meet the water supply and sanitation needs of the population the act was established with the objectives of construction, operation and maintenance of necessary infrastructure for water supply for domestic, industrial and commercial purpose, construction, operation and maintenances of sewerage system and solid waste management. In 1989, the responsibility of Storm Water Drainage management was transferred to WASA from the Department of Public Health Engineering (DPHE) (Jafar Ullah, 2004).

2.1.2 Water Supply and Sewerage Authority Law 1996

This law has been enacted in 1996 for guideline of creating an authority responsible for cities water supply and sewerage system in Bangladesh. The law mainly discusses about how the authority will form, what will be the area of jurisdiction, how the governing body and employee will be selected, what will be the funding method, legal basis for employee, delegation of power, budgeting and auditing procedure, fixing tariff to city dwellers etc. The law says no person other than the authority has the right to create any facility for extracting, filtering and pumping water as well as sewerage system. In case the authority lack or fail to create such facilities in particular area permission may be given with fixed tariff to any individual or any company for creating such facilities (Water Supply and Sewerage Authority Ordinance, 1996).

2.1.3 National Policy for Safe Water Supply and Sanitation, 1998

The GoB through the Local Government Division (LGD) of the Ministry of Local Government, Rural Development (LGRD) and Co-operatives, declared in October 1998 the National Policy for Safe Water Supply and Sanitation (NPSWSS). The objectives of the policy are '*to improve the standard of public health and to ensure improved environment*' by reducing water-borne disease and contamination of surface water and groundwater (LGD 2004).For achieving these objectives, steps are to be taken for reducing incidence of water borne diseases; promoting sustainable water and sanitation services; ensuring proper storage, management and use of surface water and preventing its contamination; making safe drinking water available to each household in the urban areas; ensuring supply of quality water through observance of accepted quality standards;

removal of arsenic from drinking water and supply of arsenic free water from alternate sources in arsenic affected areas (National Policy for Safe Water Supply and Sanitation, 1998).

2.1.4 National Water Policy, 1999

The National Water Policy (NWP) prepared by the Ministry of Water Resources and approved in November 1998 outlines the national policy for management of water resources (Bangladesh State of Environment, 2001). Water Supply and Sanitation is one of the key issues of NWP. Addressing issues related to the harnessing and development of all forms of surface water and ground water are among the main goals of NWP. Moreover NWP is also concerned to ensure the availability of water to all elements of society including the poor and unprivileged, and to take into account to the particular needs of the women and children (Ministry of Water Resources, 2005). It will guide management of the country's water resources by all the concerned ministries, agencies, departments, and local bodies that are assigned responsibilities for the development, maintenance, and delivery of water and water related issues (National Water Policy, 1999).

2.1.5 National Water Management Plan, 2001

Through the National Water Management Plan, the Government sets the goal of enabling the entire populace access to safe water and sewerage services by the year 2010 and raising the water supply diffusion rate in urban areas to 75% by 2010, and to 90% by 2025. The improvement of water supply in major cities where the populations are rapidly rising, particularly Chittagong with its notable gap between supply and demand, has been accorded a high level of priority. The main objectives of NWMP are rational management and wise-use of Bangladesh's water resources, people's quality of life improved by the equitable, safe and reliable access to water for production, health and hygiene and clean water in sufficient and timely quantities for multi-purpose use and preservation of the aquatic and water dependent eco-systems (Ministry of Water Resources, 2005). The plan will be executed by different agencies as determined by the government from time to time. The NWMP and all other related plans will be prepared in comprehensive and integrated manner, with regard for the interests of all water related sectors (National Water Management Plan, 2001).

2.2 Quality Standards Followed by Bangladesh

2.2.1 Bangladesh Water Quality Standards

In the year of 1991, the Department of Environment has set up "*Environmental Quality Standards for Bangladesh*" which is a set of tools and guidelines to implement government policies regarding environment pollution control and environment protection. Depending on the type of use, the Standard has classified water in several categories. As the menace of water borne diseases and epidemics still looms on large horizon of Bangladesh, drinking water has been given the most importance, specially the microbiological quality and the absence of toxic substance of water. The drinking water standards for different parameters of water mentioned in this standard (Annex A.1) is a basis for decision making of activities of the surveillance function. There is also rules regarding to the areas where water is not supplied through distribution network, rather people use water from untreated sources like well, boreholes etc. To prevent the bacteriological contamination in these type of area rules and regulation associated with water withdraw, storage have been established, like: removing obvious source of contamination from the immediate catchment, safe disposal of excreta, restricting access of man and animal by fencing near the source, lining and covering the wells and storage tank etc (Environmental Quality Standard for Bangladesh, 1991).

"The Environmental Conservation Rules (1997)" was published by the Ministry of Environment and Forest of GoB, which revised the drinking water parameters in Environmental Quality Standards for Bangladesh, 1991 and also included some new parameters those were not included in previous standard. The water quality standards for different purposes and uses are provided in the rules (Annex A.2). Moreover this conservation rules also provides inland water criteria for different purposes such as potable water, recreation, industrial and irrigation in a summarized manner (Annex A.3).

2.2.2 WHO Guidelines

The World Health Organization's (WHO) drinking water quality guidelines are the international reference points for drinking water quality standards. WHO produces international norms on water quality and human health in the form of guidelines that are used as the basis for regulation and standard setting, in developing and developed countries world-wide. In 1983–1984 and in 1993–1997, the World Health Organization (WHO) published the first and second editions of the *Guidelines for Drinking-water Quality* in three volumes as successors to previous WHO International Standards. The Guidelines are addressed primarily to water and health regulators, policy makers and their advisors, to assist in the development of national standards. The development of the third edition of the *Guidelines for Drinking-water Quality* includes a substantive revision of approaches to ensuring microbial safety. These Guidelines and associated documents are used by Bangladesh as a source of information on water quality and health and on effective management approaches. The WHO guideline has been used as a reference in the establishment of Bangladesh Drinking Water Standard also. The most common water parameters limit for drinking water by WHO Guideline has been listed in Annex A.4.

2.3 Commonly Considered Water Quality Parameters

2.3.1 Microbiological Characteristics (Coliforms)

The microbiological quality of drinking water is the most important aspect of drinking water because of its association with waterborne diseases. Typhoid fever, cholera, enteroviral disease, bacillary and amoebic dysentery, and many varieties of gastrointestinal diseases, can all be transmitted by water. Coliforms are useful indicators of the possible presence of pathogenic bacteria and viruses. Total coliforms have long been utilized as a microbial measure of drinking water quality, largely because they are easy to detect and enumerate in water. It includes many lactose fermenting bacteria which can be found both in faeces and environment as well as drinking water containing relatively high concentration of nutrients. It can be of both fecal and non fecal origin. Fecal Coliforms are defined as the group of total coliforms that are able to ferment lactose at 44-45° C. They comprise the genus Escherichia and, to a lesser extent, species of Klebsiella, Enterobacter and Citrobacter. Of these organisms, only E.coli is considered specially to be fecal origin (Payment *et al*, w/d). E. coli is a member of the total coliform group of bacteria and is the only member that is found exclusively in the faeces of humans and other animals. Its presence in water indicates not only recent fecal contamination of the water but also the possible presence of intestinal disease-causing bacteria, viruses, and protozoa (Government of Alberta, 2006).

2.3.2 pH

pH is a parameter that indicates the acidity of a water sample. The operational guideline recommended in Bangladesh and WHO drinking water standard is to maintain a pH between 6.5 and 8.5. The principal objective in controlling pH is to produce a water that is neither corrosive nor produces incrustation. Water with a pH of 7.0 to 8.5 will require more chlorine for the destruction of pathogens (disease organisms) than will water that is slightly acid. More alkaline water requires a longer contact time or a higher free residual chlorine level at the end of the contact time for adequate disinfection (0.4–0.5 mg/l at pH 6–8, rising to 0.6 mg/l at pH 8–9; chlorination alum coagulation may be ineffective above pH 9). At pH levels above 8.5, mineral incrustations and bitter tastes can occur. Corrosion is commonly associated with pH levels below 6.5 and elevated levels of certain undesirable chemical parameters may result from corrosion of specific types of pipe.

2.3.3 Residual Chlorine

Chlorine, the most common disinfectant, is effective in killing most pathogenic bacteria and viruses. Municipal potable water supplies are usually chlorinated to provide a residual concentration of 0.5 to 2.0 ppm (mg/l)**.** The presence of chlorine residual in drinking water indicates that: 1) a sufficient amount of chlorine was added initially to the water to inactivate the bacteria and some viruses that cause diarrheal disease; and, 2) the water is protected from recontamination during storage. The presence of free residual chlorine in drinking water is correlated with the absence of disease-causing organisms, and thus is a measure of the potability of water. According to WHO guideline, for effective disinfection, there should be a residual concentration of free chlorine of ≥ 0.5 mg/l after at least 30 min contact time at pH <8.0.

2.3.4 Dissolved oxygen

The dissolved oxygen content of water is influenced by the source, raw water temperature, treatment and chemical or biological processes taking place in the distribution system. Depletion of dissolved oxygen in water supplies can encourage the microbial reduction of nitrate to nitrite and sulfate to sulfide. It can also cause an increase in the concentration of ferrous iron in solution, with subsequent discoloration at the tap when the water is aerated. No health-based guideline value is recommended by WHO Guideline (WHO, 2004). But Bangladesh has set a limit of 6 mg/l (minimum) for drinking water.

2.3.5 Biological Oxygen Demand

Biological Oxygen Demand (BOD) is one of the most common measures of pollutant organic material in water. BOD indicates the amount of putrescible organic matter present in water. Therefore, a low BOD is an indicator of good quality water, while a high BOD indicates polluted water. Dissolved oxygen (DO) is consumed by bacteria when large amounts of organic matter from sewage or other discharges are present in the water. Though it is a very important parameter of water quality, WHO guideline for drinking water has not recommended any limit for BOD. But the Standard for Bangladesh Drinking Water says, the BOD limit can be maximum 0.2 mg/l for water using for drinking purpose.

2.3.6 Chemical Oxygen Demand

Chemical Oxygen Demand (COD) is used as a measure of the capacity to water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite. BOD and COD do not necessarily measure the same types of oxygen consumption. For example, COD does not measure the oxygen consuming potential associated with certain dissolved organic compounds such as acetate. However, acetate can be metabolized by microorganisms and would therefore detect in any assay of BOD. In contrast the oxygen consuming potential of cellulose is not measured during a short term BOD assay, but it is measured during a COD test. For drinking water Bangladesh has set a limit of 4mg/l (maximum) but WHO does not recommend any.

2.3.7 Turbidity

Turbidity is a measure of the cloudiness or opaqueness of the water and is measured in Nephelometric Turbidity Units (NTU). The turbidity is influenced by the amount and nature of suspended organic and inorganic material in water. Typically, the higher the concentration of the suspended material the greater the turbidity. Higher turbidities could cause aesthetic problems or inhibit the ability of a system to disinfect the water. The source of turbidity could be fine sand, silt, and clay (i.e., soil separates); organic material, particles of iron and manganese or other metal oxides, rust from corroding piping, or carbonate precipitates. Control of turbidity in drinking-water systems is important for both health and aesthetic reasons. The substances and particles that cause turbidity can be responsible for significant interference with disinfection, can be a source of disease-causing organisms and can shield pathogenic organisms from the disinfection process. Turbidity is an important indicator of treatment efficiency and the efficiency of filters in particular.

2.3.8 Total Dissolved Solids

The term "Total Dissolved Solids" (TDS) refers mainly to the inorganic substances dissolved in water. The principal constituents of TDS are chloride, sulphates, calcium, magnesium and bicarbonates. The effects of TDS on drinking water quality depend on the levels of the individual components. Excessive hardness, taste, mineral deposition or corrosion is common properties of highly mineralized water. The palatability of drinking water with a TDS level less than 500 mg/l is generally considered to be good. But in WHO and Bangladesh standard a 1000 mg/l level is recommended for drinking water.

2.3.9 Ammonia

Ammonia is one of the forms of nitrogen found in water. Ammoniacal compounds can be found in most natural waters; however, they do originate from decomposing plant and animal matter and can be used as an indicator or recent pollution by sewage or industrial effluent. The amount of ammonia in raw water is important in determining the disinfection doses for chlorine. The presence of ammonia in drinking water is undesirable because nitrification might lead to toxic levels of nitrite or adverse effects on water taste and odor and might increase heterotrophic bacteria, including opportunistic pathogens (Paul *et al*, 2009). According to WHO guideline 2004, Ammonia is not of direct relevance to health at these levels, and no health-based guideline value has been proposed.

3 Case Study

3.1 Location

Chittagong, the second largest city of Bangladesh lies between latitudes approximately 22°14' - 22°24'30" N and longitudes 91°46' - 22°53' E. Its western and southern parts are bounded by coast of the Bay of Bengal and the southeastern parts are surrounded by the river Karnafuli (Haque *et al*, 1997). It is not only the principal city of the district of Chittagong but also commercial capital of Bangladesh. The growth of this city is mainly contributed to the port. After independence Chittagong city has grown at a tremendous pace. Many large medium and small scale industries have been set up here. The first Export Processing Zone (EPZ) of the country was established in the city. There was unprecedented growth of Garments industries in the last few decades (Amin, 2006).

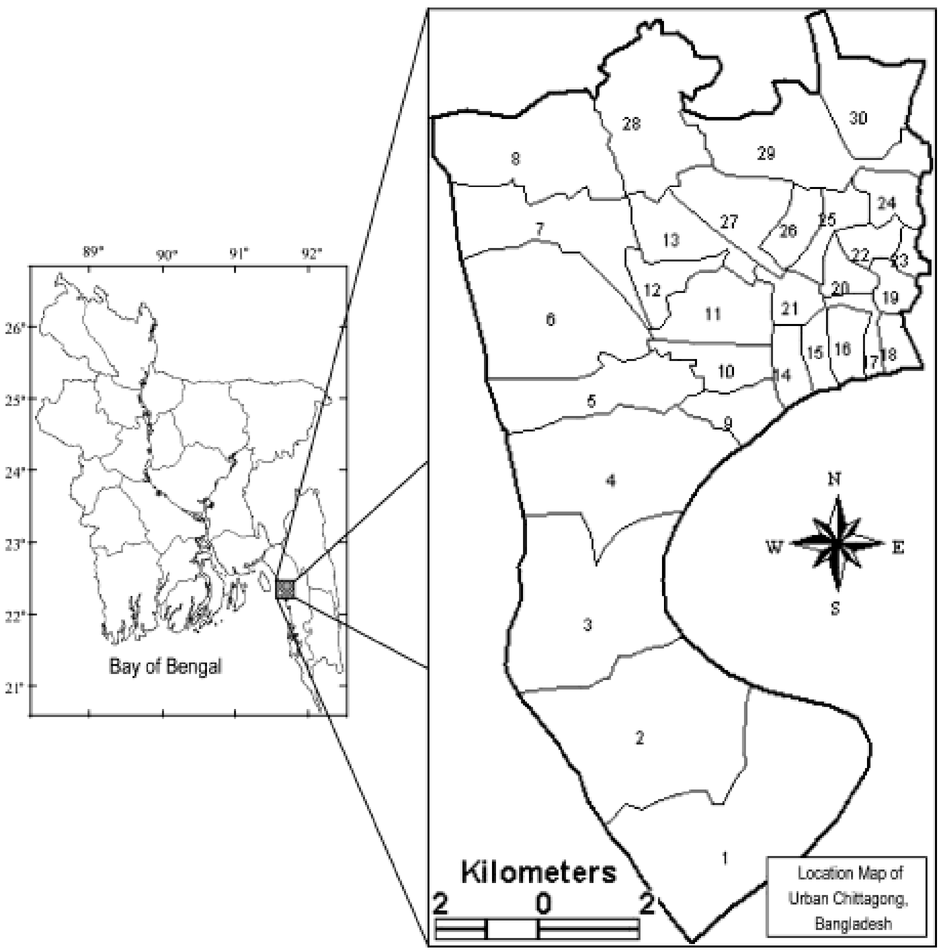


Fig 3.1: Geographic Location of Chittagong city (Hossain et al, 2009)

3.2 Area and Population

According to Chittagong City Corporation, the area of Chittagong City is 154 sq. km (Chowdhury, 2007). Again Bangladesh Bureau Statistics (BBS), 2001 claimed that total city corporation area is 209.67 sq. km. The city has total 41 in no wards the jurisdiction of City Corporation. Furthermore it is divided into 9 Zone by Chittagong Development Authority (CDA) on the basis of some facilities provided and problem arises (Majumdar *et al*, 2007). According to master plan of CDA made in 1961, total 259 sq. km area is being covered which means in near future the jurisdiction of City Corporation is likely to broaden up.

In Bangladesh, it has been revealed between 1991 and 2001 census, an estimated urban population evolved from 22.45 million in 1991 to 28.7 million in 2001. The share of the urban population represented slightly more than 20% of a total population of 111.45 million in 1991 increased slightly less than 23.5% of a total population of 129.25 million in 2001 with a growth rate 1.48% per annum as shown in Table 3.1. It indicates that people are inclined more towards urbanization with the passage of time.

Table 3.1: Total Urban and Rural population levels and trends in Bangladesh

Year	Total population (million)	Growth rate %	Urban population (million)	Urban %	Growth rate (urban) %	Rural population (million)	Rural %	Growth rate (rural) %
1961	55.2	-	2.6	4.8	--	52.6	95.20	--
1974	76.4	2.5	6.0	7.9	6.6	70.4	92.10	4.3
1981	89.9	2.4	14.1	15.7	10.6	77.8	84.30	6.1
1991	111.45	2.17	22.45	20.15	5.4	89.0	79.61	1.5
2001	129.25	1.48	28.8	23.39	4.2	100.44	76.61	1.3

Source: Country Reports on Local Government Systems, 2005.

The trend of the ensuing study described in above paragraph is evident in almost all the metropolitan of Bangladesh. Likewise, Chittagong Metropolitan city had a population of 2,202,637 in 2001 (Bangladesh Bureau of Statistics, 2001). According to the Urban Agglomaration report of United Nation 2007, it increased to 4.5 Million in the year 2007 and projected to be 7.6 million by 2025 with the estimation of present growth rate, through which the city is going to secure the 46^{th} place from 174^{th} rank basing on population. Up to 2007, 2.7% of country’s total population was living in this city. Another report of World Urbanization Prospects: The 2009 Revision population Database states that the current population of Chittagong city is 49, 62,000 and the growth rate is 3.43%. The population is going to increase about 1.46 times becoming 72, 65,000 by 2025 (Fig: 3.2).That means presently Chittagong has a population density of about 23,665 per sq. km.

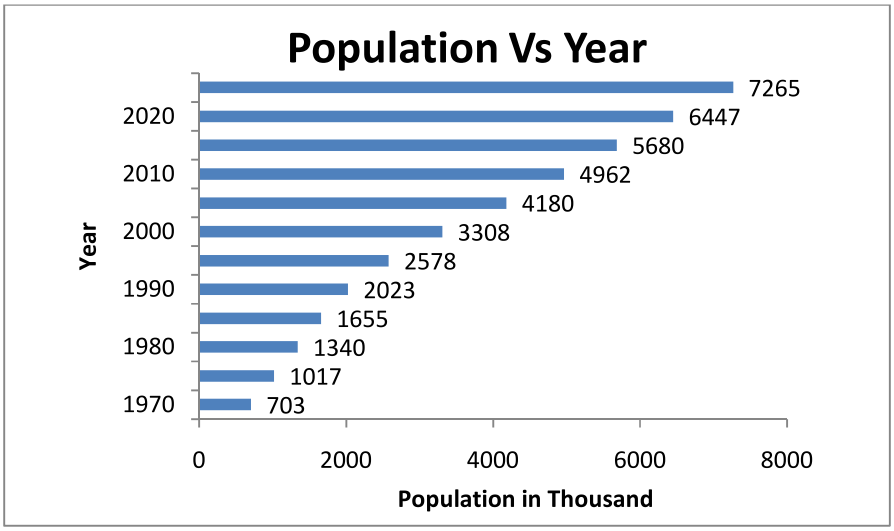


Fig 3.2: Population trend of Chittagong City

Source: World urbanization Prospects: The 2009 Revision population Database

3.3 Climate

Chittagong has a tropical monsoon-type climate, with a hot and rainy summer and a pronounced dry season in the cooler months. January is the coolest month of the year, with the lowest monthly average low temperature is 13°C and April and May are the warmest month with the highest monthly average high temperature is 32°C. About 15% of the annual rainfall occurs during this period mainly as thunder storms and often accompanied by strong winds and cyclones. The humidity is generally high throughout the period. The average temperature in Chittagong is 25.1°C. The cool season extends from November through February and is generally pleasant and comfortable. Rainfall in this season is infrequent. The lowest temperature of the year which vary from 7°C to 11°C are recorded in these months and daily maximum are usually below 28°C as shown in Table 3.2. Skies are generally cloudless during this season.

The climate is one of the wettest in the world; rainfall in Chittagong is second highest in the country. On an average Chittagong's climate receives 2,735 mm (107.7 in) of rainfall per year, or 228 mm (9.0 in) per month. The monsoon season normally begins in June and continues through October. In an average 75% to 80% of the annual rainfall occur during this period. Rain storms of several days duration characterized by relatively slow but steady rain occur during this season. Most of the destructive cyclonic storms with wind of more than 75 miles per hour occur during pre monsoon and post monsoon period, i.e. April-May and November. On average there are 135 days per year with more than 0.1 mm (0.004 in) of rainfall or 11 days with a quantity of rain, sleet etc. per month. The driest weather is in January when an average of 6 mm of rainfall occurs across 2 days. The wettest weather is in July when an average of 598 mm of rainfall occurs across 26 days. The average annual relative humidity is 73.7% and average monthly relative humidity ranges from 58% in January and February to 86% in August (World weather and Climate Graphs, 2008).

Table 3.2: Average Temperature and Rainfall of Chittagong

Features \ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C	32	34	37	39	37	37	34	34	35	34	34	31	39
Average high °C	26	28	31	32	32	31	30	30	31	31	29	26	30
Average low °C	13	15	19	23	24	25	25	24	24	23	18	14	21
Record low °C	7	8	11	15	18	20	19	22	22	17	11	8	7
Precipitation (mm)	5	28	64	150	264	533	597	518	320	180	56	15	2730

Source: BBC Weather Center

3.4 Water Supply in Chittagong City

3.4.1 Responsible Authority

WASA Chittagong is a semi-autonomous corporation, engaged in water supply and drainage system in the port city of Chittagong. In terms of administration it is under the Ministry of Local Government and Rural Development (LGRD). On 16 October 1963, the government promulgated the Water Supply and Sewerage Ordinance 1963 and on 7th November that year, the Chittagong Water Supply and Sewerage Authority was founded (Banglapedia, 2006).WASA Act 1996 has been made effective from May 4, 2008. The main objectives of CWASA are:

• Construction, improvement, expansion, operation and maintenance of necessary infrastructures for water supply, for domestic, industrial and commercial purpose;

• Construction, operation and maintenance of sewerage system and drainage facilities to carry rain, flood and surface water;

• Solid waste management.

To provide all these utility services to the city dwellers is a tremendous challenge for the CWASA. In spite of broad mandates, CWASA's activities are now confined to piped water supply only.

3.4.2 Water Demand and Supply

When the CWASA was established in 1963, the water demand of the city was nearly 30 million liter per day (MLD). After 40 years the demand has increased to about 536 MLD. In the year of 2006 CWASA supplied only 175 MLD where the demand was about 585 MLD. So the shortfall of water supply is about 410 MLD. With available supply, demand of about 30% of the city population can be met. From its starting, CWASA could never meet the demand of the city dwellers and now at present the situation is really worse. The growth of demand and supply of water by CWASA is shown in the Table 3.3 below. In another report of CWASA, the demand and supply relation has been shown as bar diagram in Fig 3.3.

Table3. 3: History of water supply and demand in Chittagong

Year	**Demand (MLD)**	**Supply of Water (MLD)**			**Portion of Demand met**
		Underground Water	**Surface Water**	**Total**	
1963	30	20.5	-	20.5	68%
1970	60	25	-	25.0	42%
1980	140	30	-	30	22%
1990	270	45	89.5	134.5	50%
1996	366	55.3	89.3	144.6	40%
1997	382	58.4	89.7	148.0	39%
1998	400	73.5	89.8	163.3	41%
1999	418	78	90.1	168.1	40%
2000	450	73	90.7	163.7	36%
2001	470	70	905	160.5	34%
2002	491	72	90.4	162.4	33%
2003	513	77	91.6	168.6	33%
2004	536	83.7	91.3	175	33%
2005	560	84	91.0	175	31%
2006	585	84	91.0	175	30%

Source: Amin, 2006.

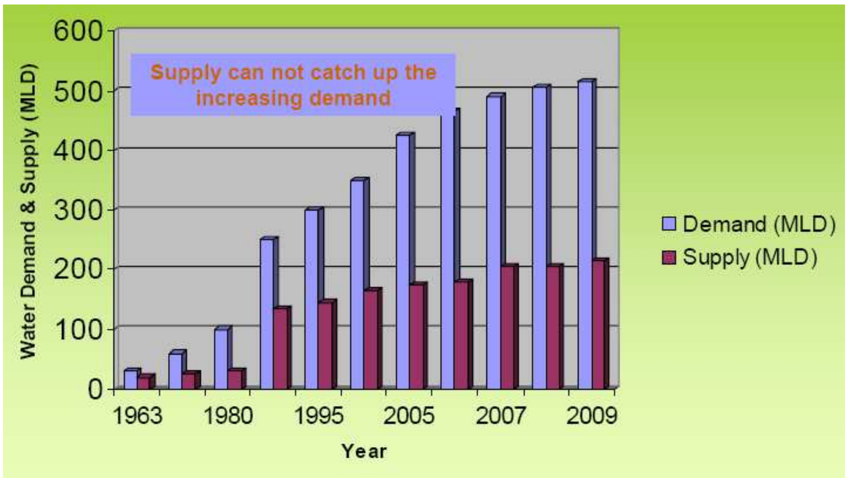


Fig 3.3: Water Supply and Demand Scenario (Source: CWASA, 2010)

3.4.3 Source of Water

The main source of CWASA's supply water is surface water from the river Halda. In the year of 2005 about 52% of the total water supply came from this river and the other 48% came from the groundwater from different deep tube wells (DTW) located in the city (Fig 3.4). After acquiring, the surface water is passed through a process of purification in Mohra Water Treatment Plant (MWTP) whereas groundwater is being treated at Kalurghat Iron Removal Plant (KIRP).

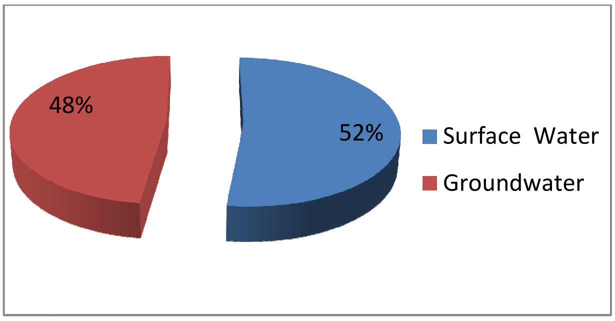


Fig 3.4: Water supply source of CWASA (Source:Amin, 2006)

But as the demand of the city is increasing day by day, CWASA is striving hard to supply the water. So to support the present demand CWASA is getting more dependent on groundwater. It was reported from one of the key informant of CWASA that the present waster source sharing is 55% groundwater and 45% surface water.

The surface water source Halda is about 1 km up from the confluence of the main river Karnafuli (Fig 3.5). The river is about 81 km long and has a very turbulent tributary. Halda River receives pollution from non point pollution sources including engine boat/ships, wastes from human activities and agricultural activities. Further some industries are located in the Halda basin and the effluent may discharge into the river Halda through a canal.

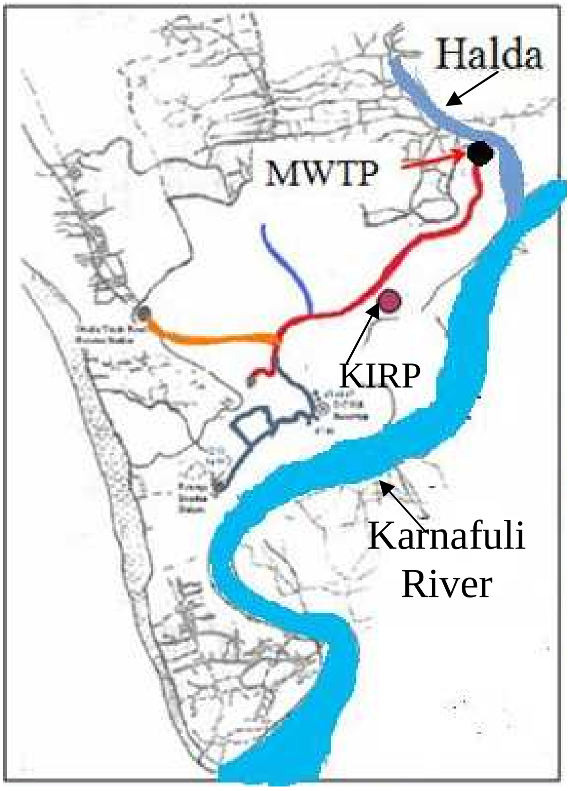


Fig 3.5: Location Map of River Karnafuli, Halda, MWTP and KIRP (Source: Zuthi et al, 2009)

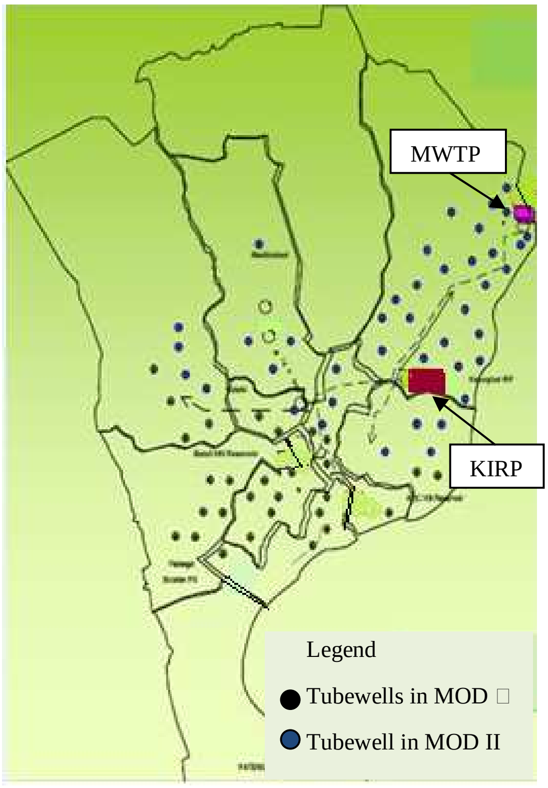


Fig 3.6: Map showing location of tube well in the city (Source: CWASA, 2010)

According to CWASA, there are 78 DTW in the entire CWASA jurisdiction (Fig 3.6) most of which contain high iron concentration (2~8 mg/l). That is why the wells strainer and the gravel pack become clogged with iron bacteria causing decline in water production within few years of installation. As CWASA is not able to meet the demand of water in the city, many household and industries have constructed their own tube wells. It is expected that due to abstraction of water by CWASA and private tube wells, the ground water development in aquifer within Chittagong city area is in near limitation. As a result, the ground water would no longer be a sustainable source of raw water for future (Amin, 2006).

3.4.4 Existing Water Distribution System

3.4.4.1 Service Area

The existing CWASA service area is divided into 2 Maintenance Operation Distribution (MOD) areas, MOD I and MOD II. At MOD I, groundwater is used as major source of water whereas MOD II is supplied with water from KIRP, MWTP and ground water wells. Among the 78 deep tube wells of CWASA, 48 deep tube wells are in MOD II zone and 30 are situated in MOD I zone. Not all of the 78 deep tube wells are connected to the KIRP. It has been reported from the key informant that only from 37 tube wells of MOD II zone water goes to the KIRP for treatment. Water from the rest 41 tube wells are directly used by the consumers without any treatment. This facility of direct use of groundwater is called Small- Size Water Supply System. The city area is using water coming from MWTP, KIRP and Small- Size Water Supply System.

3.4.4.2 Water Treatment Plants

As mentioned above, CWASA has two water treatment plants MWTP and KIRP. The existing Mohra Water Treatment Plant (MWTP) has the production capacity of 20 MGD or 90MLD. The construction of this plant was implemented during the year of 1988 and 1990. At Kalurghat Iron Removal Plant, 2 lines of treatment processes are being operated. Initially in 1977 the line with the capacity of 45, 5 MLD was commissioned as a part of CWASA □ project. In 1987, 22.7 MLD of line was completed and commissioned (*KOICA, 2008*).

Table 3.4: Overview of Kalurghat IRP and Mohra WTP (as of 2007)

Kalurghat Iron Removal Plant		Mohra Water Treatment Plant		Total Capacity (MLD)
Capacity (MLD)	Year of commission	Capacity (MLD)	Initiation of operation	
Primary line (45.5) Secondary line (22.7)	1977 1987	90.5	1990	158.7
Sum (68.2)				

Source: KOICA, 2008

3.4.4.3 Reservoirs

Within the distribution network of CWASA there is about 10 large and small reservoirs, most of which were constructed during the age of East Pakistan (before 1971). But at present, it has been informed from the key informant that only two of them are in use, ADC Hill Reservoir and Percival Hill Reservoir. The Largest reservoir was the Battali Hill Reservoir.

a) Battali Hill reservoir:

Battali Hill Reservoir has the largest storage volume of 13,640 m^3 (13.64 million liter). Distribution trunk main of the Kalurghat system and Mohra system was connected to Battali Hill Reservoir. These pipelines were supposed to be used as inlet outlet pipe, and Battali Hill Reservoir was planned as “balancing tank” for both systems. However this reservoir has not been operated due to the following reasons:

- To cope with the large water demand in the service area, distribution pump in both systems are operated in low head. As a result, pumped water cannot reach to HWL of +51.5 m of Battali Hill Reservoir.
- Further, it seems that Battali Hill reservoir, rectangular reservoir (40m×40m) with a depth of about 8.8 m, has structural defects, in which cracks with 2-3 mm width exists along all wall of the reservoir. According to CWASA, heavy water leakage was detected during running test, and the reservoir has not been used since then.

b) ADC Hill Reservoir:

Transmission pipeline of Mohra system is connected to ADC hill Reservoir (capacity 4,540 m^3 or 4.54 ML) but pumped water cannot reach to the reservoir due to low pumping head. Groundwater produced from nearby 2 exiting well has been pumped up to the reservoir temporarily. However since the production volume of the two wells is small; the reservoir has not been used to its full capacity.

c) Percival Hill Reservoir:

Treated water from the Kalurghat system is sent to the receiving chamber and then is pumped to an elevated tank on the Percival hill. Water is supplied by gravity. The water stays in reservoir at night for 3 to 4 hours and then supplied to the nearest areas in early morning (CWASA, 2008).

3.4.4.4 Booster Pump Stations

There are three existing booster pump station (BPS) in CWASA service area. The first one is in Kalurghat Iron Removal Plant. The other two are Dhaka Trunk Road Booster Pump Station and Patenga Booster Pump Station. All three are used for distribution purpose. Location of these BPS are shown in Fig 3.7. The pump installed in the Kalurghat Booster pump station is used to force the water towards the service area. Dhaka Trunk Road Booster Pump Station is serving the northern western areas of the service zone and the Patenga booster pump station is serving the southern part of the service area (CWASA, 2008).

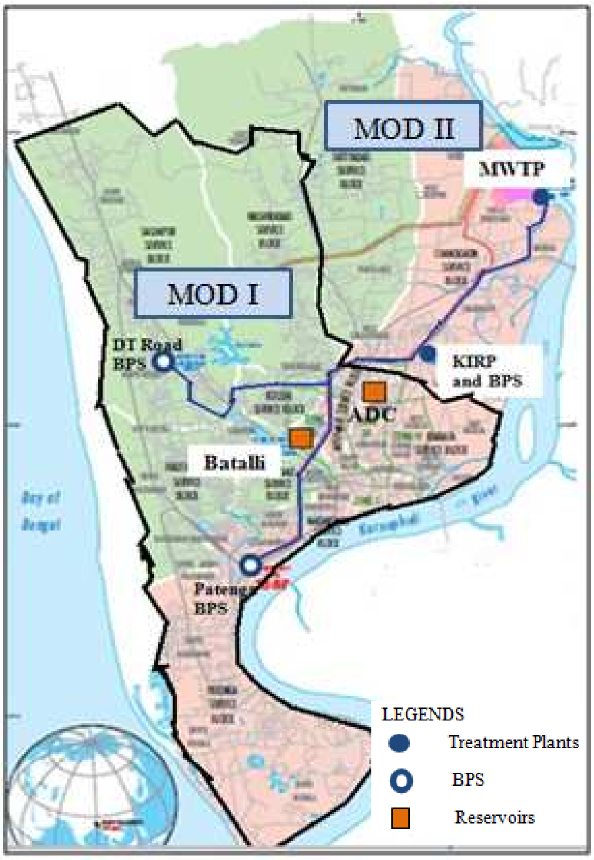


Fig 3.7: Location of BPS and reservoirs in CWASA service area
Source: World Bank, 2010

3.4.4.5 Hydrants

As there is water shortage within the city , CWASA established hydrants or stand post in several locations of the city mainly to supply water to the people who are living in Semi Pucca or Kuccha house and those who does not have CWASA water connection as shown in Fig 3.8. It has been reported from the key informants of CWASA that previously there was about 600 hydrants in the whole city. But at present only 315 of those are activated.

Fig 3.8: People taking water from hydrant for daily use

3.4.4.6 Distribution Pipeline and Connections

Presently CWASA is supplying the water to the city with a distribution network having a pipeline length of about 564 km. Major transmission and distribution pipeline of asbestos cement (AC) were installed from 1966 to 1979. After that some ductile iron (DI) and PVC pipeline were constructed in the year of 1988 and later after. The materials of pipe line which were installed before 2000 are shown in Table 3.5.

Table 3.5: Pipe length by pipe material and installed year

Pipe Material	Length (meter): Installed Year				
	Total	Before 1970	1971-80	1981-90	1991-2000
PVC	150,60o	17,500	100,900	11,700	20,500
AC	128,000	51,200	70,100	6,700	0
DI	129,900			129.900	---

Source: CWASA, 2008.

Distribution trunk main from Kalurghat BPS having diameter of 600 mm is connected to Battali Hill Reservoir. From this distribution trunk main, two semi-trunk mains with a diameter of 450 mm are extended to Dhaka Trunk Road BPS and Patenga BPS. Currently treated water in Kalurghat BPS is directly supplied by pumps without utilizing Battali Hill Reservoir. The interconnection pipe of diameter of 450 mm connects the discharge pipe of Kalurghat BPS with diameter 900 mm and transmission pipe from Mohra WTP. Thus Mohra system together with Kalurghat system directly distributes water without using existing reservoir. From Mohra WTP the transmission line was connected to Battali Hill Reservoir and a diversion line was connected to the ADC Hill Reservoir. There are five diversion points along said transmission line which are connected to the existing network. Two of them (both 600 mm) are connected to the BPS (CWASA, 2008). Still now, CWASA does not contain any clear and detailed distribution network map. A Japan International Cooperation Organization (JICA) project named “PANI Project” is going on presently which is making a detailed network map of CWASA.

3.4.4.7 Water Distribution and Consumption

In a report of CWASA called SAPROF Study 2005, the average water distribution in the 2005 was about 168 MLD among which 49% was domestic, 15% non domestic, 7% hydrant and 29% was Unaccounted-for-Water (UFW). This UFW was due to technical and commercial loss of water. Share of the average water consumption of that year is shown in Fig 3.9 (CWASA, 2008). According to the key informant, presently CWASA has a total connection of 46,299. But in the year of 2006, the number was about 41,114 among which 35,844 was domestic and 5,270 was non domestic (Amin, 2006). Currently, about 45,000 households are directly connected with treated piped water by CWASA out of about 600,000 households in the Chittagong City Corporation (CCC) area (World Bank, 2010).

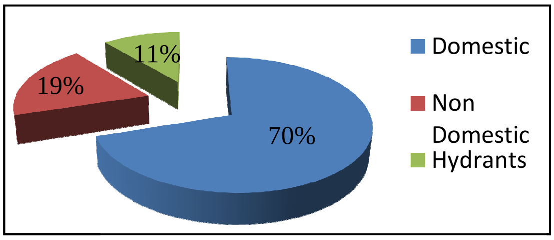


Fig 3.9: Percentage of Water consumption, Source: (CWASA, 2008).

3. 5 Water Treatment Procedure

3.5.1 Mohra Water Treatment Plant

The existing Mohra Water Treatment plant was completed as the first phase out of two phases. High Rate Clarifier and Rapid Sand Filter treatment method is adopted in treatment processes. Schematic diagram of the treatment process is shown in Fig 3.10.

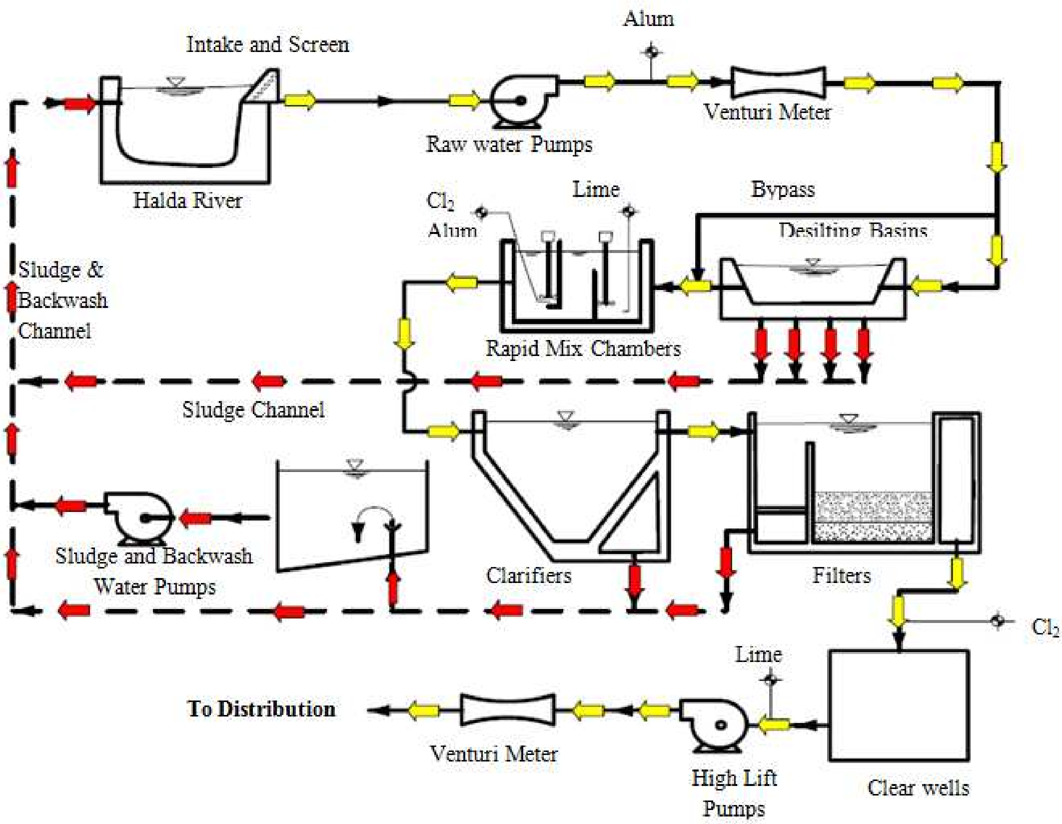


Fig 3.10: Schematic Process Flow Diagram of Mohra Water Treatment Plant

The main components and the working procedure of Mohra water treatment plant are discussed below:

3.5.1.1 Intake and Raw Water Pump Station

The intake and pump station has been constructed on the west riverbank of the Halda River. To increase the water supply in future, the intake and raw water pump station has been constructed with a capacity of 180 MLD. One intake pump is for each intake mouth and five mouths are provided in total in the intake structure (Fig 3.11). An opening of intake mouth has a dimension of 1.8 m in width and 1.2 m in depth with stop logs and a bar screen. The bar screen has been provided to prevent any floating debris or other large things to enter and hit the pump and the log groups are used to stop water flow in any reason. Suction pipe with a length of 50 m lead water to the pump house.

Installation space for five units of pumps, including a future expansion unit, is secured at the intake pump house. Four vertical shaft type pumps are already installed. The capacity of every pump is 59 ML. There is an option of increasing or decreasing the speed in one pump. Presently there are 4 pumps of which two pumps are continuously operating and two of them remained as stand by. Every pump is connected to a pipeline coming from intake, where a revolving strainer is also connected (Fig 3.12).

Fig 3.11: Intake structure

Fig 3.12: Revolving Strainer

3.5.1.2 Desilting Basins

Provision for two desilting basins has been made to reduce the load to consequent clarifiers and filters. Turbidity level of Halda water varies from 20 NTU to 800 NTU but the design turbidity is set as 350 NTU. Pre-coagulation by alum is conducted at inlet of these basins when turbidity exceeds 300 NTU (CWASA, 2008). There are 3 inlet pipes at the bottom of the sedimentation basins through which water comes (Fig 3.13). In the winter, when the turbidity is low, water is directly sent to the rapid mixing chamber through a by-pass system and settled silt in the basins is dried and removed manually during this time.

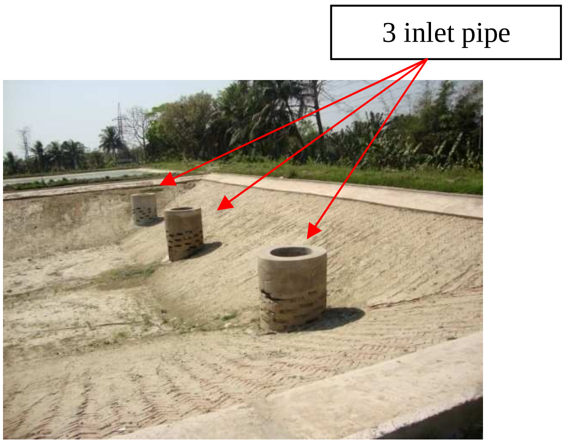


Fig 3.13: Inlet pipes of desilting basin

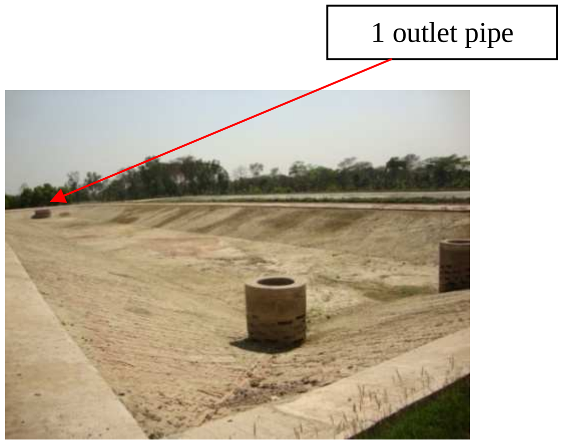


Fig 3.14: Outlet pipes of desilting basin

During monsoon river water first brought to the desilting basins, turbidity is reduced by the settlement of mud, sludge etc. Each basin has a dimension of 33.5 m × 134 m (110 ft × 440 ft).The depth of the basin in the inlet side is 3.048 m (10 ft) and at the outlet side is 3.35 m(11ft). Water from the sedimentation basin flows to the rapid mixer by gravity through an outlet pipe located at the end of the basin (Fig 3.14). The elevation of the mouth of this pipe is 1 meter higher than the bottom of the basin which allows only the water to flow into it without the suspension. The loading rate of these 2 basins is 15.21 $m^3/d/m^2$ (311gpd/ft^2) and detention time 120 minutes. During operation sediment is removed by closing all the pipes located at the bottom of the basin. There are also valves at the bottom of the basins which are connected to the sludge drain. By opening these valves, sludge is allowed to flow to the drain. The cross section of the desilting basins is shown in Fig 3.15.

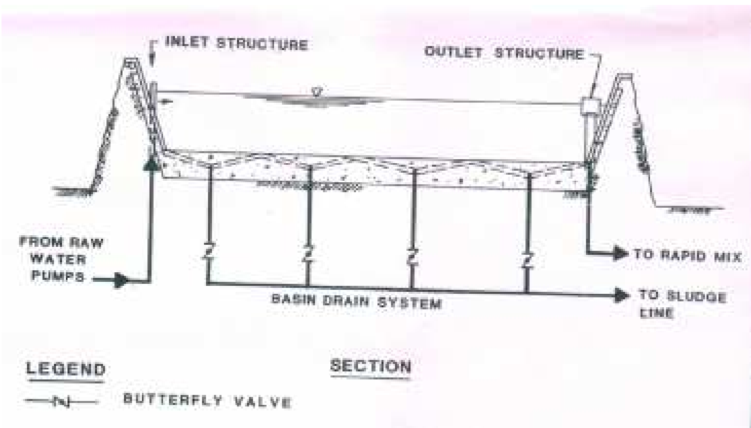


Fig 3.15: Cross section of desilting basins; Source: CWASA, 2010.

3.5.1.3 Rapid Mixing Chamber

The Rapid Mixing Chamber is composed of two units of flash mixers installed in series (Fig 3.16). Water from desilting basins/raw water pump station comes in the rapid mix chamber and alum and lime coming from the chemical building, are injected upstream of each mixer, separately. Alum is added for the coagulation process and lime is added to balance the pH. The capacity of each mixer is 7.5 Horse Power (hp) each with detention time 10 second /chamber. The detention time of the chamber is kept very short to mix the chemicals very quickly and to prevent the formulation of flocks in this chamber. There is a provision of pre chlorination to the water during the monsoon to prevent the growth of the algae. Pre chlorination is done in a concentration of 4-5 mg/l.

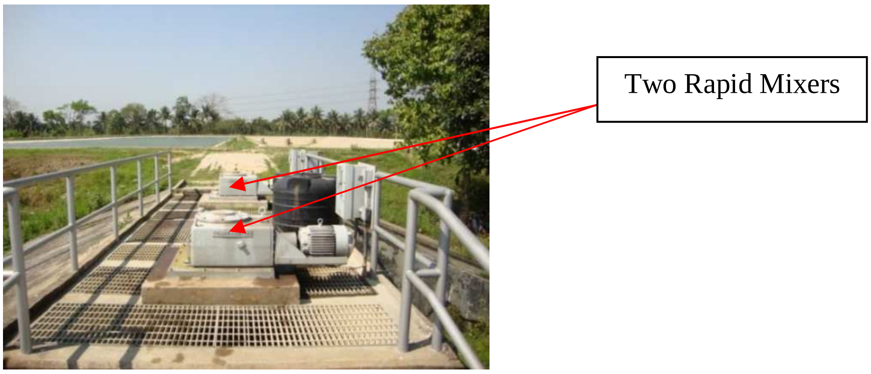


Fig 3.16: Rapid Mixing Chamber

In drinking water, organic carbon is measured as total organic carbon. These organic compounds can be separated into two categories: biodegradable dissolved organic carbons (BDOC) that can be used by heterotrophs as a nutrient; and refractory, or non-biodegradable, dissolved organic carbons (RDOC) which cannot be consumed by heterotrophs. Assimilable organic carbon (AOC) is a sub-category of BDOC, the most readily available fraction of the BDOC (EPA, 2007). Research shows that pre chlorination oxidizes the biodegradable matter into more biodegradable matters and increases the AOC level in the water. These BDOC and AOC are taken by the heterotrophic microorganisms as nutrient for their growth. Control of heterotrophic microorganisms is important because all of the primary pathogens found in drinking water, and most of the opportunistic pathogens in humans, are heterotrophic microbes.

3.5.1.4 Clarifiers

Twenty four unit of hopper type clarifier is provided in the treatment plant. The volume of each clarifier is 207 m^3 (7215 ft^2) and the depth is 8.22 m (27 ft). The cross section of clarifier is shown in Fig 3.17.

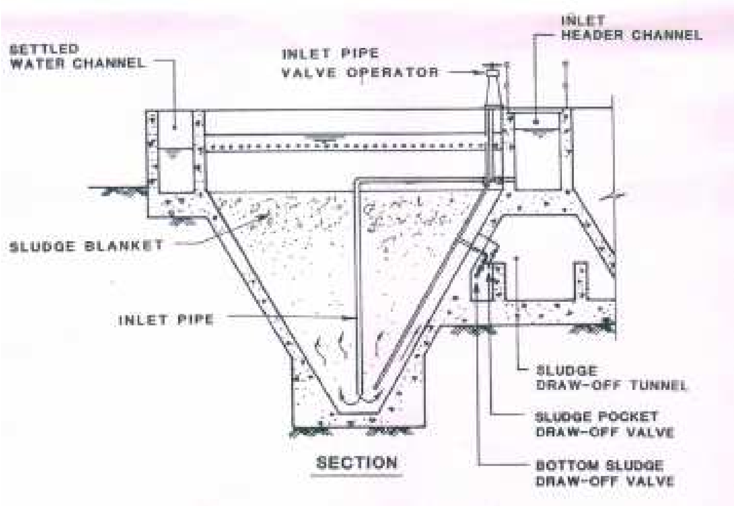


Fig 3.17: Cross section of Clarifier; Source: CWASA, 2010.

Water from Rapid Mixer through an inlet pipe of 300 mm diameter comes into the bottom of the clarifiers. As the clarifiers are hopper type, the velocity of the water gets reduced while flowing upward. So all the flocks that are formed through the coagulation process due to adding alum cannot come upward due to lack of necessary velocity. Coagulation is a step associated with pre-treating water prior to conventional and direct filtration. The purpose of coagulation is to form large aggregate particles from smaller particles naturally present in raw water. This is accomplished through the addition of chemicals, typically alum that destabilize negatively-charged particles, preventing them from repelling each other and allowing them to form larger particles. Coagulation is primarily associated with removing the hydrophobic, high molecular weight fraction of organic compounds present in the water typically associated with humics. Coagulation also removes 30% BDOC, 56% AOC and 37% dissolved organic carbon (EPA, 2007).

Fig 3.18: Clarifiers

Fig 3.19: Clean water is collected from the upper part of the clarifier

These flocks combine to each other by the process of flocculation and create a blanket type suspended slurry layer, through which other flocks also get trapped and only clean water come upward, which flow towards the filters through a channel (Fig 3.18 and 3.19). The total retaining period of water in the clarifiers is 1.2 hours. To retain the slurry interface at the stable level, a sludge pocket is provided inside of each clarifier and slurry is drained by manual valve operation.

3.5.1.5 Filters

There are eight units of filter down flow conventional type rapid gravity filters each of which has an area of 44.64 m^2 (480 sq. ft) (Fig 3.20). Water from clarifier comes to the filter and passes through 1.22 m (4 ft) deep sand and 0.45 m (1.5 ft) deep gravel media. The size of sand ranges from 0.85-1.2 mm. Filtration rate is 260 m/d which rises to 306 m/d when one unit is backwashed.

Fig 3.20: Filters

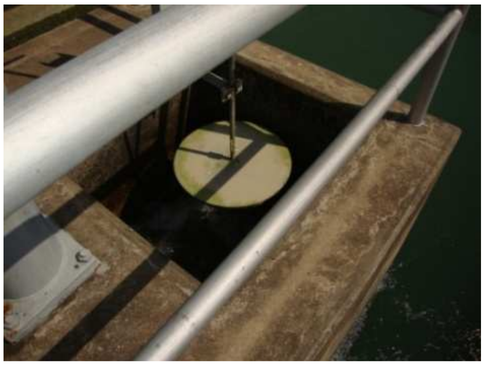


Fig 3.21: Water flowing from clarifier to filter

The primary purpose of filters is to remove suspended materials, although microbiological organisms and color are also reduced. But conventional filtration with media appears to decrease the level of bound nutrients, but not dissolved nutrients.

3.5.1.6 Chlorine Contact Chamber

From filters the water pass through the chlorine contact chamber which is provided at the beginning of the clear water reservoir. Chlorination is done at a concentration of 1-1.5 mg/l to disinfect the water. Chlorine contact time in the contact chamber is 30 minute at 90MLD. It has not been cleaned after commissioning of the plant because water cannot be stopped due to its structure.

The contact (retention) time in chlorination is that period between introduction of the disinfectant and when the water is used. A long interaction between chlorine and the microorganisms results in an effective disinfection process. Contact time varies with chlorine concentration, the type of pathogens present, pH, and temperature of the water (Wilkes University, w/d).

3.5.1.7 Clearwater Reservoir and High Lift Pumps

The reservoir is divided into two tanks with a capacity of 3,360 m^3 per compartment and the retention time is 1 hour 45 minutes. Treated and disinfected water is pumped to the city by four duty and one stand-by high lift pumps of capacity 15.79 m^3/min and 350 kilo watt (KW) each. At present pumps are operated in low head and large discharge position to cope with the increased water demand and restriction caused by the connection to the Kalurghat System. So irregular pump operation, two units in daytime and 3 units at night time, has been obliged.

3.5.1.8 Waste Water Discharge Facility

Waste water generated at the treatment plant is discharged in the Halda River via a wastewater drain basin. When water level in the river is low, waste water can be directly discharged to the river by gravity. If river water level is high, a flap gate installed in halfway of effluent pipe is closed and wastewater flows into a wastewater drain basin. Wastewater stored in that basin is drained and discharged to the river by a slurry pump automatically operated by water level switch. The basin receives wastewater from the desilting basins, clarifiers and filters. In Fig 3.22 and 3.23 it has been shown that water from the bottom of the clarifier is being discharged.

Fig 3.22: Wastewater drain below clarifier

Fig 3.23: Waster discharging from clarifier

3.5.1.9 Chemical Dosage Facility

Necessary storage, mixing & dosing of chlorine, alum and lime are done by pumps centrally from the chemical building. 35 mg/l alum is added with water by recirculation pump of a capacity of 0.75 m^3/min (758 lpm). It recirculates the alum solution within the alum tank to promote the dissolution of lump alum to keep the alum solution mixed and the solution is kept for 24 hours in a tank (Fig 3.24). Likely 5-10 mg/l lime is mixed with water by stirring system and is kept for 12 hours in lime tank (Fig 3.25). Gaseous Chlorine is taken from the container with high capacity vacuumed type chlorinator and is mixed with water through injector.

Fig 3.24: Alum mixing tank

Fig 3.25 : Lime mixing tank

3.5.1.10 Plant Monitoring System

There is plant monitoring system in the control room of the main administrative building. Only monitoring is done by the plant monitor panel which contains graphic display panel, plant alarm panel, and status indicators of certain treatment plant process. The raw water level, raw water flow rate, clear water level, clear water flow etc can be observed through this monitoring system. There is also an intercom paging systems for easy communication of the operation staffs within the plant.

3.5.1.10 Laboratory

There is a laboratory in this treatment plant where raw water and treated water is being tested in order to bring the treated water quality within the limits of the maximum allowable standards set by the World Health Organization (WHO) and Bangladesh. This laboratory is equipped with various sophisticated instruments for regular testing of turbidity, pH, residual chlorine, alkalinity, hardness, TDS etc. Depending on raw water quality the quantity of chemicals such as alum, lime and chlorine are also determined through various tests. This laboratory also collects water sample from distribution network and tests different parameter on daily, weekly and monthly basis shown in Annex A.5.

3.5.2 Kalurghat Iron Removal Plant

Kalurghat Iron Removal Plant (KIRP) and Booster Pump Station were constructed in 1977 with a nominal capacity of 45,500 m^3/ day (45.5 MLD). Groundwater, which contains high iron, is pumped and sent to the KIRP. Therefore aeration tower, sedimentation basins and filters are provided in the plant for iron removal. In addition to originally constructed facilities, new filters with a capacity of 27,700 m^3/day (27.7 MLD) were constructed in 1987 which was aimed to reduce load on the existing old filters instead of amplification of plant capacity. This new system/ unit is without aeration.

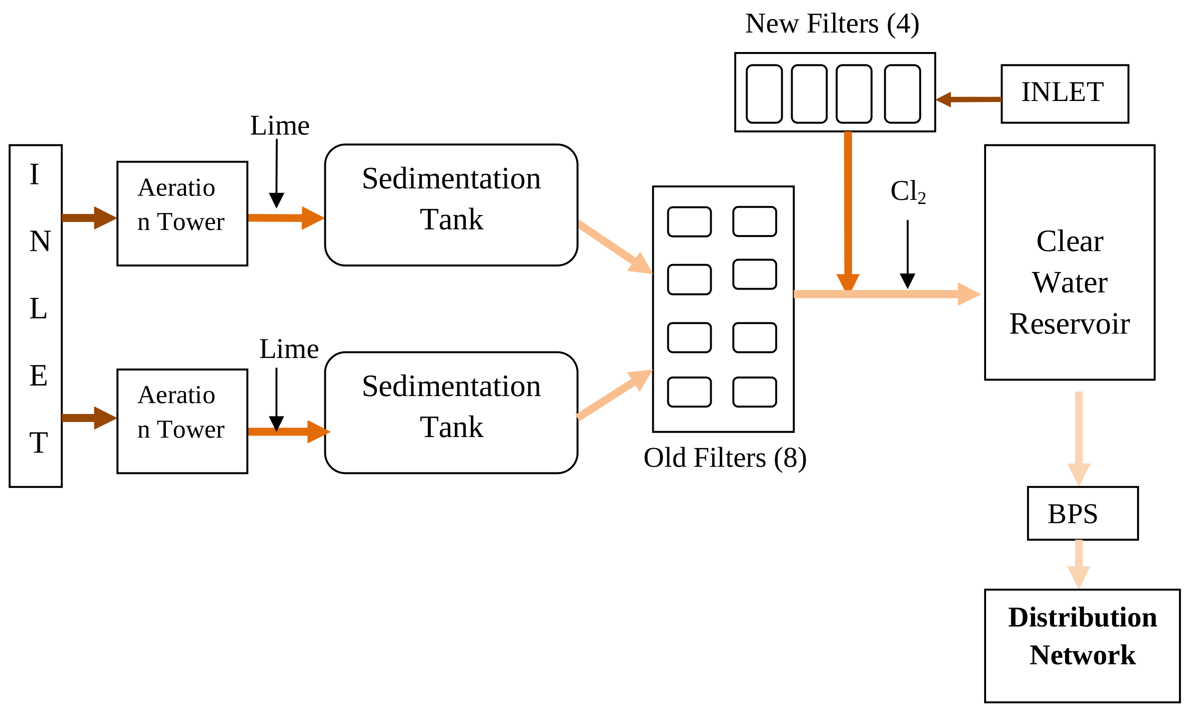


Fig 3.26: Schematic Process Flow Diagram of Kalurghat Iron Removal Plant

Different parts of the Treatment plant and their working process are described below:

3.5.2.1 Aeration Tower/ Aerator

Groundwater entering the older unit is divided into two paralleled streams, with each stream passing to an aerator where it is aerated by gravity sprinkling aeration towers. Aeration is advantageous in the treatment of water as it changes or oxidizes the dissolved iron to insoluble ferric forms that can be removed by settling. It is also useful to remove carbon dioxide before lime–soda ash softening.

Fig 3.27: Aeration tower and Sedimentation Basin

There are two distribution tray type aerators with, 14.29 mm (9/16 inch) holes at 15.24 cm (6-inch) centers. Each aerator has 5 aeration trays with 5 cm (2 inch) square slats at 10.16 cm (4-inch) centers and an area of 43 m^2 (464 ft^2) (CWASA, 2010). After aeration water flows to the sedimentation basins (Fig 3.27). As mentioned before, water coming to the new system is not passed through the aerators and sedimentation basin but goes directly to the new filters from the inlet which is situated in the other side of the old system.

3.5.2.2 Sedimentation Basins

Aerated water flows by gravity into two reaction/settlement tanks, with a base area of 2,276 m^2 (24,500 ft^2) and a depth of 3.048 m (10 ft) each. Lime is dosed at 5 mg/l concentration at the inlet of the sedimentation basin to increase the pH. The purpose of these basins is to provide a period of retention to allow full oxidation of ferrous to the insoluble ferric iron and to allow settlement of the majority of iron formed. Retention time 7.2 hours. Sludge is removed from the tanks periodically from central drains. Water is fed into the reaction tanks over a flooded weir along the width of each tank (34 m or 112 ft) and settled water is taken off over a second weir extending across the opposite end of each tank. Sludge is removed from the tanks periodically from where it is hosed to a central drain from which it gravitates to a pump discharge sump. (CWASA, 2010).

3.5.2.3 Filters

Water from the two-reaction/settlement tanks is combined in a single channel to feed eight rapid gravity filters in parallel with surface area 32.7 m^2 (352 ft^2) each. The operation depth range is 1.5 m (5 ft) with filter surface loading 7.32 $m^3/h/m^2$ (2.5 gpm /ft^2). The filter media is composed with anthracite and 0.61 m (24 inches) 0.45 to 0.54 mm sand and 0.3 m (12 inches) supporting gravel. The four new filters (Fig 3.29) have a dimension of 8.23 m × 13.30 m each with same filter media as old ones(Fig 3.28). In old filters under the media, ceramic nozzles drains are installed for backwashing. The rate of backwashing is 44 $m^3/h/m^2$ (15gpm /ft^2). But new filters have blower so as to scour filter media by air during backwashing which is more efficient than the older filters system.

Fig 3.28: Old filters

Fig 3.29: New Filters

3.5.2.4 Clear Water Storage Tank

Filtered water from both units enters the clear well from the filtered water channel over four weirs. A baffled section provides retention time for thorough chlorination. Chlorination is done at 1 mg/l concentration. Dimension of the reservoir is 29.8 m ×99 m with area 2,950 m^2 and the depth is 3.32 m .The capacity of the reservoir is 9,100 m^3 (9.1 ML).

3.6 Consumers' Consequence in Chittagong City Due to Existing System

The port city of Chittagong has been reeling under the acute shortage of pure drinking water that has made the civic life miserable. Especially during summer they escalate when drinking water is in short supply, forcing people to use contaminated sources. It was learnt that booster pump of CWASA placed in different location remain stop due to frequent power failure unable to develop require amount of pressure for supply in distribution network. On the other hand this frequent power failure also impedes to upheaval water from ground source. For those ensuing reason ultimately crippling the CWASA's total productivity and capacity during summer. So the shortage become much more acute and CWASA has to supply water by rationing. Some areas get water in every two or three days where as others get water even after 15 days.

Most of the time CWASA supplies water to the end users during mid night, and the time of supply are undeclared. So the people of those areas have to suffer a lot while they remain awake waiting for the water. As water supply is not continuous, people have to use their own reservoir to store water for two or three days or sometimes even more. Some people has illegal pump in their connection to take more water during the unavailability of water. As a result people who do not use nor cannot effort this extra cost of pump, face more problem.

Sometimes CWASA has to face some unforeseen challenges of salt not worth use for human consumption. Residents of different city areas including Agrabad, Halishahar, Maderbari, Nasirabad, Chandgaon, Patenga, Bakalia, Muradpur and Chawk Bazar, reported their sufferings due to high salinity in WASA water. As these areas are within MOD I, people are using this water without any type of treatment. WASA sources said the water of the River Halda become salty during winter as the seawater enters Halda through the River Karnaphuli. Climate change is responsible for the situation, they added. In contrast place like south Patenga where CWASA does not have any infrastructure, situated near the sea, and its available groundwater has a high salt content. There is no other source of safe drinking water for household consumption, and families from the poor households would walk down 5 km a day to get safe drinking water. The community used a rain-fed pond for bathing and washing, but it was heavily polluted because the water was stagnant and people dumped waste in it.

3.7 Sewerage System

At present Chittagong city has no central sewerage system and sewage treatment. The majority, 85% of households and establishments, use individual septic tanks; the rest use more primitive systems (AUICK, 2008). As there are no houses connection pipes connecting drainage and each household, sewage produced from household is disposed directly through drainage along the road causing severe odor or hygiene problem. At upscale residential areas like Khulshi, household sewage including sewage from kitchen and septic tank is discharged through PVC pipes to the drainage. But at slum areas sewage is collected through storm water drainage and carried to khal (KOICA, 2008).

3.8 Storm-water Drainage

Though as per ordinance it is the responsibilities of CWASA to construct operate and maintain drainage facilities to carry rain, flood and surface water. This has not yet been transferred to CWASA. Chittagong City Corporation (CCC) is now looking after the drainage system. CCC are constructing and maintaining drains and canals in the city. Also, CCC has constructed one storm water box type under drain Agrabad commercial area. There are some 443 miles of open drains connected with 5 canals that carried a great deal of untreated wastes (KOICA, 2008).

4 Methodology

The study is basically based on primary data. These primary data were collected from the study area Chittagong city, Bangladesh during a field visit of six weeks. Secondary data were also collected from CWASA and from other sources for making the research more informative. Then the data have been analyzed to produce a significant and representative presentation of the present water quality of the water supplied by CWASA.

4.1 Primary Data Collection

Primary data collection was done by collecting mainly by water sample data from different points within the study area. Moreover observation and interview with key personal of CWASA was also done for primary data collection.

4.1.1 Sampling Location

Water sample data were collected from the Halda River and MWTP, KIRP and from different points of the distribution network and also from consumers' reservoirs.

Halda River and MWTP

From Halda River the water sample were collected not only one day but on three different days and times. That means the first day there was extreme low tide in the river, second day during full tide and the third day during mid tide. It was done to see the variation of result with the tidal situation. Moreover the water samples were collected from three different locations to have a reliable data. These are 1 km upstream of the intake point of Mohra Water Treatment Plant (MWTP), near the intake and 1 km downstream of the intake. To observe the treatment efficiency of MWTP water samples, right after the treatment, were collected on the same days it was collected from Halda River. So the total numbers of samples from Halda were nine and for MWTP were three.

KIRP

To determine the treatment efficiency of KIRP water samples were collected at two different days. Each day from two locations in the treatment plant; one is from the incoming of the raw water and other is from the clear water reservoir of the KIRP, just before going to the distribution network.

Distribution Network

From the distribution network water samples were collected from 57 different points among which the first 46 points were where water was coming directly from distribution network from

Fig 4.1 :Map showing the locations of sample collection

the treatment plant. In the other 11 points water were collected from the consumers' reservoir (Fig 4.1). The points were selected depending on the availability of water during the time of sample collection. The name of the locations has been listed in the Table 4.1

Table 4.1: Name of the locations from where samples were collected

Serial No	Name of the locations	Serial No	Name of the locations	Serial No	Name of the locations
1	Rahmatganj	20	Ice Factory road	39	Kajir Dewri
2	DewanBajar	21	Shadarghat	40	Mayor Gali
3	Sirajudullah road	22	Baijid Bostami	41	Kotwali thana
4	Anderkilla	23	Oxygen	42	Patharghata
5	Sulakbahar	24	Nasirabad CDA	43	Alkoron
6	Khulshi WASA pump	25	Pahartali	44	Court Building
7	Katalgonj	26	Jhawtala	45	Foy's Lake
8	Sagorika Stadium	27	Kusumbag	46	Dewanhat
9	Kabillah dham	28	Pathantuli	47	Halishahar
10	Port collony WASA pump	29	Goshaldanga	48	Baijid Thana
11	Navy Colony	30	Monsurabad	49	Kadamtoli
12	Agrabad WASA office	31	CDA Collony	50	Miakhan Nagar
13	Lalkhan Bajar	32	West Madarbari	51	East Madarbari
14	Hamjarbag	33	Dampara WASA Resorvoir	52	Jamal khan
15	Mohammedpur	34	Bakalia Thana	53	Cantonment
16	Bahaddarhat	35	1Kilometer	54	Port Colony
17	Khaja Road	36	College Road	55	Chittagong Medical
18	CMB Road	37	Panchlaish Thana	56	Amirbag
19	Kamal Bajar	38	Jubli Road	57	Probortok

4.1.2 Sample Collection

Two samples were collected from each sample point: one in half liter plastic bottle for the microbial analysis and other in two liter plastic bottle for the analysis of chemical parameters as shown in Fig 4.2 and 4.3.

Fig 4.2: Water sample in 2 liter bottle

Fig 4.3: Water samples of microbial test in ice box for preservation

The samples were collected after letting the water flow for 1 minute. For microbial analysis it was important to leave some gap for a continuous aerobic activity and the half liter sample bottles were preserved in an ice box. On the other hand the two liter bottles were closed tied to prevent any exchange of oxygen, while the DO was measured from that sample bottle. As the microbiology has to be analyzed within the 6 hours of sample collection, maximum 6 or 7 samples could be collected in each day.

4.2 Secondary Data Collection

Some secondary data were collected from previous research reports, thesis, journals, conference proceedings and official websites. Moreover water supply and quality related acts, rules and regulations, legislations, standards etc were collected through the review of government reports. Some papers, brochures and other published and unpublished sources of concerned agency were also used.

4.3 Water Analysis

After collecting the water samples, it was taken to the laboratory of the CWASA to perform the analysis of different parameters.

Microbial Parameter (Total coliform, E. Coli and Fecal coliform)

The microbiological tests were done by Membrane Filtration Method. For Total coliform (TC) and E.Coli (EC), M-Endo Broth was used as medium. 48 gm of media was suspended in 1000 ml distilled water containing 20 ml of ethanol and 14 gm of Agar. Then the mixture was boiled to dissolve the media completely. After that the mixture was cooled in room temperature. The sample water was then filtered and the absorbent membrane filter was placed on a petri dish and saturated with 2 ml of transport media. The same process was followed for fecal coliform (FC) where 37.1 gm of M-FC Broth media was mixed with 1000 ml of distilled water containing 10 ml of 1% Rasolic acid. For Total coliorm and fecal coliform the plates were incubated at 37°C for 24 hours and for E.Coli at 44°C for 48 hours. Total and E.coli colonies on M-Endo media have metallic golden sheen where as the fecal coilform shows a definite blue color.

Fig 4.4: a) Sample water is being filtered through filter pad; b) absorbed membrane filters are placed on the patri plates; c) M-Endo media solution with Agar are boiling; d) M-FC Broth media solution; e) Media are being poured on the patri plates; f) filters pads are placed on the media g) Total coliforms colonies with golden metallic sheen; h) fecal colonies with blue dots.

Residual Chlorine:

The residual chlorine was measured by DPD Method (Powder pillows) by Direct Reading Spectrophotometer. The program number for chlorine was entered and the wavelength was dialed to 530 neno meter (nm). 25 ml of sample was poured into a sample cell and the content of one DPD Free Chlorine Powder Pillow was added to the sample and was shaked for 20 seconds. The sample was placed into the cell holder of the spectrophotometer immediately. Then the button was pressed to see the result in mg/l.

pH

The determination of the pH is based on a method using a combined pH mercury electrode which combines both the mercury electrode and the reference electrode into one body. For measuring the pH a sample was taken and the probe was inserted into the sample. The concentration of the hydrogen ion is detected by the electrode and the pH was got in digital form and recorded.

Dissolved Oxygen (DO)

The dissolved oxygen of the water sample was measured by a DO meter. The electrode of the DO meter was inserted into the sample and the reading of DO level was directly shown in the screen. The DO meter had its own automatic electronic calibration.

Biological Oxygen Demand (BOD)

The BOD_5 of the samples were determined at the temperature of 20°C. To determine the BOD_5 of the samples, the DO was measured simply by the DO meter on the first day. Then the samples were incubated at 20°C for five days**.** After 5 days the DO was again measured and subtracted from the initial DO to see the consumption of oxygen.

Chemical Oxygen Demand (COD)

The COD was determined by titration method by oxidizing the sample with a strong chemical reagent potassium dichromate. Sulfuric acid- silver sulfate solution, ferroin indicator solution ferrous ammonium sulfate solution and mercuric sulfate was also used as reagents. All the reagents were added with the sample except ferroin indicator and ferrous ammonium sulfate solution and were heated. Then the mixture was diluted, cooled and titrated with ferrous ammonium sulfate solution by using ferroin indicator. The end point was taken when the color change from blue- green to reddish.

Turbidity

The turbidity was measured by Absorptometric Method by Direct Reading Spectrophotometer. The Program number for turbidity was entered and the wavelength was dialed to 450 nm. The sample was shaked and 25 ml of sample was poured into a sample cell and was placed into the cell holder of the spectrophotometer. Then the button was pressed to see the result in Nephelometric Turbidity Unit (NTU).

Suspended Solids (SS)

The suspended solids of the samples were measured by the filtration method. For each sample a filter paper was heated in the oven at temperature of 104°C and the weight of the filter paper was then taken. After that 100 ml of the sample was filtered through that filter paper and the filter paper was again heated at 112°C and weighted. The difference between the weights is the residual weight of the suspended solids per 100ml of sample.

Total Dissolved Solids (TDS)

The TDS of the water samples were measured through the HACH Conductivity Meter which has three options in it; one for the TDS and another two are salinity and conductivity. Before measuring the TDS of the samples, the meter was first calibrated by the water of known TDS. Then the probe of the meter was inserted into the water samples of which TDS was to be measured and the TDS was displayed in the digital form.

Ammonia-Nitrogen (NH_3 -N)

In the ammonia test, Nessler Reagent (K_2HgI_4) reacts with the ammonia present in the sample (under strongly alkaline conditions) to produce a yellow-colored species. The intensity of the color is in direct proportion to the ammonia concentration. First 1 ml of Zinc Sulfate ($ZnSO_4$) is added to 100 ml sample and then 0.5ml 6N NaOH (sodium hydroxide) is added to the solution to obtain a pH of 10.5. Secondly 50 ml sample is diluted to 50 ml distilled water where 0.05 ml EDTA reagent and 2 ml Nessler Reagent are added. After that both the solution are mixed and then after 10 minutes some color develops. Then ammonia nitrogen of the solution is measured by the Direct Reading Spectrophotometer.

4.4 Data Analysis

All water-quality results were stored in the database, and later exported to Excel for analysis. Data were analyzed following the guidelines provided by the WHO and Bangladesh Environmental Conservation rule, 1997 (Annex A.6). Household samples collected from the reservoirs were also analyzed for microbiological and chemical parameters, with a focus on how drinking-water quality deteriorated between the distribution system and household taps.

4.5 Limitation and Uncertainties of the Study

Though efforts had been made to make the study more realistic and informative, still it has some limitations. As the demand of the city dwellers is far ahead from the supply, it was not possible to collect sample from lots of areas where water was not available at collection time. So the samples do not exactly represent the whole distribution network. The recommended minimum sample numbers for verification of the microbial quality of drinking-water are recommended by WHO. In distribution systems for a population >500000 the sample number is 12 per 100000 head of population plus an additional 180 samples per year (WHO, 2004). But this could not be followed as the time period for data collection was short and also due to lack of man power. A group of student/researcher with adequate manpower requires for collecting and interpreting such huge amount of samples Moreover the season during the data collection was summer, the time of maximum water demand. It was not possible to meet that soaring demand by CWASA at every area other than adopting policy of rationing. That really created difficulties in data collection for ensuing research work. As there were lots of areas without any water supply for 7 to 10 days or more, some data were collected from the reservoirs of the consumers.

One of the idea before sample collection was that, sample would be taken from the overhead reservoirs of the city to see whether the retention time has any effect on the quality of water or not. But unfortunately it was not possible to take those samples. In earlier chapter it was mentioned that the Battali Hill reservoir is not used anymore and the Parcival Hill and ADC Hill reservoir is mostly used at midnight. It was learnt that water is reserved only for a very brief period of time like 1 to 2 hours and then delivered to the consumers in early morning before 6 am. So it was not possible to take samples from those two reservoirs.

For microbial test the sample should had been analyzed within 6 hours of collection of the sample. But sometimes it was not possible to perform the tests within 6 hours as there is only one lab expert in CWASA. So the result of the coliform may not be exactly correct. Moreover CWASA laboratory normally does not practice to determine fecal coliform and E.Coli. It was for the first time by CWASA lab to perform these tests. So there might be some mistake or lack of accuracy in the result considering the lab technician expertise.

Moreover the overall study was done during the summer. So the result of this study does not portrait the picture of the whole year but only for a certain time period of the year. Results may be different in rainy season or winter; like the rainfall can greatly increase the levels of microbial contamination and turbidity in source waters. As the CWASA was unable to provide any defined and documented distribution network map, it was not possible to know the pipe material at the point of sample collection. For that reason the influence of pipe material on sample water could not be analyzed.

5 Results and Discussion

In the following chapter the water quality parameters of the treatment plants, distribution system and the consumers' reservoir will be presented and discussed. The sections of discussion are comprised of the results, reasons and criticism of some existing followed methods.

5.1 Water Quality of the Halda River

From the quality parameters data of Halda River it can be said that though the river is contaminated with coliform bacteria but the values are far below the Bangladesh Environmental Conservation Rule'97 (BECR'97) value. The minimum concentration of TC 1000/100 ml has been found during the high tide where as the highest value was found during low tide 2200/100ml. For FC and EC it was like same, minimum 62/100ml and maximum 150/100 ml FC and for EC it was 8/100ml and 28/100 ml for high tide and low tide respectively. The BECR'97 does not provide any standard value for FC and EC of surface water using as a source of drinking water. In all tidal situations all type of coliform concentration was increasing from upstream to downstream as shown in Fig 5.1, 5.2 and 5.3. All the data are available in Annex A.7.

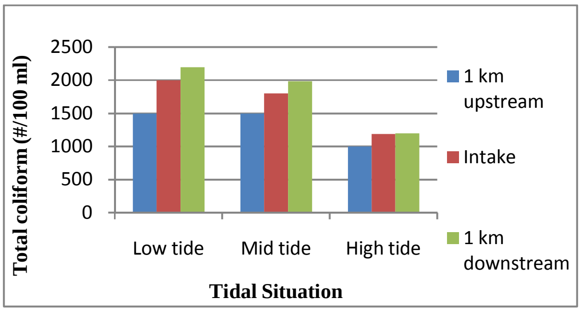


Fig 5.1: TC concentarion variation with tide and sampling point

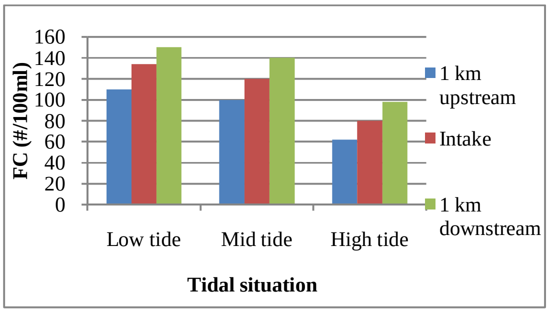


Fig 5.2: FC concentration variation with tide and sampling point

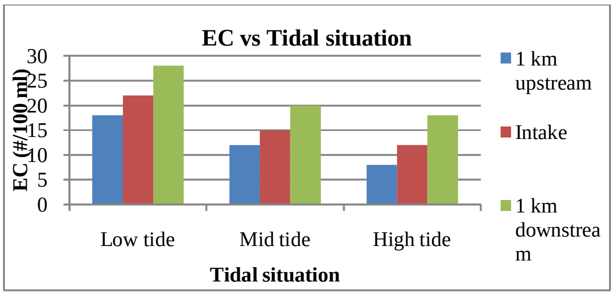


Fig 5.3: EC concentration variation with tide and sampling point

Other parameters like BOD_5, pH, DO were in permissible limit of BECR'97 in all three tidal conditions. But there were no standard value in BECR'97 for COD, NH_3-N, turbidity, TDS and

SS. The behavior COD was also similar to the coliform groups; increasing from upstream to downstream and highest 55mg/l in low tide and lowest 32 mg/l in high tide was found (Fig 5.4). But the concentration of turbidity was found to be high in the intake point and low at the downstream in every tidal situation and it decreases from low to high tide (Fig 5.5). A maximum turbidity of 250 NTU and a minimum of 110 NTU were measured during low tide and high tide respectively.

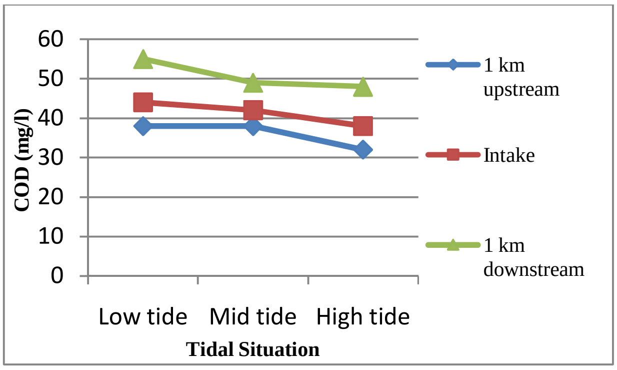


Fig 5.4: COD variation with tide and sampling point

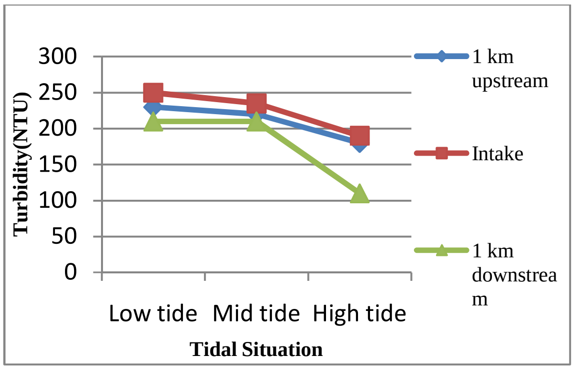


Fig 5.5: Turbidity variontion with tide and sampling point

As the city does not have any sewer system thus most of the domestic pollutants find their way to the river. Discharges of municipal wastewater can be a major source of pathogens; urban runoff and livestock can contribute substantial microbial load; body contact recreation can be a source of fecal contamination. The concentration of the all type of coliform was found to maximum in the downstream and during low tide. Though in the upstream there is contamination, but 1 km downstream of Halda, Karnafully River is flowing which is highly polluted and its contamination had a effect on the data of downstream. Moreover during low tide there is less water, which shows the concentration high. The high DO and low BOD_5 level indicates that the environment is good for fish and other aquatic species. Though the microbial contamination is still within permissible limit, but such practice can turn Halda into unsuitable source of drinking water.

The growth of industries along the river and specifically the tanneries discharging toxic affluent including heavy metal is a matter of great concern. Release of effluents from tanneries built along the Halda close to the Mohra water treatment plant is one of the causes of high COD level near the intake than the upstream. Moreover lots of industries are also discharging their effluent without proper treatment in Karnafully. Thats why the COD was highest in the downstream. The reason of getting a lower value in high tide is that, during high tide the amount of water is relatively high than other situation which make the concentration low. But the concentration of the turbidity was higher in the intake point. As the pumps are pumping the water with high force there is always a high turbulence working in the intake point. But this effect reduces in the downstream point. Halda originates from the hill carries lots of mud and particles. That's why the turbidity was higher in the upstream than the downstream. And the reason of higher value in the low tide is as same like the coliform and COD.

5.2 Water Quality of Mohra Water Treatment Plant

Reviewing the three days data of Mohra Water treatment plant just after treatment it can be said that the treatment system is perfectly efficient in removing the microbial contamination from the raw water. No sample contains TC, FC or EC, which means the processes or disinfectant used by the treatment plant are sufficient for the removal of contamination from the raw water. The residual chlorine was found to be within the range of 0.6-0.66 mg/l before entering the distribution system. The efficiency of the treatment plant in removing COD is about 95%. Though the treated water contains NH_3-N (0.08-0.15 mg/l), it is far below than the maximum standard of BECR'97. The BOD_5 and the DO values were all within the permissible limit of the drinking water. A maximum value of turbidity in the treated water was found to be 0.84 NTU which is also very low compared to the standard. All other parameters pH, SS and TDS were also within the permissible limit. All the data are available in Annex A.7.

Though the treatment plant is able to remove all the contaminant, but the procedure followed have some effects on the quality of water available in the distribution network. It has been seen that the required free chlorine concentration in the distribution network is very low, which is described later. This indicates that the chlorine concentration which is using for post chlorination is not sufficient enough for providing required free chlorine even a 30 min chlorine contact time is maintained. Moreover it has been found that the treated water contains some ammonia. In the presence of ammonia, organic matter, and other chlorine-consuming materials, the required chlorine dosage to produce a free residual will be high. Another point of discussion is the pre chlorination. Though pre chlorination prevents the growth of algae, there are also some disadvantages associated with this process. As mentioned in the earlier chapter pre chlorination may produce water with nutrient supply that can stimulate bacterial growth in the distribution. So this can also be a reason of bacterial contamination of water in the distribution network. Moreover though CWASA collect samples from distribution network and tests water quality on a weekly basis (like TC Test), but FC and EC of the samples are not tested.

5.3 Water quality of Kalurghat Water Treatment plant

5.3.1 Raw water

The raw water sample from the intake point of KIRP shows microbial contamination, TC 10/100ml, but no FC and EC were detected. Other parameters like pH, BOD_5, COD, NH_3-N and

TDS were within the permissible limit same as drinking water. A maximum value of turbidity 20 NTU and suspended solids 36 mg/l were observed in one of the raw water samples. Moreover the main problem of ground water was higher iron concentration, 6.2mg/l and 6.8 mg/l in the samples. All the data are shown in Table 5.1.

5.1: Water quality of treated and untreated water of KIRP

Parameter	Sample collected on 1st day		Sample collected on 2nd day	
	Untreated sample	Treated sample	Untreated sample	Treated sample
TC (#/100ml)	**10**	0	**8**	0
EC (#/100ml)	0	0	0	0
FC (#/100ml)	0	0	0	0
Res. chlorine (mg/l)	-	0.4		0.45
pH (mg/l)	7.1	7.2	6.98	7.22
DO (mg/l)	5.5	7.6	4.2	7.4
BOD_5 (mg/l)	0.8	0.1	0.18	0.15
COD (mg/l)	2.1	2.4	1.3	1
NH_3-N (mg/l)	0.28	0.1	0.32	0.08
Turbidity (NTU)	11	2.8	20	2.4
SS (mg/l)	24.5	2	36	5.8
TDS (mg/l)	184	180	140	145
Total Iron (mg/l)	6.2	**1.2**	6.8	**1.3**

The groundwater of Chittagong normally contains high iron concentration. That is why the iron removal plant was installed where water only from high iron containing deep tube wells come for treatment. The absence of FC and EC indicates the water were free from fecal contamination. But the TC concentration may be due to that the water may contaminate on its way from source to the intake of KIRP. Though no fecal contamination was observed, nevertheless there is a possibility that the water may get fecaly contaminated. The reason behind this is, though the area of the deep tube well are sealed may be up to 5m ×5m area but there are household or easy access of human and animal within 10-15 m of the source. And as people use septic tank, pit latrines or sometimes open defecation depending on the area, the aquifer may easily get contaminated. Normally groundwater should not contain suspended solids or turbidity. But from the higher value of suspended solids and turbidity in the raw water indicates that the water may have come into contact with some particles on its way to the plant, as the pipeline collecting the raw water is not free from leakage or damage.

5.3.2 Treated Water

All the quality parameters of treated water of KIRP are within the standard limit of drinking water except the iron concentration. Though the plant is able to remove about 80% of the iron concentration but still the remaining concentration is not suitable for drinking. The two treated water sample show a higher iron concentration of 1.2 mg/l and 1.3 mg/l whereas WHO has a standard of 0.3mg/l and BECR'97 has a threshold value 1 mg/l of iron for drinking water (Fig 5.6). All the parameters of treated water are also presented in Table 5.1.

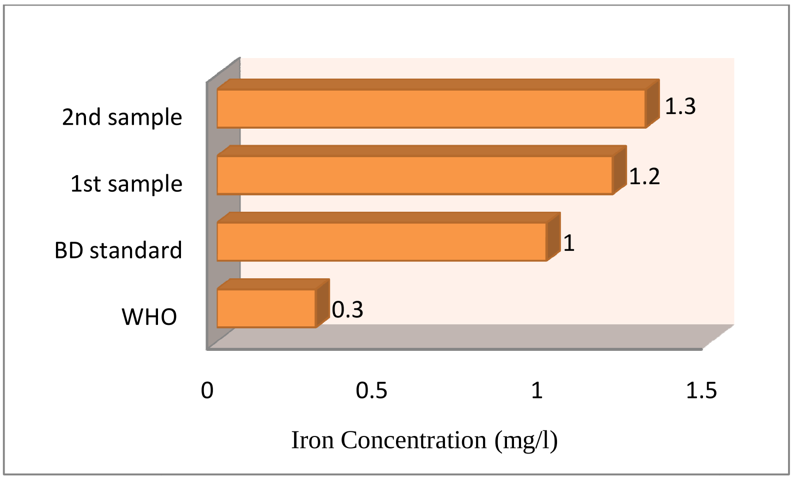


Fig 5.6: Concentration of iron in treated water of KIRP

As discussed in the previous chapter that only the water coming to the older filters of KIRP goes through the process of oxidation and sedimentation before filtration. But in the new filters water comes directly from intake without any oxidation. As a result ferrous iron (soluble) is not getting the chance to transfer into ferric ion (insoluble) and directly pass right through the sand filters. Treatment of groundwater without aeration is of no meaning as the iron remains soluble in the water, only filtration cannot help to remove iron. Moreover the older part of the treatment plant was installed about 33 years back and the new filters were installed about 23 years back. Since then the filters are in continuous operation without following proper maintenance schedule. The backwash facility of the older filters is not working properly, which can also be the reason of the remaining iron in the treated water. As a result when this iron is flowing to the distribution network, they are promoting the growth of iron bacteria in the system.

5.4 Water Quality of the Distribution Network

From the whole distribution network samples were collected from 46 locations and 12 parameters of water quality were analyzed for samples of each location. As these contain a lots of data, an overall view of results of each parameter are presented first in this section. The detailed data are presented in Annex A.8. Then the samples of which any of the parameter/s were not within the permissible limit of the compared standards, were separately presented and discussed. An effort was made to make a correlation between the parameters and to find out the probable reasons.

5.4.1 Results of Analyzed Parameters

Microbial Parameters

Among the 46 samples collected from the whole distribution network (DN), total coliform was found in 8 samples which are about 17.5%. According BECR'97 and WHO guideline, water sample should be free of microbial contamination. The locations where water is contaminated with total coliform are shown in figure 5.7 with red dots and the areas where FC was available are shown in Fig 5.8 with blue dots. Exact concentration of TC and FC are available in Annex A.8.

The maximum TC count 8/100 ml was found in 3 locations; Sagarika, Oxygen and Patharghata. The fecal coliform counts of those samples were 0/100 ml, 1/100 ml and 0/100 ml respectively. Only the water from Oxygen contains EC (1/100ml) among the entire eight contaminated water sample. The lowest TC was found in Dewanhat 1/100 ml. Within these eight samples, five were containing FC. That means about 11% of the samples collected from the distribution network is fecal contaminated. The maximum FC count was found in Foy's Lake 3/100 ml and the minimum was 1/100 ml found in Dewanhat.

Fig 5.7: Location where total coliform were detected in DN

Fig 5.8: Locations where fecal coliform were detected in DN

Residual Chlorine

Residual chlorine is one of the critical parameter of water quality. The residual chlorine of only 11 samples among the 46 was within permissible range of 0.2 mg/l according to the BECR'97 and WHO guideline. About 76% of the samples' residual chlorine is below the standard value. The minimum value of residual chlorine 0mg/l was found in 7 samples and the others were very close to zero. From a gross behavior of the samples it was seen that most of the TC contamination occurred in a residual chlorine concentration 0.1 mg/l or less than that as shown in Fig 5.9.

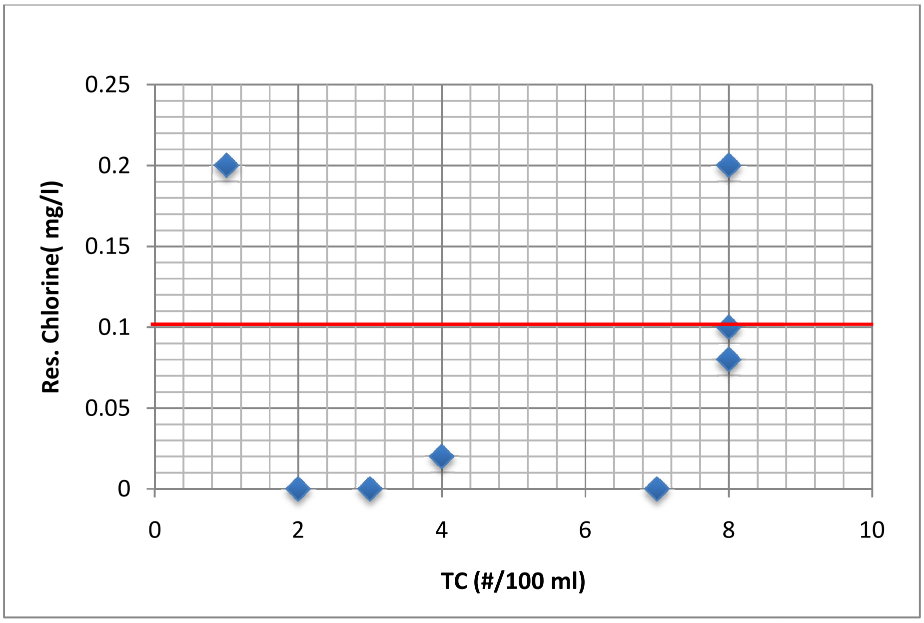


Fig 5.9: TC contaminated sample in less residual disinfectant

pH

The pH of all the samples was within the range of 6.5-8.5 which meets the standard of BECR'97 and WHO guideline. The maximum pH value 7.9 was found in Rahmatganj, Sirajudulla Road and Katalgonj and a minimum of 6.88 in Baijid Bostami.

Dissolved oxygen

Among the 46 samples, the DO of 5 samples was below the standard value of 6 mg/l by BECR'97. The DO of those samples ranges between 4.2-5.8 mg/l. The minimum DO value was found in the location Oxygen where microbiological contamination was also detected.

BOD_5 and COD

Of all the samples only 3 samples showed a higher BOD_5 value within the range of 0.3-0.4 mg/l than the standard value of 0.2 mg/l. The highest BOD_5 0.4mg/l was found in Sagarika where water sample was contaminated with total coliform. All the samples analyzed showed a COD value well below the standard value of 4 mg/l for drinking water according to the BECR'97.

Ammonia Nitrogen (NH_3-N)

The ammonia nitrogen of all the water samples of the DN within the permissible limit of 0.5 mg/l recommended by BECR'97.The maximum value of NH_3-N was found to be 0.42 mg/l. In a report of WHO it was mentioned that taste and odor problems as well as decreased disinfection efficiency are to be expected if drinking-water containing more than 0.2 mg of ammonia per liter is chlorinated, as up to 68% of the chlorine may react with the ammonia and become unavailable for disinfection. About 11 of the 46 samples show NH_3-N concentration higher than 0.2 mg/l; this may lead the reason of lower residual chlorine in the samples.

Turbidity and Suspended Solids

Typically higher the concentration of suspended solid higher will be the turbidity. It was clearly observed in the water sample analysis. The samples which showed a higher value of turbidity was also higher in suspended solids value. From analyzing the all 46 data, relation between suspended solids and turbidity can be established by taking the ratio of these two parameters. The maximum ration between suspended solid and turbidity was found to be 3.0 and the minimum was 1.44. But the gross behavior (92% of the samples) showed a range between 1.80- 2.40 (Annex A.9).

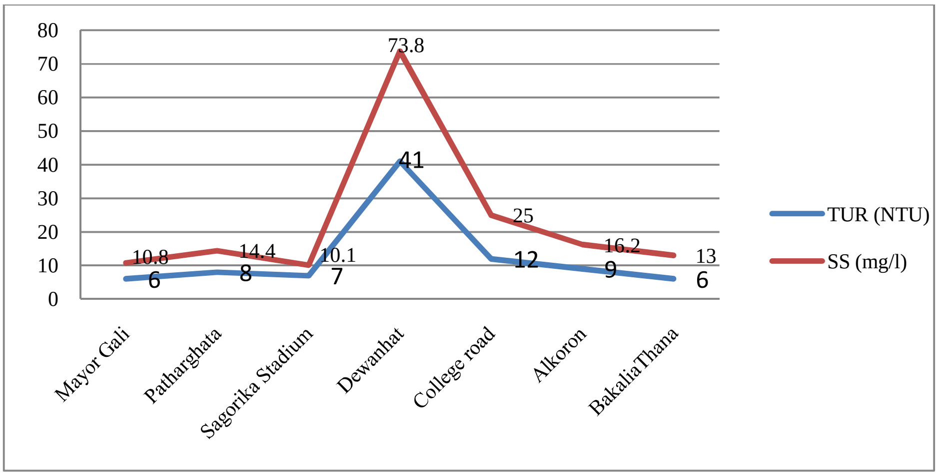


Fig 5.10: Relation between turbidity and suspended solids

Among all samples, the suspended solids of 7 samples were not in permissible range of 10 mg/l recommended by WHO and BECR’97. These same samples were also not in the recommended turbidity range of 5 NTU by WHO. But only 2 of them were exceeding the BECR’97 standard of 10 NTU. The maximum turbidity and suspended solids was found to be 41 NTU and 73.8 mg/l respectively in Dewanhat area as shown in Fig 5.10.

Total Dissolved Solids

The TDS value of the entire water sample was far below the standard value of 1000 mg/l according to WHO and BECR’97. The maximum value of TDS was 532 mg/l and found in Sagorika.

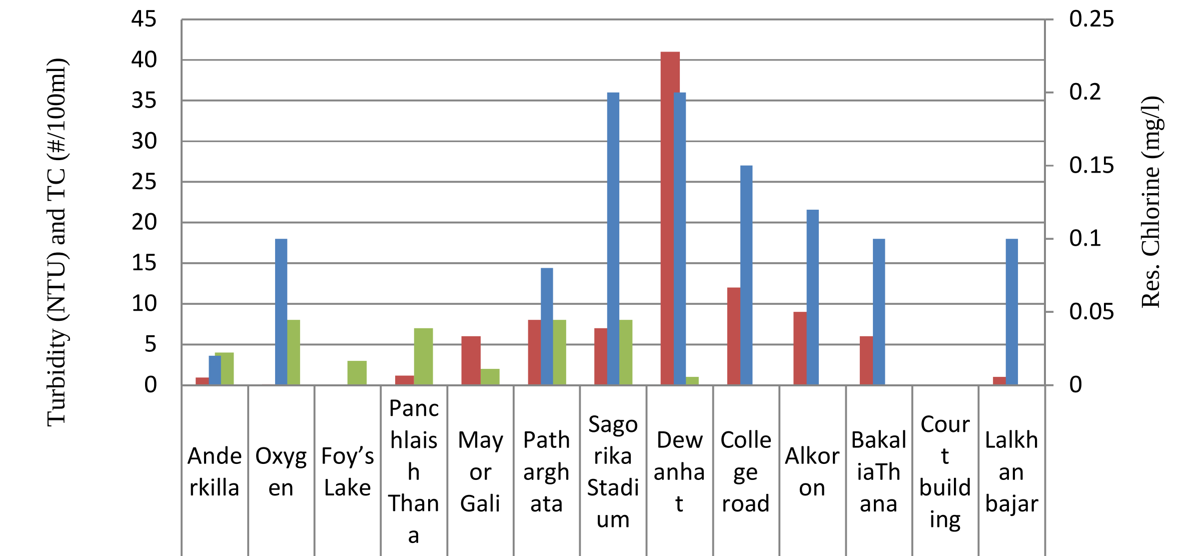
5.4.2 Correlation among the Data of Selected Samples

The samples which were not within the permissible limit of the standards regarding to any of the parameters are chosen and presented in Table 5.2. As the pH, COD, NH_3-N and TDS value of all the samples were within the permissible limit, these parameters have not included in the above mentioned table.

Table 5.2: Water quality parameters of the DN samples which were not in permissible limit

Sl. No	Name of Location	**Parameters**							
		TC (#/100 ml)	E.Coli (#/100 ml)	FC (#/100 ml)	Residual Chlorine (mg/l)	DO (mg/l)	BOD_5 (mg/l)	Turbidity NTU	SS mg/l
1	Anderkilla	**4**	0	**2**	**0.02**	**5.0**	**0.3**	0.9	2.0
2	Oxygen	**8**	**1**	**1**	**0.1**	**4.2**	**0.3**	0.1	0.24
3	Foy’s Lake	**3**	0	**3**	**0.0**	6.0	0.15	0	0
4	Panchlaish Thana	**7**	0	0	**0.0**	**4.8**	0.0	1.2	2.8
5	Mayor Gali	**2**	0	**2**	**0.0**	6.4	0.15	**6.0**	**10.8**
6	Patharghata	**8**	0	0	**0.08**	7.0	0.0	**8.0**	**14.4**
7	Sagorika Stadium	**8**	0	0	0.2	6.0	**0.4**	**7.0**	**10.1**
8	Dewanhat	**1**	0	**1**	0.2	6.4	0.0	**41**	**73.8**
9	College road	0	0	0	**0.15**	6.7	0.1	**12.0**	**25**
10	Alkoron	0	0	0	**0.12**	6.6	0.0	**9.0**	**16.2**
11	BakaliaThana	0	0	0	**0.1**	6.5	0.15	**6.0**	**13**
12	Court building	0	0	0	**0**	**5.8**	0.1	0	0
13	Lalkhan bajar	0	0	0	**0.1**	**5.8**	0.2	1	2.2
Bangladesh Standard		0	0	0	0.2	6 (min)	0.2 (max)	10 max	10 max
WHO Standard		0	0	0	0.2	-	-	5 max	10 max

From the above table it can be seen that 13 sampling locations/areas having water quality parameters are out of prescribed standard value. Reviewing the data, it can be said that residual chlorine and the turbidity are the most significant parameters for the microbial quality of the water samples as disinfection effectiveness is also dependent on the absence of turbidity, less than 1 NTU. The coliform or coli data mainly depends on low residual chlorine or high turbidity or suspended solids which are shown in Fig 5.11.



	Anderkilla	Oxygen	Foy's Lake	Panchlaish Thana	Mayor Gali	Pathargha ta	Sagorika Stadium	Dewanhat	College road	Alkoron	BakaliaThana	Court building	Lalkhan bajar
Tur(NTU)	0.9	0.1	0	1.2	6	8	7	41	12	9	6	0	1
TC(#/100 ml)	4	8	3	7	2	8	8	1	0	0	0	0	0
Res cl(mg/l)	0.02	0.1	0	0	0	0.08	0.2	0.2	0.15	0.12	0.1	0	0.1

5.11: Relation between TC, turbidity and residual chlorine.

In the sample of Anderkilla, which is a commercial place and also a populated area of the city, 4 TC and 2 FC per 100 ml sample were found, which lead to a lower DO level. Though the turbidity and suspended solids value was not so high but residual chlorine concentration is very low near to zero. That means at this location the residual disinfectant was not enough to prevent the contamination. The higher BOD_5 than the standard values also shows that the water is contaminated. The same interpretation can be done for the samples from Oxygen, Panchlaish and Foy's Lake area where a large number of microbial contaminations were found and which also shows a very low residual chlorine concentration. Except Foy's Lake the other two samples show a low DO level that indicates that the water or pipe work has a high oxidant demand due to growth of bacteria In Foy's lake area all the coliform were fecal originated. This can be due to that there are some slums in this area where people use pit latrine or open defecation.

But the pictures of Mayor Gali and Patharghata are totally opposite than the previous case. At Patharghta maximum concentration 8/100 ml of TC was found but no FC were detected. And in Mayor Gali 2 TC/100 ml was detected which was fecal originated. The water samples from both of these areas show lower residual chlorine and higher turbidity; which means both turbidity and residual chorine is significant in these areas for microbial contamination.

Water samples from Sagorika Stadium and Dewanhat was contaminated with 8 TC/100ml and 1TC/100 ml respectively. Though the residual chlorine concentration in both area were 0.2 mg/l, within permissible limit recommended by WHO and BECR'97, the turbidity and suspended solids value were higher in both areas. That means in this case turbidity is dominating over residual chlorine.

One of the examples of strong chlorine influence was seen in the sample of College Road where the water sample was free from microbial contamination. Both the turbidity and suspended solids concentration was higher in this area, 12 NTU and 25 mg/l respectively but the chlorine concentration 0.15mg/l was below the standard value. But this amount of residual chlorine was more influential over the higher turbidity to prevent contamination. This was the same case seen in Alkoron and Bakalia Thana area where turbidity was high but no contamination was detected.

The samples from Lalkhan Bajar and Court building did not show any contamination but a lower DO level and lower residual chlorine concentration gives an indication that there is a risk of getting contamination easily in these areas.

5.4.3 Probable Reasons of Water Quality Deterioration

Analyzing the result of sampling water quality parameter, it has been revealed that about 17% of the samples have microbial contamination of which 62% is fecaly contaminated and 12% shows E.Coli contamination. Moreover 50% of the contaminated samples are associated with high turbidity and 75% were showed low chlorine contamination. This means these samples got contaminated in the network from any nearby contamination source, as all the parameters of treated water just before entering the distribution network were within permissible limit and the contamination of water was influenced by high turbidity or low residual chlorine. So the probable reasons of the contamination source, high turbidity or low residual chlorine are discussed below.

a) Most of the pipe network in the city passes over the open drains or very near to the septic tanks, pit latrines or other contamination source. As the city does not have an sewer system, these open drains carry the waste water and most of the time the household waste (Fig 5.12 a) and b)).The presence of the fecal coliform and E.coli provides evidence of recent fecal contamination. One of the great means of water getting contaminated in distribution network is leakage and damage. Because of low internal pipe pressure or through the effect of a "pressure wave" within the system through the process of infiltration, contaminated water near the leaked pipe enters into the distribution network. Total coliform bacteria which occurs both in sewage and natural water also find their way with the contaminated water and are able to multiply in the water environments. Intermittent supplies are also frequently associated with contamination as the risks of infiltration and backflow increases significantly. As the contaminants enter the pipes in an intermittent supply, the charging of the system when supply is restored may increase risks to consumers, as a concentrated "slug" of contaminated water can be expected to flow through the system. From reviewing the data it can be said that most of the microbial contamination was seen at the outer skirt of the city. It also proves that as the water flowing more distance the chance of getting contamination gets higher.

b) The distribution network of the Chittagong showed that in most of the places the residual chlorine was below the standard value or even near to zero. As distribution system conditions conducive to bacterial growth can result in a loss of disinfectant residual. Moreover the concentration of chlorine in water decreases with time. As the pressure is low in the network, the water has to pump towards the city. But during absence and frequent failure of power supply for pumping, water remains stagnant in the net and the chlorine concentration get reduced. Loss of disinfectant residual can also be resulted through reactions between disinfectant and nutrients or ammonia nitrogen. The water may contain nutrient from the supplied water from the treatment plants due to the reason of pre chlorination mentioned earlier or from other sources. All these results a lower residual disinfectant in the network.

c) As mentioned in the earlier chapter, most of the parts of the distribution pipeline were installed before 1980. This age old network without having proper inspection and regular maintenance method, there is a firm possibility that it is damaged or corroded in many points. Corrosion provides a protective surface for microorganisms, slows water flow, and contributes to backflow occurrences where iron pipe walls corrode. The corrosion of pipe material is one of the big reasons of high turbidity also. As there is no detailed network map showing the pipe material of the locations exists, it is difficult to say exactly where reason for higher turbidity was pitfall of corrosion. But the high turbidity and suspended materials in Mayor Gali and College Road may be due to this reason. College road is a hilly area in the middle of the city, where soils or other particulate matter can enter to the distribution from the washed out of the hills even in very light rainfall. Higher turbidity in Sagorika Stadium, Patharghata and Alkoron may be due to the reason that these areas face tidal effect as Sagorika is near the ocean and Alkoron and Patharghata are near to Karnafuli and are low lying areas. During high tide these areas along with their supply network go under water (Fig 5.12: c) which lead the particulate material to enter the network.

Fig 5.12: a) Drain carrying household waste; b) Open drains within the city; c) Tidal effect and unauthorized waste disposal

d) Sometimes people also damage the pipe by mistake through illegal or unauthorized connections. As the city is not properly planned most often there is cutting of roads for gas line, telephone line, road construction or other reasons. This causes damage to the existing water lines leading to the introduction of contaminated soil or debris into the system. Dewanhat area is the commercial part of the city and presently going under lots of construction work. This may lead the particulate matter entering to the distribution network and showed the maximum turbidity. These organic and inorganic sediments can transport microorganisms into the distribution system and provide protection from disinfection.

All these factors discussed above, by and large, influence the microbial contamination and growth in the distribution system. Finally, the presence of total coliforms in distribution systems and stored water supplies can reveal regrowth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants. Biofilms are formed in distribution system pipelines when microbial cells attach to pipe surfaces and multiply to form a film or slime layer on the pipe. Extensive research has shown that bacteria are more resistant to disinfection when they are attached to or associated with various surfaces, such as turbidity particles, macro invertebrates, algae, pieces of carbon from treatment filters and pipe surfaces. Biofilms may not only protect bacteria from disinfection, but also provide an environment where disinfectant injured cells can repair cellular damage and grow.

5.5 Water Quality of Consumers' Reservoir

From reviewing the data, it was found that about 45% of the samples collected from consumers' reservoir (CR) were contaminated with total coliform of which 80% showed fecal and E.Coli contamination. Among the 11 reservoir microbial contamination was found in 5 reservoirs of which 4 were contaminated with FC and EC. The locations where TC, FC and EC were detected are shown in the Fig 5.13 and 5.14. To recognize the locations easily from the figures some identity numbers (ID) have been assigned to each point. The maximum TC and FC was found in the reservoir from Amirbag area (ID 5), 4/100 ml and 3/100 ml respectively. Among the contaminated samples, no fecal contamination was observed in the sample from East Madardbari (ID 2). Detailed data are available in the Annex A.10.

Fig 5.13: Location of reservoirs where TC was detected in CR

Fig 5.14:Location of reservoirs where FC and EC were detected in CR

A similarity with the data of distribution network has been found after analyzing the data of reservoirs. Relation among the residual chlorine and/or turbidity with the microbial contamination was also definite in this case. To relate these parameters samples where contamination was found have been presented in Table 5.3 with the parameters which were not in permissible limit.

Table 5.3: Water quality data of reservoirs where microbial contamination was detected

ID No.	Name of Location	Parameters							
		TC (#/100 ml)	**E. Coli (#/100 ml)**	**FC (#/100 ml)**	**Residual Chlorine (mg/l)**	**pH**	**DO (mg/l)**	**Turbidity NTU**	**SS mg/l**
1	Baijid thana	**1**	**1**	**1**	**0.01**	7.1	6.0	2.0	4.4
2	East Madarbari	**1**	0	0	**0.01**	7.3	6.5	4.8	9.4
3	Chittagong Medical	**2**	**1**	**1**	**0.07**	7.1	**5.6**	**15**	**32**
4	Miakhan Nagar	**3**	**2**	**2**	**0.0**	7.2	**5.4**	2.2	4.8
5	Amirbag	**4**	**2**	**3**	**0.0**	7.2	6.8	3.0	6.5

In all the 11 samples the residual chlorine was below the standard value of BECR’97 and WHO. There was no free chlorine at all in the reservoirs of Amirbag (ID 5) and Miakhannagar (ID 4).The maximum concentration was found in Chittagong Medical (ID 3) 0.07 mg/l. For the parameters pH, BOD_5, COD, NH_3-N and total dissolved solid, all the samples were within permissible limit. A high turbidity and suspended solids value was observed in Chittagong Medical (ID 3) 15 NTU and 32 mg/l respectively, which is above both of the WHO and BECR’97 standard. Higher suspended solids were also found in East Madarbari (ID 2) 9.4 mg/l. The ratio of suspended solid and turbidity was found to be within the range of 1.95- 2.66 for the consumers’ reservoirs (Annex A.11).

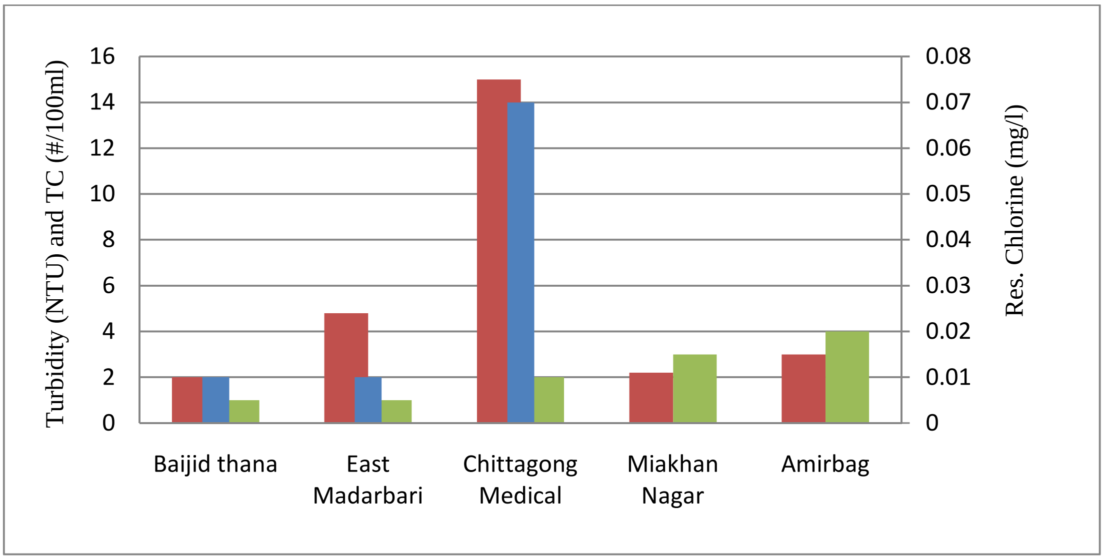


Fig 5.15: Relation between TC, turbidity and residual chlorine of CR

From reviewing the data and from Fig 5.15 it can be said that absence or very lower concentration of free chlorine influenced the microbial contamination in the reservoirs of Baijid thana (ID 1), Miakhan Nagar (ID 4) and Amirbag (ID 5), even the turbidity was low. A low DO value 5.4 mg/l in Miakhan Nagar is also an indication of microbial activity. A much higher turbidity and SS concentration respectively in Chittagong Medical (ID 3) shows that turbidity and SS were also responsible along with residual chlorine for the contamination. Turbidity and SS were also significant in East Madarbari (ID 2).

In the city more 90% of the household have underground reservoir as the availability of water is too uncertain. Those who have underground reservoir also use small plastic tanks or other concrete reservoir over the roof. Water from underground reservoir is pumped to these small reservoirs for required pressure in the supply tap. As the water supply is intermittent in Chittagong and the water has to be stored for significant periods in the home, even more than a week. This causes the loss of residual chlorine in the reservoir.

Fecal contamination in the reservoir indicates that water is getting contaminated from sources like sewage. It is very normal that both the septic tank and the underground reservoir are located very near. As the water remains stagnant in the reservoir for a time being without disinfectant, there is a chance of easy contamination. Moreover most of the concrete reservoirs have an open part through which birds can enter and can be a reason of fecal contamination. Inadequate cleaning of storage tanks is another reason of microbial contamination. As most of the storage tanks are underground people normally clean it after long time. This inadequate cleaning can introduce biofilm formation and accumulation of sediments and the problems associated with these have already discussed earlier. Moreover the low lying areas of the city go under water during rainfall or high tide due to improper drainage system. This helps the particles to enter easily in the underground reservoir and increase the turbidity of water.

5.6 Miscellaneous Influencing Factors

It is needless to say that general psyche of city dwellers towards cleanness while dumping garbage has some influence on quality of drinking water. Very often people throw their garbage other than specified area where distribution network might have passed. Beside that people are less interested to maintain reservoir or pipe placed on their own residence. Although there are several committee exist in respective housing society but reluctant on maintenance of distribution network and reservoir as well as dumping of garbage. Knowing the fact that polluted or poor quality drinking water has catastrophic effect on health, even though the awareness of general mass still could not reached up to satisfactory level. Other than this the city is growing in a much unplanned way. As the city is growing and growing and people migrating from villages, they are finding their space to live illegally over the existing few drains or khals. And due to their behavior they are polluting those drains, which is creating unhygienic environment.

On the other hand CWASA is in a stake to fulfill the water demand which is soaring up day by day. Beside that frequent power interruption and other unforeseen situation hinder the water production and distribution. As mentioned earlier in this dissertation that the production of water by CWASA is far below than demand. These tangible underlying factors compel CWASA to look only towards supplying water which incapacitates them to have eye on water quality related issues. Sometimes constraints on resources available on CWASA also impede to follow any sanitary inspection and hereby produce water fulfilling the prescribed parameter.

6. Conclusion and Recommendation

6.1 Conclusion

The water in different point or location of the distribution network in Chittagong city is not only contaminated with total coliform but in most of the cases contamination is fecal originated. These microbial contaminations were found mostly at the outer skirt of the city. Though lots of areas within the city were found to be free of microbial contamination but there is a high possibility of these areas getting contaminated as the residual chlorine is not enough within the distribution network to prevent microbial contamination. Moreover a higher turbidity is influencing to inactivate the efficiency of the residual disinfectant.

The reason behind this microbial contamination is not only the poor quality of the distribution network which means leakage, damage, intermittent water supply, pressure fluctuation or cross connection but also the waste disposal behavior of the city dwellers and the unplanned urbanization together with the sewage and storm water drainage system of the whole city. These have been found as the main source of fecal contamination.

Halda River as a source of surface water is still in suitable position but the unauthorized disposal of municipal and industrial waste and the sewage disposal can turn Halda to an unsuitable source of drinking water in near future. Though the Mohra Water treatment plant is efficiently removing the microbial contamination from raw surface water but sometimes the process of pre chlorination for reducing the access algae growth, can be proved as a reason of microbial growth in the distribution network. Because pre chlorination oxidizes the biodegradable organic matter into nutrient which promotes bacterial growth in pipe network. The lower concentration of chlorine used for post chlorination may be the reasons of lower free chlorine available in the distribution network.

Presence of total coliform in raw water of KIRP means that ground water is also not safe from microbial contamination and the way of raw water coming from source to intake of treatment plant is also vulnerable to contamination. Though the treatment procedure can efficiently remove the microbial contamination from the raw water but the higher iron concentration in the treated water than the standard value shows that KIRP is not capable anymore in fulfilling its major goal of iron removal. Missing of aeration unit in one of the part f treatment is the major cause failure of iron removal. Moreover the filters of the KIRP have not been maintained in proper way and continuously in operation for last 3 decades. Probably this is one of the reasons why the filters are not capable anymore to remove the iron to the desired level.

It is not always that the distributed water is of poor quality but sometimes higher retention period in household reservoir is responsible for the water quality deterioration. About 45% of the samples collected from consumers' reservoir were microbiologically contaminated and among those 80% was fecal contamination. Use of underground reservoir close to septic tank and improper maintenance of storage tanks are considered to be the influencing factors of the deteriorated water quality in the reservoirs.

As the responsible authority is striving hard to fulfill the water demand of the city thereby quality has always been treated as less prioritized part. As a result regular and periodic monitoring, maintenance of the distribution network and proper sanitary inspection were found to be absent in the city. Moreover the negligence and lack of awareness of most of the people about the water quality and health issue make them to grow and follow an unhygienic way of life compromising with poor water quality.

6.2 Recommendation

In order to improve the water quality of Chittagong city supplied by CWASA the following recommendation should be followed:

1) The concentration of chlorine for post chlorination in MWTP should be increased to about 2-3 mg/l so that enough residual chlorine will be available in the distribution network. To determine the applicable concentration chlorine demand should be checked.

2) Instead of pre chlorination other treatment process like enhancing flocculation or using biological filtration should be followed to reduce algae growth. Biologically active filters are any filter media that allow microorganisms to become attached, usually forming a biofilm coating (a gelatinous layer) on or between the media grains. Algae or microorganisms are removed by natural feeding as pathogens live on them. This filter can be also used to reduce nutrient level.

3) "Multi-barrier principle" should be introduced to reduce contaminant inputs from human activities into groundwater and control of land-use in protection zones should be done.

4) Proper monitoring and maintenance of damage and leakage in the pipe network conveying water from source to intake of KIRP should be followed.

5) Immediate measures should be taken so that water from both intakes of KIRP can go through the aeration and sedimentation process to increase the efficiency of iron removal.

6) A routine backwash along with rinse of filters should be maintained.

7) The filters of the KIRP should be replaced by new filter media which is efficient enough to remove iron from the raw water. Proper study is required for this to find out which type of filter is suitable.

8) As the treated water from KIRP mix with the one of MWTP, chlorination dose should increase to maintain required residual disinfectant in the system.

9) The disinfection should not be centralized but rather decentralized. Intermediate chlorination in different point of distribution should be introduced immediately. For introduction, the existing booster station can be used as a point of inter chlorination. Then with time being other suitable points have to be find out.

10) Establishing a monitoring system/team, which is not cost intensive, for the regular sanitary purpose is must, who will report problems to the higher official.

11) Distribution System Maintenance Programme should carry on to detect leakage and damage and to repair or replace defected pipe, doing regular flushing, relining and maintaining positive pressure in the distribution network etc. Moreover steps should be taken against cross-connections or illegal connections.

12) Steps should be taken to reduce the corrosion of the pipe like changing the pH to make it less corrosive or using appropriate corrosion inhibitor that will create a molecular layer between pipe material and water. Pipes that are already damaged by corrosion should be replaced as early as possible.

13) A detailed distribution network map along with pipe material, diameter, gate valve etc should be constructed as early as possible. For this GIS mapping can be a good method.

14) Detailed study should be carried out to analyze the total distribution system. CWASA should construct a detailed distribution network map. For this the GIS mapping system is recommended.

15) CWASA should provide alternative source of power supply so that water do not remain in the net for longer period due to power crisis.

16) During cutting of roads for any purpose care should be taken so that it does not hamper the water supply pipeline.

17) CWASA laboratory should test more microbial water quality parameters (at least FC and E. Coli) of the samples from the distribution network on a regular basis. And in any case of contamination detection, CWASA should warn the people of that location about this.

18) The reservoirs used by the consumers should have enough residual chlorine. Moreover people should clean the reservoir on regular basis and keep the reservoir covered.

19) CWASA should share the responsibility of maintenance of distribution network with the municipal authority of the city, Chittagong City Corporation (CCC). For this purpose, a committee in each ward, heading with the ward commissioner (the legal body from CCC) and the local people/ stakeholders can established. Initially the maintenance program can be executed on a half yearly basis which can be improved later on 3 months and monthly basis with time being.

20) CWASA should prepare at least one annual report of the result of assessment of water quality which will act as tool to initiate discussions with a wide range of stakeholders about the need to protect water quality. Consultation with the community and key decision-makers helps secure funding and community support for implementing water protection measures.

21) CWASA should also initiate treatment facility of the Small Size Water supply System, where people are using groundwater without treatment. For such small community slow sand filtration is recommended.

22) CWASA along with CCC should organize different awareness programs like "Safe Drinking Water and Health." People should know the relationship between hygiene and health. The motive this type of program should be to change peoples' behavior and to educated and grow awareness among them.

23) Capacity building program for the CWASA officials is a must so that they can strengthen their ability to supply safe drinking water to the public.

24) CWASA should implement proper sewage system and drainage facility for the city as early as possible while without these the effort of improving water quality will remain incomplete.

25) Strict law should be enforced from the DOE for unauthorized disposal of waste in the drains.

26) Steps should be taken to protect the water shed of Halda, like assess and prioritize possible threats from landuse, providing protection zone and control water at water shed etc., so that it remain as a suitable source of drinking water.

27) The government should establish a detail water quality standard for the surface water using as a source of drinking water.

28) Chittagong Development Authority along with the help of Chittagong city Corporation should take action against illegal encroachment of drains and khals.

Finally the government should take immediate steps to improve the overall quality of the drinking water. For this, detailed study on the existing network should be done which can explore further opportunities

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Annexes

A.1 Standard Values for Water (Environmental quality Standard for Bangladesh, 1991)

Standard Values								
Parameters/ Determinants	Unit	Drinking Water	Recreational Water	Fishing Water	Industrial Water	Irrigational Water	Livestock Water	Coastal water
Acidity	mg/l	NYS	NYS	Less than 20	NYS	NYS	NYS	NYS
Alkalinity(total)	mg/l	NYS	NYS	70-100	NYS	NYS	NYS	NYS
Aluminum	mg/l	0.2	NYS	NYS	NYS	1	NYS	NYS
Ammonia(NH_3)	mg/l	0.5	2	0.025	NYS	3	NYS	NYS
Ammonical Nitrogen(as N)	mg/l	NYS	NYS	1.2	NYS	15	NYS	60
Arsenic	mg/l	0.05	0.2	NYS	NYS	1	1	1
Barium	mg/l	0.5	NYS	NYS	NYS	NYS	NYS	NYS
Benzene	mg/l	0.01	NYS	NYS	NYS	NYS	NYS	NYS
Bicarbonate	mg/l	NYS	NYS	NYS	NYS	NYS	500	NYS
B.O.D	mg/l	0.2	3	6	10	10	NYS	NYS
Boron	mg/l	1	NYS	NYS	NYS	2 not Less than 1	NYS	NYS
Cadmium	mg/l	0.005	NYS	NYS	NYS	0.01	0.5	0.3
Calcium	mg/l	75	NYS	NYS	NYS	NYS	700	NYS
Carbon dioxide(CO_2) dissolved	mg/l	NYS	NYS	6	NYS	NYS	NYS	NYS
Chloride(as Cl)	mg/l	150-600*	600	600	NYS	600	2000	NYS
Chlorinated alkanes								
-carbon tetrachloride	mg/l	0.01	NYS	NYS	NYS	NYS	NYS	NYS
-1.1 dibhloreothylene	mg/l	0.001	NYS	NYS	NYS	NYS	NYS	NYS
-1.2dichloroethylene	mg/l	0.03	NYS	NYS	NYS	NYS	NYS	NYS
-Tetrachloroethylene	mg/l	0.03	NYS	NYS	NYS	NYS	NYS	NYS
Trichloroetylene	mg/l	0.09	NYS	NYS	NYS	NYS	NYS	NYS
Chlorinated phenols								
-Pentacholorphenol	mg/l	0.03	NYS	NYS	NYS	NYS	NYS	NYS
2.4.6tricholorophenol	mg/l	0.03	NYS	NYS	NYS	NYS	NYS	NYS
Chlorine (residual)	mg/l	0.2	0.3	<0.01	NYS	NYS	NYS	2
Chloroform	mg/l	0.09	NYS	NYS	NYS	NYS	NYS	NYS
Chromium (hexavalent) as Cr_6	mg/l	0.05	0.05	NYS	0.5	NYS	NYS	NYS
Chromium	mg/l	0.05	NYS	0.05	NYS	NYS	NYS	NYS
COD	mg/l	4	4	NYS	3-10|a	NYS	NYS	8

*Coasteal area 100 and in extreme case 1500. |a For boiler feed water, depending on boiler feed pressure

Standard Values								
Parameters/ Determinants	Unit	Drinking Water	Recreational Water	Fishing Water	Industrial Water	Irrigational Water	Livestock Water	Coastal water
Coliforms (fecal)	n/100ml	0	NYS	NYS	NYS	10	NYS	NYS
Coliforms (total)	n/100ml	2*	200	5000	NYS	1000	100	100
Colour	Hazen Unit	15	Clear	Normal	Normal	Normal	Normal	Normal
Copper	mg/l	1	NYS	<0.4	NYS	0.2	NYS	0.3
Cyanide(CN)	mg/l	0.1	0.1	NYS	NYS	NYS	NYS	0.2
Detergents	mg/l	0.2	NYS	NYS	NYS	NYS	NYS	NYS
DO	mg/l	6**	4-5	4-6	5	5	4-6	6
EC	mhoms /cm		500	800-1000	NYS	750	NYS	NYS
Floride as F	mg/l	1	1.5	NYS	NYS	NYS	4	NYS
Formaldehyde	mg/l	NYS	NYS	NYS	NYS	NYS	NYS	NYS
Hardness as $CaCo_3$	mg/l	200-500	NYS	80-120	250|b	NYS	NYS	NYS
Hydrogen sulfide	mg/l				1-5|c			NYS
Iodine	mg/l	NYS	NYS	NYS	NYS	NYS	NYS	NYS
Iron	mg/l	0.3-1|e	NYS	NYS	0.5|d	NYS	NYS	NYS
Kjaldahl as Nitrogen (total)	mg/l	1	1	1	NYS	NYS	NYS	NYS
Lead	mg/l	0.05	NYS	0.05	0.01	0.1	0.05	0.2
Magnesium	mg/l	30-50	NYS	NYS	NYS	NYS	250	NYS
Manganese	mg/l	0.1	NYS	NYS	0.1|f	2	NYS	NYS
Mercury	mg/l	0.001	NYS	0.001	NYS	NYS	NYS	NYS
Nickel	mg/l	0.1	NYS	NYS	NYS	0.5	NYS	0.2
Nitrate as N	mg/l	10	NYS	NYS	NYS	NYS	250	NYS
Nitrate($No_{2)}$)	mg/l	<1	NYS	0.03	NYS	NYS	None	NYS
Odour		Odour-less	Unobectiona ble	normal	Normal	Normal	Normal	Normal

*2 per 100 ml in two consecutive samples or in more than 100% of the samples examined, for drinking water.

|b For boiler feed water 2-40 depending on boiler feed pressure, tanning 5-130. |c For cooling water -5, for air conditioning water -1. |d Textile dyeing -0.25. Tanning -0.2. |e In some areas the maximum tolerable limit may be upto 5 mg/l in absence of better source of drinking water. |f For air conditioning water – 0.5, for textile dyeing -0.2, Tanning -0.2.

**Desirable limit for drinking water

Standard Values								
Parameters/ Determinants	Unit	Drinking Water	Recreational Water	Fishing Water	Industrial Water	Irrigational Water	Livestock Water	Coastal water
Oil and grease	mg/l	0.01	0.1	0.01	NYS	NYS	NYS	15
Organic Phosphorous compound	mg/l	0	0	NYS	NYS	NYS	NYS	NYS
Organo chlorine compound								
-Aldrin & dieldrin	mg/l	0	0	NYS	NYS	NYS	NYS	NYS
-Chlordane	mg/l	0	0	NYS	NYS	NYS	NYS	NYS
-DOT	mg/l	0	0	NYS	NYS	NYS	NYS	NYS
-Hexachloroben-zene	mg/l	0	0	NYS	NYS	NYS	NYS	NYS
Heptachloro and heptachlorepo-xide	mg/l	0	0	NYS	NYS	NYS	NYS	NYS
-Lindane	mg/l	0.003	NYS	NYS	NYS	NYS	NYS	NYS
-Methoxychlor	mg/l	0.03	NYS	NYS	NYS	NYS	NYS	NYS
-2.4.D	mg/l	0.1	NYS	NYS	NYS	NYS	NYS	NYS
Percent Sodium								
pH		6.5-8.5	6-9.5	6.5-8.5	6-9.5	6.5-8.5	5.5-9	6-9
Phanolic compounds (as C_6H_5OH)	mg/l	0.002	0.001	NYS	NYS	NYS	NYS	1
Phosphate (PO_4)	mg/l	6	6	10	NYS	10	NYS	NYS
Phosphorous	mg/l	0	NYS	1.0	NYS	NYS	NYS	NYS
Potassium	mg/l	12	NYS	NYS	NYS	NYS	NYS	NYS
Radioactive materials								
-Gross Alpha activity	Bq/l	0.01	NYS	NYS	NYS	NYS	NYS	NYS
-Gross Beta Gamma activity	Br/l	0.1	NYS	NYS	NYS	NYS	NYS	NYS
Solenium	mg/l	0.01	0.05	NYS	NYS	0.05	NYS	NYS
Silica	mg/l	NYS	NYS	NYS	NYS	NYS	NYS	NYS
Silver	mg/l	0.02	NYS	NYS	NYS	NYS	NYS	0.05
Sodium	mg/l	200	NYS	NYS	NYS	NYS	1000	NYS

Standard Values								
Parameters/ Determinants	Unit	Drinking Water	Recreational Water	Fishing Water	Industrial Water	Irrigational Water	Livestock Water	Coastal water
Sodium absorption ratio	-	-	-	-	8-16	-	-	-
Sodium carbonate ($NaCO_3$) Residual	mg/l	NYS	NYS	NYS	NYS	NYS	NYS	NYS
Sodium Chloride	mg/l	NYS	NYS	NYS	NYS	NYS	2860-12000	NYS
S-S	mg/l	10	20	25	75	NYS	NYS	75
Sulfide as S	mg/l	0	NYS	NYS	NYS	NYS	NYS	NYS
Sulfate(So_4)	mg/l	400	NYS	NYS	NYS	1000	NYS	NYS
Tar	mg/l	0	0	0	NYS	NYS	NYS	NYS
Taste		Not offensive	Normal	Normal	Normal	Normal	Not offensive	Normal
T.D.S	mg/l	1000	NYS	NYS	1500	2000	5000	NYS
Temperature	℃	20-30	20-30	20-30	20-30	20-30	20-30	30
Tin	mg/l	2	NYS	NYS	NYS	NYS	NYS	NYS
Turbidity	JTU	10	10	NYS	50	NYS	NYS	75
Zinc	mg/l	5	NYS	10	NYS	5	NYS	NYS

Note:

Drinking Water

1. Water intended for human consumption should not contain pathogenic organisms, parasites, algaes, other organisms.
2. If it is necessary to supplement the microbiological analysis of water intended for human consumption, the samples should be examined not only for coliforms but also for pathogens including salmonella, pathogenic straphylococci, fecal bactor iophages, entero-viruses.

A.2 Standard Values for Water (Environmental Conservation Act,1997)

Sl. No.	**Parameter**	**Unit**	**Standards**
1	Aluminium	mg/l	o.2
2	Ammonia	,,	0.5
3	Arsenic	,,	0.05
4	Belium	,,	0.01
5	Benzene	,,	0.01
6	BOD_5 at 20° C	,,	0.2
7	Boron	,,	1.0
8	Cadmium	,,	0.005
9	Calcium	,,	75
10	Chloride	,,	150-600*
11	Chlorinated alkanes		
	carbontetrachloride	,,	0.01
	1.1 dichloroethylene	,,	0.001
	1.2 dichloroethylene	,,	0.03
	tetrachloroethylene	,,	0.03
	trichloroethylene	,,	0.09
12	Chlorinated phenols		
	-pentachlorophenol	mg/l	0.03
	-2.4.6 trichlorophenol	,,	0.03
13	Chlorine(residual)	,,	0.2
14	Chloroform	,,	0.09
15	Chromium(Hexavalent)	,,	0.05
16	Chromium(Total)	,,	0.05
17	COD	,,	4
18	Coliform (fecal)	n/100 ml	0
19	Coliform(total)	n/100 ml	0
20	Color	Hazen Unit	15
21	Copper	mg/l	1
22	Cyanide	,,	0.1
23	Detergents	,,	0.2
24	DO	,,	6
25	Fluride	,,	1
26	Hardness as $CaCO_3$	,,	200-500
27	Iron	,,	0.3-1.0
28	Kjeldhl Nitrogen (total)	,,	1
29	Lead	,,	0.05
30	Magnesium	,,	30-35
31	Manganese	,,	0.1
32	Mercury	,,	0.001

Sl. No.	Parameter	Unit	Standards
33	Nickel	,,	0.1
34	Nitrate	,,	10
35	Nitrite	,,	<1
36	Odor	,,	Odorless
37	Oil and grease	,,	0.01
38	pH	,,	6.5-8.5
39	Phenolic Compounds	,,	0.002
40	Phosphate	,,	6
41	Phosphorus	,,	0
42	Potassium	,,	12
43	Radioactive materials (gross alpha activity)	Bq/l	0.01
44	Radioactive materials (gross beta activity)	Bq/l	0.1
45	Selenium	mg/l	0.01
46	Silver	,,	0.02
47	Sodium	,,	200
48	Suspended particulate matters	,,	10
49	Sulfide	,,	0
50	Sulfate	,,	400
51	Total dissolved solids	,,	1000
52	Temperature	°C	20-30
53	Tin	mg/l	2
54	Turbidity	JTU	10
55	Zinc	mg/l	5

Source: The Environment Conservation Rules, 1997

A.3 Standards for Inland Surface Water

Best Practice based classification	Parameter			
	pH	BOD mg/l	DO mg/l	Total Coliform number/100
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 or more	200 or less
c. Source of drinking water for supply after conventional treatment	6.5-8.5	6 or less	6 of more	5000 or less
d. Water usable by fisheries:	6.5-8.5	6 or less	5 of more	--
e. Water usable by various process and cooling industries	6.5-8.5	10 or less	5 of more	5000 or less
f. Water usable for irrigation	6.5-8.5	10 or less	5 of 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 temperature of 25°C); Sodium less than 26%; boron less than 0.2%.

Source: The Environment Conservation Rules, 1997

A.4 Most Common Water Quality Parameters Limit for Drinking Water by WHO Guideline

Parameter	Unit	WHO 2004
Total Coliform	#/100ml	0
Fecal Coliform	#/100ml	0
Escherichia coilform	#/100ml	0
Residual Chlorine	mg/l	0.2 (min)
Color	TCU	15
Taste and Odor		Unobjectionable
Suspended Solids	mg/l	10 (max)
Turbidity	NTU	5(max)
TDS	mg/l	1000(max)
pH		6.5-8
Hardness	mg/l	500
Iron	mg/l	0.3 (max)
Manganese	mg/l	0.1
Nitrate	mg/l	3(short term exposure), 0.2 (Long term exposure)
Arsenic	mg/l	0.01

A.5 Parameters of water being tested by CWASA laboratory

Sample monitoring routine	Daily	Weekly	Monthly
Parameters	pH, Turbidity, T-Alkalinity, Residual Chlorine, Chloride	T-Fe, Mn, Coli. Bacteria, TDS, Ca Hardness, T- Hardness	BOD, COD, DO, As, Cd,Cr. Ld, Zn. CN, F,NH3-N(NH3), NO3-N(NO3), PO4 ,SO4

A.6 Bangladesh Standard and WHO Standard for drinking water quality parameters

Parameters	**Bangladesh Standard**	**WHO Standard**
TC (#/100 ml)	0	0
EC(#/100 ml)	0	0
FC (#/100 ml)	0	0
Residual Chlorine (mg/l)	0.2 (min)	0.2 (min)
pH	6.5-8.5	6.5-8.0
DO(mg/l)	6(min)	-
BOD_5 (mg/l)	0.2 (max)	-
COD(mg/l)	4 (max)	-
NH_3-N(mg/l)	0.5 (max)	-
Turbidity(NTU)	10 (max)	10 (max)
SS(mg/l)	10 (max)	10 (max)
TDS(mg/l)	1000 (max)	1000 (max)

A.7: Water quality data of raw water (from Halda) and treated water of MWTP

A.7.1Quality parameters of water sample collected during full tide in Halda

Parameter	Raw water from Source			Bangladesh Standard for surface Water Quality	Treated Water
	1 km upstream	Intake point	1 km downstream		
TC (#/100 ml)	1000	1190	1200	5000/less	0
EC(#/100 ml)	8	12	18	-	0
FC (#/100 ml)	62	80	98	-	0
Residual Chlorine (mg/l)					0.66
pH	7	6.9	7	6.5-8.5	7.1
DO(mg/l)	7.8	7.5	7.2	6 (min)	6.8
BOD_5 (mg/l)	1.2	1.4	1.8	6 or less	0.1
COD(mg/l)	32	38	48	-	1.7
NH_3-N(mg/l)	0.42	0.58	0.65	-	0.15
Turbidity(NTU)	180	190	110	-	0.84
SS(mg/l)	324	342	198	-	1.6
TDS(mg/l)	580	540	610		120

A.7.2Quality parameters of water sample collected from MWTP during low tide in Halda

Parameter	Raw water from Source			Bangladesh Standard for surface Water Quality	Treated Water
	1 km upstream	Intake point	1 km downstream		
TC (#/100 ml)	1500	2000	2200	5000/less	0
EC(#/100 ml)	18	22	28	-	0
FC (#/100 ml)	110	134	150	-	0
Residual Chlorine (mg/l)					0.62
pH	7.3	7.8	7.32	6.5-8.5	7.18
DO(mg/l)	7	6.8	6.2	6 (min)	7.2
BOD_5 (mg/l)	1.3	1.2	1.6	6 or less	0.1
COD(mg/l)	38	44	55	-	1.8
NH_3-N(mg/l)	0.25	0.2	0.2	-	0.08
Turbidity(NTU)	230	250	210	-	0.6
SS(mg/l)	414	450	378	-	1
TDS(mg/l)	83	87	86	-	94

A.7.3 Quality parameters of water sample collected from MWTP during mid tide in Halda

Parameter	Raw water from Source			Bangladesh Standard for surface Water Quality	Treated Water
	1 km upstream	Intake point	1 km downstream		
TC (#/100 ml)	1500	1800	1980	5000/less	0
EC(#/100 ml)	12	15	20	-	0
FC (#/100 ml)	100	120	140	-	0
Residual Chlorine (mg/l)					0.6
pH	7.01	6.92	7.11	6.5-8.5	7.12
DO(mg/l)	6.8	6.6	6.1	6 (min)	7.1
BOD_5 (mg/l)	1.5	1.4	1.8	6 or less	0.1
COD(mg/l)	38	42	49	-	2.2
NH_3-N(mg/l)	0.38	0.32	0.18	-	0.12
Turbidity(NTU)	220	235	210	-	0.8
SS(mg/l)	396	420	378	-	2
TDS(mg/l)	150	135	160	-	90

A.8: Water Quality Data of samples from Distribution Network

Sl. No	Name of Locations	Parameters (Date of Analysis: 30.03.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
1	Rahmatganj	0	0	0	0.1	7.9	6.5	0.1	1.8	0.1	0.8	1.8	172
2	DewanBajar	0	0	0	0.3	7.5	7.0	0	1.5	0.15	1.2	2.0	148
3	Sirajudullah road	0	0	0	0.2	7.9	7.8	0	1.2	0.42	1.0	2.2	164
4	Anderkilla	4	0	2	0.02	7.6	5.0	0.3	3.0	0.32	0.9	2.0	226
5	Sulakbahar	0	0	0	0.35	7.6	8.7	0	1.7	0.2	1.4	2.7	139
6	Khulshi WASA pump	0	0	0	0	7.7	7.4	0	2.0	0.18	2.0	3.8	164
7	Katalgonj	0	0	0	0.35	7.9	6.7	0.1	2.8	0.22	2.4	4.9	12

Sl. No	Name of Locations	Parameters (Date of Analysis: 01.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	TDS (mg/l)
8	Sagorika Stadium	8	0	0	0.2	6.9	6.0	0.4	2.0	0.18	7.0	10.1	532
9	Kabillah dham	0	0	0	0.0	7.02	6.4	0.2	1.8	0.2	1.0	2.4	192
10	Port collony WASA pump	0	0	0	0.1	7.01	7.0	0.1	2.2	0.15	4.0	7.4	297
11	Navy Collony	0	0	0	0.1	7.11	6.2	0.2	2.0	0.18	1.2	2.8	240
12	Agrabad WASA office	0	0	0	0.1	6.98	6.0	0.1	1.4	0.25	0.4	1.2	240
13	Lalkhan bajar	0	0	0	0.1	7.18	5.8	0.2	1.0	0.28	1.0	2.2	204

Sl. No	Name of Locations	Parameters (Date of Analysis :07.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
14	Hamjarbag	0	0	0	0.8	6.92	6.5	0.15	1.8	0.15	0.8	1.8	142
15	Mohammedpur	0	0	0	0.1	7.01	7.0	0.1	1.2	0.21	2.0	4.2	155
16	Bahaddarhat	0	0	0	0.15	7.08	6.8	0.0	1.0	0.2	2.8	5.8	122
17	Khaja road	0	0	0	0.10	7.12	6.4	0.1	1.2	0.25	2.1	4.4	130
18	CMB Road	0	0	0	0.13	7.18	6.2	0.12	1.3	0.20	2.0	3.8	128
19	Kamal Bajar	0	0	0	0.28	7.0	7.0	0.0	1.0	0.22	1.4	3.0	110

Sl. No	Name of Locations	Parameters (Date of Analysis: 11.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
20	Ice Facory road	0	0	0	0.1	7.2	7.2	0.0	1.7	0.11	0.8	2.0	142
21	Shadarghat	0	0	0	0.0	7.18	6.8	0.1	1.2	0.08	1.2	2.4	220

Sl. No	Name of Locations	Parameters (Date of Analysis : 15.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (ppm)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
22	Baijid Bostami	0	0	0	0.08	6.88	6.8	0.1	2.0	0.1	0.8	1.8	124
23	Oxygen	8	1	1	0.1	7.1	4.2	0.3	2.4	0.25	0.1	0.24	138
24	Nasirabad CDA	0	0	0	0.2	6.92	7.6	0.15	2.0	0.15	0.2	0.44	132
25	Pahartali	0	0	0	0.15	7.24	6.5	0.2	2.2	0.12	0.15	0.3	190
26	Jhawtala	0	0	0	0.1	7.19	6.7	0.15	2.0	0.08	0.1	0.22	120
27	Kusumbag	0	0	0	0.12	7.04	7.2	0.10	2.1	0.15	0.12	0.28	135

Sl. No	Name of Locations	Parameters (Date of Analysis : 18.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
28	Pathantuli	0	0	0	0.1	6.92	6.4	0.1	2.0	0.2	4.0	8.2	344
29	Goshaldanga	0	0	0	0.15	7.02	6.7	0.1	2.1	0.15	3.0	6.4	272
30	Monsurabad	0	0	0	0.1	7.18	6.0	0.0	2.0	0.18	4.0	8.4	190
31	CDA Collony	0	0	0	0.20	6.99	7.0	0.1	2.4	0.1	2.0	3.8	308
32	West Madarbari	0	0	0	0.1	7.08	6.8	0.08	2.2	0.3	4.0	8.2	360
33	Dampara WASA Resorvoir	0	0	0	0.15	7.21	6.4	0.15	2.0	0.2	3.0	6.4	240

Sl. No	Name of Locations	Parameters (Date of Analysis : 20.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
34	Bakalia Thana	0	0	0	0.1	6.95	6.5	0.15	2.8	0.15	6.0	13	192
35	1Kilometer	0	0	0	0.15	7.15	7.0	0.1	3.0	0.2	4.0	8.2	165
36	College road	0	0	0	0.15	7.12	6.7	0.1	2.0	0.22	12.0	25	149
37	Panchlaish Thana	7	0	0	0.0	6.92	4.8	0.0	3.2	0.2	1.2	2.8	152
38	Jubli Road	0	0	0	0.2	7.01	7.2	0.02	2.4	0.12	0.5	1.2	126
39	Kajir Dewri	0	0	0	0.1	7.18	6.9	0.15	3.0	0.10	1.2	2.4	143

Sl. No	Name of Locations	Parameters (Date of Analysis : 22.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
40	Mayor Gali	2	0	2	0.0	7.20	6.4	0.15	3.0	0.1	6.0	10.8	250
41	Kotwali thana	0	0	0	0.06	7.18	6.8	0.0	3.2	0.12	4.0	7.2	159
42	Patharghata	8	0	0	0.08	7.32	7.0	0.0	2.8	0.10	8.0	14.4	167
43	Alkoron	0	0	0	0.12	7.28	6.6	0.0	3.2	0.18	9.0	16.2	160
44	Court Building	0	0	0	0.0	7.40	5.8	0.1	3.6	0.20	0.0	0	99
45	Foy's Lake	3	0	3	0.0	7.30	6.0	0.15	3.0	0.17	0	0	184
46	Dewanhat	1	0	1	0.2	7.41	6.4	0.0	2.4	0.2	41	73.8	138

A.9 Ratio of Suspended Solids and Turbidity of the Distribution Network's samples

Sample No	Turbidity (NTU)	Suspended Solid (mg/l)	SS: Turbidity	Sample No	Turbidity (NTU)	Suspended Solid (mg/l)	SS: Turbidity
1	0.8	1.8	2.25	24	0.2	0.44	2.20
2	1.2	2.0	1.66	25	0.15	0.3	2.00
3	1.0	2.2	2.20	26	0.1	0.22	2.22
4	0.9	2.0	2.22	27	0.12	0.28	2.33
5	1.4	2.7	1.93	28	4.0	8.2	2.05
6	2.0	3.8	1.90	29	3.0	6.4	2.13
7	2.4	4.9	2.04	30	4.0	8.4	2.10
8	7.0	10.1	**1.44**	31	2.0	3.8	1.90
9	1.0	2.4	2.40	32	4.0	8.2	2.05
10	4.0	7.4	1.85	33	3.0	6.4	2.13
11	1.2	2.8	2.33	34	6.0	13	2.16
12	0.4	1.2	**3.00**	35	4.0	8.2	2.05
13	1.0	2.2	2.20	36	12.0	25	2.08
14	0.8	1.8	2.25	37	1.2	2.8	2.33
15	2.0	4.2	2.10	38	0.5	1.2	2.40
16	2.8	5.8	2.07	39	1.2	2.4	2.00
17	2.1	4.4	2.09	40	6.0	10.8	1.80
18	2.0	3.8	1.90	41	4.0	7.2	1.80
19	1.4	3.0	2.14	42	8.0	14.4	1.80
20	0.8	2.0	2.50	43	9.0	16.2	1.80
21	1.2	2.4	2.00	44	0.0	0	0
22	0.8	1.8	2.25	45	0	0	0
23	0.1	0.24	2.40	46	41	73.8	1.80

A.10 Water Quality Data of samples from Consumers' Reservoirs

Sl. No	Name of Locations	Parameters (Date of Analysis : 25.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
1	Halishahar	0	0	0	0.03	7.20	5.4	0.08	2.8	0.20	0.8	1.8	340
2	Baijid thana	1	1	1	0.01	7.10	6.0	0.05	2.0	0.18	2.0	4.4	165
3	Kadamtoli	0	0	0	0.02	7.20	6.3	0.08	1.7	0.15	1.0	2.2	160
4	Miakhan nagar	3	2	2	0.0	7.20	5.4	0.10	2.3	0.12	2.2	4.8	210
5	East Madarbari	1	0	0	0.01	7.30	6.5	0.10	1.2	0.22	4.8	9.4	320
6	Jamal khan	0	0	0	0.02	6.90	6.1	0.10	2.2	0.24	4.8	9.6	170

Sl. No	Name of Locations	Parameters (Date of Analysis : 28.04.2010)											
		TC (#/100 ml)	EC (#/100 ml)	FC (#/100 ml)	Res. Chlorine (mg/l)	pH	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	NH_3-N (mg/l)	Turbidity N.T.U	SS (mg/l)	Total Dissolved Solids (mg/l)
8	Cantonment	0	0	0	0.01	7.0	6.2	0.1	2.3	0.18	7.0	15	190
9	Port collony	0	0	0	0.01	6.90	6.4	0.15	1.8	0.3	3.2	6.5	430
10	Chittagong Medical	2	1	1	0.07	7.10	5.6	0.2	3.4	0.32	15	32	158
11	Amirbag	4	2	3	0.0	7.20	6.8	0.1	1.8	0.18	3.0	6.5	190
12	Probortok	0	0	0	0.03	7.10	6.2	0.1	2.0	0.12	1.5	4	130

A.11Ratio of Suspended Solids and Turbidity of the Consumers' Reservoirs samples

Sample no	Turbidity (NTU)	Suspended Solid (mg/l)	Ratio (SS: Turbidity)
1	0.8	1.8	2.25
2	2.0	4.4	2.20
3	1.0	2.2	2.20
4	2.2	4.8	2.18
5	4.8	9.4	**1.95**
6	4.8	9.6	2.00
7	7.0	15	2.14
8	3.2	6.5	2.03
9	15	32	2.13
10	3.0	6.5	2.16
11	1.5	4	**2.66**