ASSESSMENT OF WATER QUALITY AT DND CONVEYANCE CANAL AND ITS IMPLICATIONS ON TREATED WATER QUALITY AT SAIDABAD WATER TREATMENT PLANT

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A Thesis Submitted by

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The thesis titled **"ASSESSMENT OF WATER QUALITY AT DND CONVEYANCE CANAL AND ITS IMPLICATIONS ON TREATED WATER QUALITY AT SAIDABAD WATER TREATMENT PLANT"** submitted by FARZANA SHARIF KHAN, Roll No 100504133F, Session: October 2005 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering (Environmental) on 17th May, 2008.

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Farzana Sharif Khan

Farzana Sharif Khan

Dedicated

To

My Loving Mother

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ABSTRACT

The Saidabad Water Treatment Plant (SWTP), commissioned by DWASA in July 2002, serves as one of the major potable drinking water sources for the people of Dhaka. DWASA utilizes a section of the DND open conveyance canal to convey raw water from Sarulia intake on the Sitalakhya river to the SWTP. During dry season each year, water quality of the Sitalakhya river deteriorates significantly, resulting in poor quality of treated water at the SWTP. In this study, water quality of Sarulia intake, DND canal and the SWTP were intensively monitored during the dry season (January to March) of 2007. For this purpose water samples were collected from the Sarulia intake, 6 locations along DND canal, and 5 locations within the SWTP and analyzed for a wide range of parameters. The water quality of the DND canal was also monitored during the wet season (June to September, 2007).

The water quality of Sitalakhya river and the DND canal appears to deteriorate progressively from January to March as dry season progresses. The water quality during the dry season is characterized by high concentrations of BOD_5, COD, TOC, Ammonia, Phosphate and Chlorophyll-A (algae); and low concentrations of DO. Water quality within the DND canal does not appear to change significantly, with the exception of Chlorophyll-A, whose concentration increases by a factor 2 to 3 within the canal. Removal of Ammonia or conversion of Ammonia to Nitrate is insignificant along the canal. BOD reduction within the canal by biodegradation appears to be insignificant. Suspended solids reduction (up to ~ 40%) within the canal during dry season is not accompanied by BOD reduction, which possibly suggests that any reduction in BOD due to settling of particulate BOD (and also biodegradation) is probably accompanied by addition of BOD of similar magnitude from the surrounding areas and from the sediment.

During the wet season (June to September), water quality of Sitalakhya river and DND canal improves significantly due to rainfall and freshwater inflow from upstream, which results in significant reduction of BOD_5, COD, Ammonia, Phosphate and Chlorophyll-A concentrations and increase in DO concentration. Suspended Solids (SS) concentration in the Sitalakhya river increases significantly during the wet season; however, the DND canal appears to function as a sedimentation basin and significant reduction in SS concentration (up to 80%) occurs within the DND canal. The potential sediment oxygen demand (pSOD) of sediments of DND canal was found to be very high and thus could exert significant oxygen demand on the water, especially during re-suspension events.

With deterioration of raw water quality, the treated water quality at the SWTP also suffers during the dry season. In dry season, higher alum doses are also required for removal of SS and algae. Relatively high concentrations of Aluminum (Al), exceeding the Bangladesh drinking water standard, were also detected in the treated water, which most likely comes from high doses of alum (up to 60 mg/L) used during the dry season, suggesting need for optimization of the coagulation process. During dry season almost the entire applied Chlorine is likely to be converted into Monochloramine. The residual chlorine at SWTP appears to exceed the available standard (USEPA) and guideline (WHO) of total Chlorine and Monochloramine during the dry season. During wet season the Chlorine to Ammonia

ratio at the SWTP may become very high (> 4), which may promote formation of Dichloramine and Nitrogen Trichloride and give rise to taste and odor problems. Break point chlorination (BPC) does not appear to be a feasible option during the dry season, but BPC could be considered as an option to ensure effective chlorination during the wet season. Total ammonia concentration of treated water at the SWTP is slightly lower than that in the raw water, possibly due to oxidation of some Ammonia to Nitrate. A significant fraction of total Ammonia in the treated water is likely to exist as Chloramines.

In the assessment of THM formation potential, the principal uncertainty is the amount of free chlorine that would be available for reaction with organic matters and bromide, leading to THMs formation. The raw water at the SWTP has been found to be very susceptible for THM formation during dry season because of high concentration of DOC and bromide, and relatively higher pH and temperature. Presence of high concentration of Ammonia, however, may significantly reduce TTHM formation by limiting the concentration of free chlorine. The predicted Total THMs (TTHMs) concentration for the wet season was relatively low, satisfying the Bangladesh standard (for chloroform) and USEPA and EU drinking water standards; but the predicted TTHMs concentration during the dry season exceeds these standards by a large margin. Limited laboratory measurements of THMs during the dry season (April 2008) showed that the values are well within the available drinking water standards. THM precursors (e.g., DOC, bromide), THMs, and applied Chlorine dose should be included in the regular monitoring program at the SWTP.

Therefore, the quality of the raw water drawn through the intake structure varies significantly over the year and this affects the efficiency of treatment at the plant and the quality of treated water. Dry season (January to March) is the critical period for the SWTP, during which raw water quality deteriorates significantly, putting strains on the treatment processes. Doses of alum and chlorine used at the plant also depend on the quality of raw water. Possible presence of non-biodegradable organic materials in raw water from industrial discharges may contribute to the high COD and TOC values along the DND canal and at the SWTP. The high concentrations of ammonia, organic matter and algae appear to be the major water quality problem of raw water at the SWTP.

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LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
BPC	Break Point Chlorination
COD	Chemical Oxygen Demand
DBPs	Disinfection Byproducts
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DoE	Department of Environment
EC	Electrical Conductivity
EU	European Union
pSOD	Potential Sediment Oxygen Demand
SOD	Sediment Oxygen Demand
SWTP	Saidabad Water Treatment Plant
TDS	Total Dissolved Solids
THMFP	Trihalomethane Formation Potential
THMs	Trihalomethanes
TOC	Total Organic Carbon
TSS	Total Suspended Solids
TTHM	Total Trihalomethanes
USEPA	United Stated Environmental Protection Agency
UV	Ultraviolet
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

To meet the increasing demand of potable water in Dhaka City, DWASA commissioned the Saidabad water treatment plant (SWTP) in July 2002, which draws water through an intake structure located at Sarulia (near Demra *ghat*), on the Sitalakhya river. From the Sarulia intake, raw water flows through a box-culvert into the DND open conveyance canal. DWASA utilizes a section of the DND conveyance canal from Sarulia to Kajla to convey raw water from the Sitalakhya river. The length of the canal section is 4.6 km with an average width of about 40 meters. From the end of DND conveyance canal, water flows into the SWTP (intake pit) through a 1.6 km long box culvert. Currently, in its first phase, the plant treats 225 million liters of water per day (MLD). After completion of the proposed second and third phases, the capacity of the treatment plant would be raised to 450 and 900 MLD, respectively.

At the Saidabad water treatment plant (SWTP), the processes involved in the treatment include: (i) pre-chlorination and pH adjustment (with lime, if necessary) of the raw water, (ii) coagulation with alum in a pulsating clarifier; (iii) filtration of the water coming from the clarifier; and finally (iv) post-chlorination and pH-adjustment (if necessary) of the water before its introduction in the distribution system.

The principal raw water quality problem at SWTP, particularly during the dry season (December to April) is the high concentrations of ammonia, organic matter and algae in the raw water. The pre-chlorination of the raw water at SWTP helps in the elimination of algae (besides reducing the number of fecal bacteria and pathogens) during subsequent coagulation (with alum) and filtration processes. Chlorine disrupts the air sac in algae that allows it float in water. However, if ammonia concentration is high, it consumes the added chlorine forming chloramines and no free chlorine exists for elimination of algae. The resulting problems include: (1) increase in treatment cost; (2) poor removal of algae; (3) probable formation of unwanted disinfection by-products (e.g., THMs); and (4) excess ammonia/chloramines in the treated water. Although, ammonia does not have any particular toxic effect, its presence in the treated water would cause taste and odor problems.

Possible change in quality of raw water within the DND conveyance canal is an important issue with regard to controlling algae and ammonia problem in the SWTP. Ideally, raw water quality should improve within the DND canal due to sedimentation and biodegradation processes. But, the DND canal is not properly protected and is widely used by people of the surrounding localities for bathing, washing of clothes and utensils, etc. Thus, there is also a significant concern that raw water quality could deteriorate within the DND canal. However, no systematic data is available to assess the water quality changes within the DND conveyance canal. There is also no data on quality of sediment of the DND canal, which may accumulate trace contaminants such as heavy metals with passage of time, and may act as a source of such contaminants in the future.

Formation of potentially harmful disinfection by-products (e.g., THMs) in the presence of organic substances is probably the most significant concern related to organic matter. The THMs occur in drinking water principally as products of the reaction of chlorine with naturally occurring organic matter and with bromide. With respect to drinking water contamination, only four members of this group are important; these are chloroform, bromoform, dibromochloromethane (DBCM), and bromodichloromethane (BDCM). The WHO guideline value for drinking water for these four constituents are 200, 100, 100, and 60 μg/L, respectively. However, no data is available on concentration of THMs in the treated water from SWTP, primarily because of lack of laboratory facilities for such measurements.

Water quality parameters that serve as precursors for THM formation include DOC, bromide, UV_{254}, etc. Presence of ammonia on the other hand reduces formation of THMs by limiting the concentration of free chlorine for reaction with organic matter (Capece, 1998). A number of studies have assessed formation and formation potential of THMs in water treatment plants of different countries (e.g., Edzwald et al., 1985; Amy et al., 1987; El-Dib and Ali, 1995; Yoon et al., 2003). It may be possible to assess THM formation potential for the SWTP based on information on raw water quality and chlorination process used.

1.2 OBJECTIVES

The overall objective of the present research is to assess the water quality at the DND conveyance canal and its implication on the treated water quality at the SWTP. Specific objectives of this study include:

(a) Assessment of changes in raw water quality (especially changes in pH, suspended solids, DO, BOD_5, ammonia, nitrate, phosphate, algae) within the DND conveyance canal.
(b) Assessment of sediment quality of DND conveyance canal, especially with respect to selected heavy metals and sediment oxygen demand (SOD)
(c) Assessment of treatment processes at SWTP, with special focus on THMs Formation Potential (THMFP).

Expected outcomes of the proposed research work include: (i) Better understanding of the role of DND canal on raw and treated water quality at SWTP, (ii) Suggestion of intervention for improvement of water quality (especially with respect to algae, organic matter and ammonia) within the DND conveyance canal; (iii) Estimate of THM formation potential for the SWTP; (iv) Suggestion of possible intervention for improvement of treatment processes at the SWTP, especially focusing on controlling algae and THMs.

1.3 OUTLINE OF METHODOLOGY

For assessment of water quality within the DND conveyance canal and the SWTP, water samples were collected from: (i) Sarulia intake, (ii) DND canal (6 locations) and (iii) the SWTP (3 locations). Majority of water samples were collected during the dry season, which is the critical period for the SWTP.

The water samples were tested for pH, DO, TDS, TSS, Alkalinity, Chloride, EC, Ammonia, Nitrate, Nitrite, Phosphate, BOD_5, DOC, UV_{254} and Chlorophyll-A. Ammonia, Nitrate, Nitrite, Chlorine, Phosphate and UV_{254} concentrations were measured with a Spectrophotometer (HACH, DR4000U). Chlorophyll-A (algae) concentrations were measured from the Environmental Microbiological Laboratory of ICDDR,B, Dhaka. The sediment samples were analyzed for total concentrations of Pb, Cd, Cu and Cr. Heavy metal concentrations were determined with an AAS (Shimadzu, AA6800). Sediment Oxygen Demand (SOD) was estimated using the ex-situ method outlined by Matlock et al. (2003).

Trihalomethane (THM) formation potential were estimated following the method/model developed by Amy et al. (1998), which is based on concentrations of DOC, Cl_2, Bromide, temperature, pH and contact time with chlorine dose. THM formation potential was also estimated from UV_{254}, following the method used by Yoon et al. (2003).

1.4 ORGANIZATION OF THESIS

This thesis comprises of five Chapters. The contents of each chapter are summarized below.

Chapter 1: This introductory Chapter presents the background and objectives of the study. The methodology followed in the study has also been outlined briefly in this Chapter.

Chapter 2: This Chapter presents literature review covering background information on Saidabad Water Treatment Plant (SWTP) and previous studies regarding raw and treated water quality at the SWTP. It also briefly describes different aspects of disinfection byproducts with particular emphasis on THMs.

Chapter 3: This Chapter briefly presents an assessment of water and sediment qualities along the DND open conveyance canal. It describes the sampling plan and methods of analysis of both water and sediment samples of the DND canal. The assessment of water quality is based on analysis of the test results of samples collected during both dry and wet seasons.

Chapter 4: This Chapter presents an assessment of the quality of raw water on the treatment efficiency of the SWTP. The water sampling plan and methods of analysis has been described. It also presents an evaluation of trihalomethane formation potential (THMFP) at the SWTP. The assessment has been made for both dry season and wet season, based on methodology available in the literature. In addition, the Chapter also presents results of limited measurement of THMs in DWASA water.

Chapter 5: This final Chapter summarizes the major conclusions from the present study. It also presents recommendations for future study, and also suggests some measures aimed at improving the water quality at the SWTP.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Dhaka Water Supply and Sewerage Authority (DWASA) is responsible for water supply in Dhaka city. Water supply in Dhaka city is heavily dependent on groundwater; over 450 deep tubewells constitute of backbone of water supply in the city. However, groundwater level is going down very rapidly due to this huge abstraction, putting the groundwater supply at risk. To meet the increasing demand of potable water in Dhaka city and to reduce dependency on groundwater resources, DWASA started operation of Saidabad Water Treatment Plant (SWTP) on July 27, 2002. The water being treated at the SWTP is abstracted from the Sitalakhya river near Sarulia, around 400 m downstream of Demra. Currently groundwater accounts for about 85% of total DWASA supply and surface water accounts for the rest. Currently, production from surfaces water is about 300 MLD; about 225 MLD, that is majority of the surface water supply, come the SWTP, while about 39 MLD come from Dhaka Water Works at Chandnighat and about 35 MLD from Narayanganj Water Treatment Works.

From the inception of the SWTP operation, the quality of raw water was found unsatisfactory during the dry season, in comparison with the treatment strategy being implemented. In recent time, the situation has further aggravated due to continued pollution of the Sitalakhya by domestic sewage and untreated industrial effluent. The major raw water quality problems at the SWTP include high concentrations of ammonia, organic matter and algae. The pre-chlorination of the raw water at SWTP helps in the elimination of algae during subsequent coagulation (with alum) and filtration processes. However, if ammonia concentration is high, it consumes the added chlorine forming chloramines and no free chlorine exists for elimination of algae. The resulting problems include: (1) increase in treatment cost; (2) poor removal of algae and suspended solids; (3) probable formation of unwanted disinfection byproducts (e.g., THMs); and (4) excess ammonia/chloramines in the treated water.

This chapter briefly presents an overview of the raw and treated water quality at SWTP. It also presents a discussion on the effects of raw water quality on the treatment processes and treated water quality at SWTP. This Chapter also presents discussions on the health effects of THMs, factors affecting formation of THMs in water utilities, and different options available for management and control of disinfection by-products.

2.2 TREATMENT PROCESSES AND WATER QUALITY AT SWTP

2.2.1 The Saidabad Water Treatment Plant

In the year 1992 the Government of Bangladesh (GoB) with assistance from the donors developed a master plan for water supply in Dhaka city. On the basis of the plan, a long term investment program was developed. Dhaka WASA implemented the Phase-I of the investment program with the construction of 225 MLD capacity Saidabad water treatment plant (SWTP). With the completion of the Phase-II and Phase-III the total capacity of Saidabad site will be increased to 900 MLD. The major components of SWTP are briefly described below:

(i) <u>Pumping Station, Intake Works and Twin Culvert:</u>

Intake Structures: The intake structure is about 400 meters downstream of Demra *Ghat* at Sarulia village. The intake has a capacity to deliver 275 Imperial Million Gallons/Day (IMGD) of water to the raw water pumping station.

Raw Water Pumping Station: The pump station has initial delivery capacity of 50 IMGD; it has provision for another 145 IMGD when Phase-II and Phase-III will be implemented.

Twin Culvert: Water is carried from the raw water pumping station and delivered to the DND conveyance canal by a twin RCC culvert having a capacity of 275 IMGD.

(ii) <u>DND Conveyance Canal:</u>

DWASA utilizes a section of the DND canal from Sarulia to Kajla to convey raw water from the Sitalakhya river to the water treatment plant at Saidabad. The length of the canal section is 4.6 km with an average width of about 40 meters. The stretch of DND canal, which conveys water from the Sarulia intake to the SWTP, is not properly protected. As a result, people in the area use DND khal for various purposes like, bathing, washing clothes and utensils, etc. It is not uncommon to find people disposing wastes directly into the canal. The raw water to SWTP is further polluted by these activities.

(iii) Culvert from DND Canal to SWTP Site:

The DND conveyance canal terminates 1.6 km from SWTP site. A second twin box culvert with a capacity of 900 MLD links the canal to the pumping station.

(iv) The SWTP:

The present site was at average level of 2-3 meters above the zero benchmark level (PWD); it has been raised by about 5 meter to keep it flood free in wet seasons. A conventional surface water treatment plant with a capacity of 225 MLD is presently under operation. It has various components such as (i) Mixing tanks (ii) Clarifiers (iii) Filter beds (iv) Chlorination tank (v) Treated water pump (vi) Power installations (vii) Chemical storages (viii) Sludge recovery facilities, and (ix) Miscellaneous facilities. Ancillary facilities include (i) Laboratories and other building (ii) Workshops, and (iii) Various support facilities.

As noted earlier in Chapter 1, the water treatment processes at the SWTP involves: (i) pre-chlorination and pH adjustment (with lime, if necessary) of the raw water, (ii) coagulation with alum in a pulsating clarifier; (iii) filtration of the water coming from the clarifier; and finally (iv) post-chlorination and pH-adjustment (if necessary) of the water before its introduction in the distribution system.

About 36.6 km of primary and interim transmission mains composes the network of pipes with diameters ranging from 300 mm to 1800 mm for transmission.

2.2.2 Water Quality Issues

As mentioned earlier, the main concern for the Saidabad water treatment plant during the dry season is the high concentration of ammonia, organic matter and algae in the intake water. Besides, possible presence of toxic metals and persistent organic pollutants of industrial origin are also of particular concern. The impact of major water quality parameters on the water treatment at the SWTP is summarized below:

(a) Ammonia:

Besides reducing fecal bacteria and pathogens, the pre-chlorination of the raw water at the SWTP helps in the elimination of algae during subsequent coagulation and filtration processes. Chlorine disrupts the air sac in algae that allows it float in water. However, if ammonia concentration is high, it would consume the added chlorine forming chloramines (Eq. 2.1-2.3) and no free chlorine would be available for elimination of algae.

$$NH_3 + HOCl = NH_2Cl + H_2O \qquad (2.1)$$

$$NH_2Cl + HOCl = NHCl_2 + H_2O \qquad (2.2)$$

$$NHCl_2 + HOCl = NCl_3 + H_2O \qquad (2.3)$$

Theoretically, it would require 3 moles of chlorine for complete conversion of ammonia to nitrogen trichloride (trichloramine), and 4 moles for the complete oxidation to nitrate (Eq. 2.4-2.5). Thus, about 8 mg/L of chlorine is required to oxidize 1 mg/l of ammonia.

$$3\,Cl_2 + 2NH_3 = N_2(g) + 6H^+ + 6Cl^- \qquad (2.4)$$

$$4\,Cl_2 + NH_3 = NO_3^- + 9H^+ + 8Cl^- \qquad (2.5)$$

Thus if the ammonia concentration reaches 10 mg/L, a level it approached during the dry season of 2004, the chlorine requirement would be about 80 mg/L. The resulting problems include: (1) increase in treatment cost; (2) poor removal of algae; (3) probable formation of unwanted disinfection byproducts, particularly chlorinated organics including trihalomethanes (THM) (as a result of reaction of chlorine with dissolved organic matter); and (4) excess ammonia/chloramines in the treated water.

Although ammonia has no particular toxicity, its presence in the treated water may cause significant taste and odor problems. It may be noted that Bangladesh standard for ammonia in drinking water is 0.5 mg/L (GoB, 1997). Ammonia promotes rapid bacterial proliferation in the water distribution network. The autotrophic bacteria uses ammonia and consumes oxygen and thus may create anaerobic environment and induce corrosion of pipes of the distribution network, which are not internally corrosion protected (Degremont, 2004).

(b) Organic Matter:

Organic waste loads in the Balu and Sitalakhya river systems are significant and the situation turns alarming during the dry season. High BOD_5 (5-day biochemical oxygen demand) and COD (chemical oxygen demand) values have already been detected in the water samples from both Balu and Sitalakhya rivers (IWM, 2004). If the present trend of pollution continues, the BOD_5 and COD values of raw water drawn at the existing intake point of Saidabad water treatment plant may go up even higher. In such a case, adequate BOD removal from the water may become a major concern. It should be noted that the Bangladesh drinking water standard for BOD_5 and COD are 0.2 mg/L and 4.0 mg/L, respectively. In the coming years, with the high probability of elevated BOD and COD values of raw water at the existing intake location, it may be difficult to meet these standards.

Formation of potentially harmful disinfection by-products in the presence of organic substances is probably the most significant concern related to organic matter. Possible formation of trihalomethanes, which form as a result of reaction of chlorine with organic matter and bromide, is of particular concern in this regard. For effective control on the formation of trihalomethanes in water treatment systems based on coagulation/sedimentation, the initial chlorine application is often carried out after the coagulation/sedimentation process. However, for water treatment plants like Saidabad, where the water is abstracted and treated without storage, pre-chlorination (or pre-disinfection) is common. For the Saidabad water treatment plant, pre-chlorination appears to be essential for effective algae removal. For this reason, high organic matter in the raw water is a major concern.

(c) Heavy Metals:

A number of heavy metals including aluminum, cadmium and chromium have been found, sometimes at levels exceeding the drinking water standards, in water samples collected from both the Balu and the Sitalakhya Rivers. High heavy metal concentration in the water at the intake point is another major concern. The existing treatment plant is not specifically designed for heavy metal removal. Hence, both the raw and treated water samples should be regularly monitored for heavy metals.

2.2.3 Raw and Treated Water Quality at SWTP

The assessment of raw and treated water quality at the SWTP presented here is based on the analysis of raw and treated water quality data for the period July 2003 to December 2006[1], from daily water control analysis at the SWTP (Arisa, 2008). It should be noted that no systematic data is available in the literature on water quality of DND conveyance canal. Water quality monitoring data at the SWTP shows that the raw water at SWTP has a clear seasonal variation. During wet season the concentration of a number of water quality parameters get reduced significantly due to dilution by rain water / upstream fresh water. These parameters include conductivity, TDS, color, alkalinity, hardness, chloride, sulphate, phosphate, ammonia. On the other hand, turbidity value increases significantly during wet season due to higher sediment load in river water. DO concentrations are typically higher during the wet season. Coliform concentrations are typically high throughout the year.

The concentrations of a number of water quality parameters do not change significantly during the treatment process; these parameters include alkalinity (Fig. 2.1), hardness, TDS and conductivity (Fig. 2.2). The SWTP appears to be very effective in removing total coliform, fecal coliform (Fig. 2.3) and turbidity from raw water. Color removal however was not found to be very efficient. Higher color in raw water results in relatively higher color in treated water and this occurs primarily in the dry season (see Fig. 2.4).

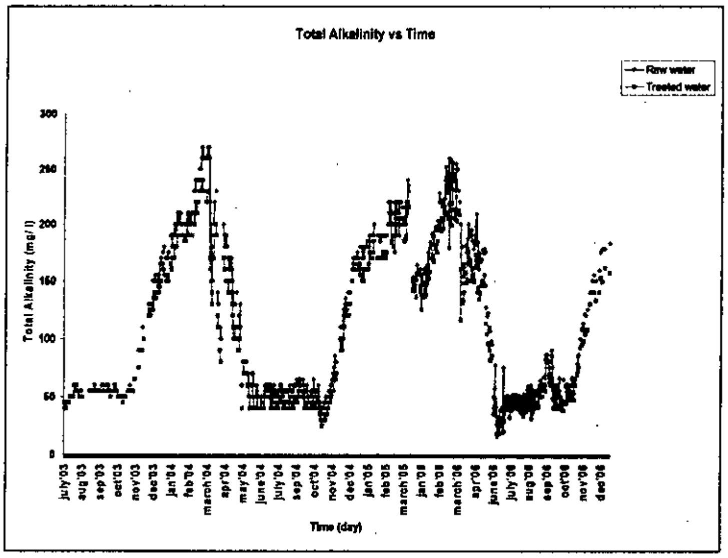

Fig. 2.1: Alkalinity in raw and treated water at SWTP (Arisa, 2008)

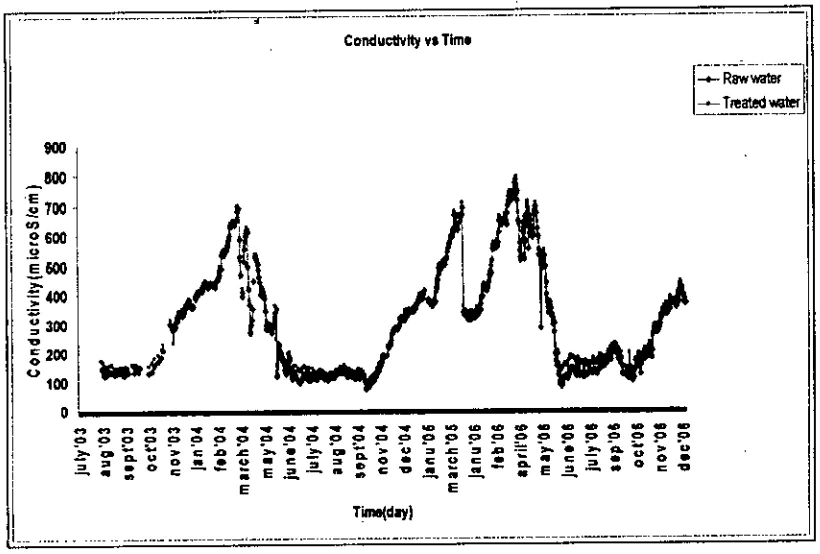

Fig. 2.2: Conductivity in raw and treated water at SWTP (Arisa, 2008)

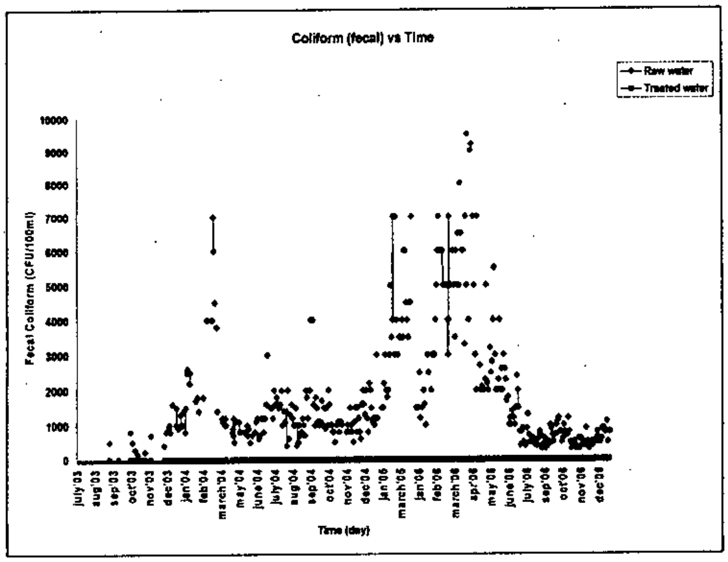

Fig. 2.3: Fecal Coliform in raw and treated water at SWTP (Arisa, 2008)

While aluminum (Al) concentration of raw water remains low (< 0.05 mg/l) throughout the year, Al concentrations of treated water have been found to be much higher (Fig. 2.5). Very high aluminum concentrations have been recorded during the dry season of 2006 (February - May), some exceeding the Bangladesh drinking water standard (0.2 mg/L) and WHO Guideline Value (0.2 mg/L). This could be due to high alum doses (often in excess of 50 mg/L) used during the dry season, when raw water quality becomes very poor.

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[1] Data for the period April-December 2005 were not available

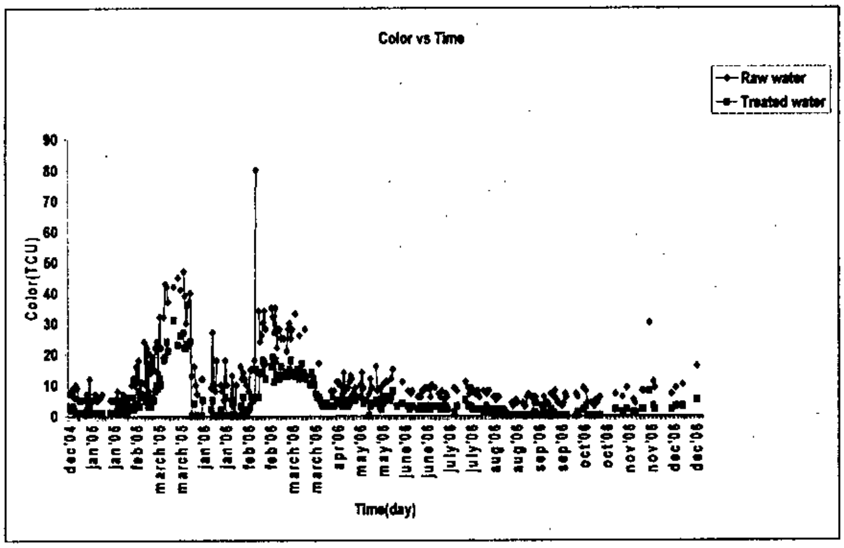

Fig. 2.4: Color concentration in raw and treated water at SWTP (Arisa, 2008)

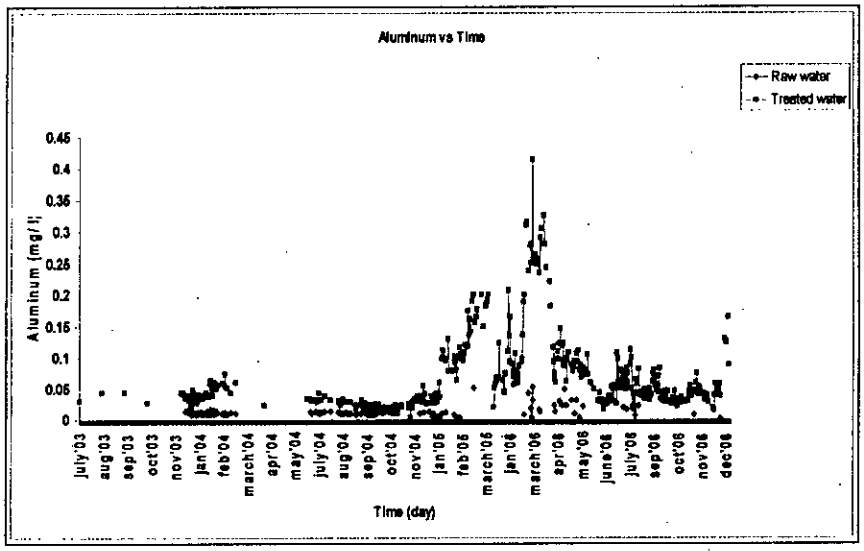

Fig. 2.5: Aluminum (Al) concentration in raw and treated water at SWTP (Arisa, 2008)

As noted earlier, ammonia concentration in raw water increases significantly during the dry season (particularly during January to March), sometimes exceeding 10 mg/L; during wet season ammonia concentration comes down to below 0.5 mg/L (Fig. 2.6). In the treated water, total ammonia concentration decreases only slightly. However, due to addition of chlorine (at a dose of about 6.5 mg/L during dry season), a part of the free ammonia present in raw water is converted to chloramines; at the chlorine to ammonia ratio used at the SWTP, most of the chloramines are likely to exist as NH_2Cl (monochloramine).

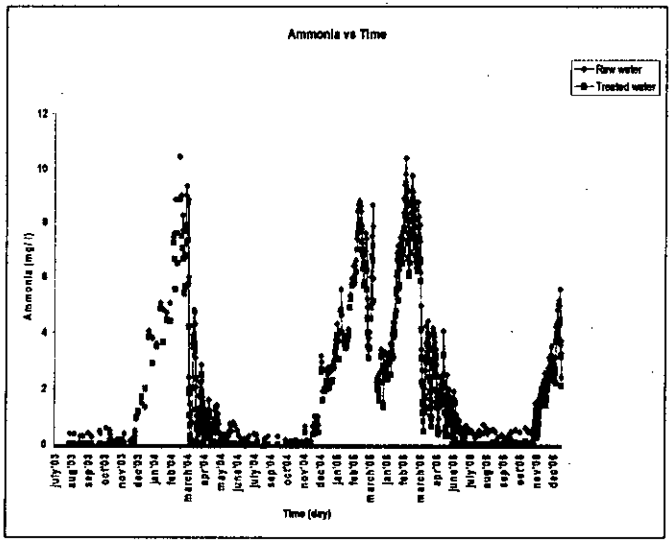

Fig. 2.6: Total ammonia concentration in raw and treated water at SWTP (Arisa, 2008)

Only limited data is available for total chlorine concentration in clarified water. Figures 2.7 and 2.8 show that most of the chlorine exists as combined chlorine and only a small fraction exists as free chlorine. Free chlorine varies from 0.1 mg/l to 0.8 mg/l; on the other hand, the value of total chlorine is as high as 9 mg/l, which exceeds the USEPA MCL for chloramines (4 mg/L) and WHO guideline value of 3 mg/L for Monocloramine. The total chlorine concentration follows the trend of applied chlorine doses. Higher chlorine doses (~ 6.5 mg/l) are applied during the dry season (to take care of high ammonia concentration), while lower doses are applied during the wet season (~ 3.5 mg/l). So values of total chlorine in treated water are much higher during the dry season.

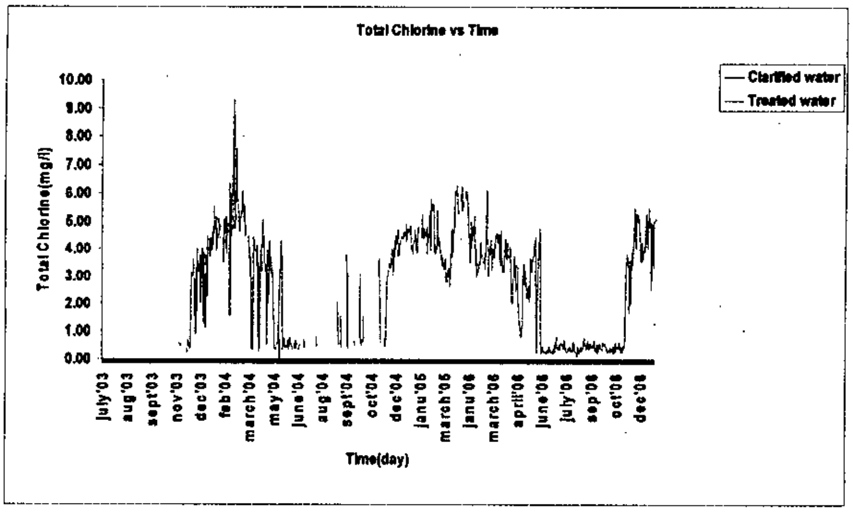

Fig. 2.7: Total Chlorine concentration in clarified (after filtration) at SWTP (Arisa, 2008)

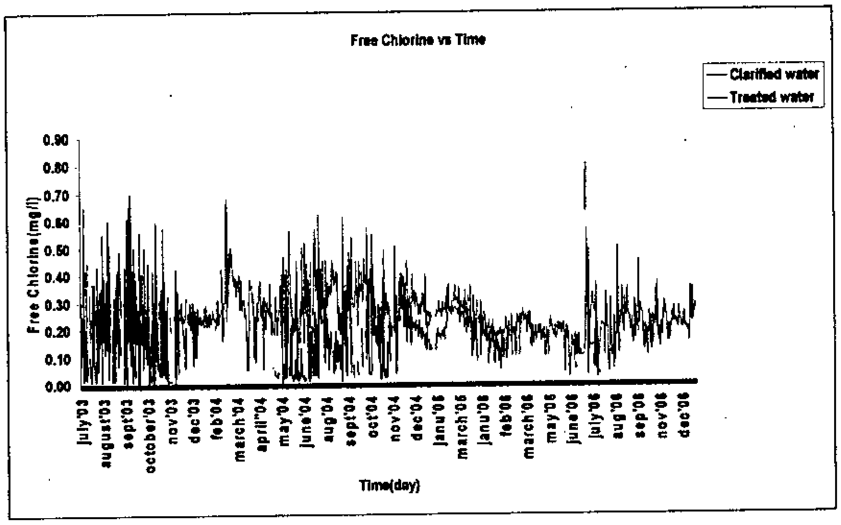

Fig. 2.8: Free Chlorine concentration in clarified (after filtration) at SWTP (Arisa, 2008)

Thus, the treated water at the SWTP appears to deteriorate during the dry season. Total ammonia concentration exceeds the drinking water standard; color and aluminum also exceed drinking water standard occasionally.

2.3 FORMATION AND EFFECTS OF THMs

Trihalomethanes are a class of disinfection byproducts found when chlorine reacts with natural organic matter and bromide. They are comprised of four compounds:

a) Chloroform ($CHCl_3$)
b) Bromoform ($CHBr_3$)
c) Dichlorobromomethane ($CHCl_2Br$)
d) Dibromochloromethane ($CHClBr_2$)

There are other THMs under study. There are other families of disinfection byproducts that are recognized as drinking water contaminants. Trihalomethanes in drinking water are undesirable but are created by unavoidable reactions of chlorine disinfectants with organic materials already in the water. Some of the THMs found in drinking water may be from contamination from the industrial processes. THMs became a public health concern due to their carcinogenic nature.

The major routes of exposure to THMs in water are through drinking the water, eating foods prepared with water, and by breathing vapor or mist from the water. Studies have shown that the major exposure route is inhalation during showering, bathing, general cleaning and washing clothing and dishes. The United States Environmental Protection Agency (USEPA) estimates that 3-4 additional cancers may occur among every 10,000 persons consuming 2 liters of water which contains only 0.1 ppm chloroform on a daily basis for 70 years.

The production of THMs in drinking water is best controlled by removing as much organic matter as possible from water before adding chlorine disinfectants. Coagulation, sedimentation and filtration will greatly reduce the amount of organic carbon (TOC), which would otherwise react to form THMs. THMs are more difficult and expensive to remove from water once they have formed. Some THMs can be removed from water by oxidation and activated carbon filtration.

Another way to avoid THMs is to use something other than chlorine gas or hypochlorite as disinfectants. Chloramines, chlorine dioxide, UV light and ozone are other possible disinfectants, but they also produce harmful by-products.

2.3.1 Formation of THMs

Most common causes of formation of Total Trihalomethanes (TTHM) are as follows:

- Interaction of chlorine with the commonly present organic matter, such as decaying plants, leaves and other dead materials in surface water source. This organic material is generally measured as total organic carbon (TOC). Amounts of THMs formed are directly related to the amount of TOC and the amount of disinfectant used.
- Initial oxidation of bromide ion in solution by added chlorine
- Rapid bromination of the organic matter

Surface water is more likely to produce higher THMs than groundwater. Formation also depends on a number of factors, including:

  - Season
  - Chemical composition of raw water and treatment methodology

- Type of disinfectant, dose, and residual concentration
- Concentration and characteristics of precursors
- Water temperature
- Water chemistry (including pH, bromide ion concentration, organic nitrogen concentration, and presence of other reducing agents such as iron and manganese)
- Contact time and mixing conditions for disinfectant (oxidant), coagulant, source water, and other treatment chemicals

A brief discussion on some of the important parameters affecting THMs formation is presented below.

Impact of Disinfection Method on Organic THMs Formation

Halogenated organic disinfection byproducts are formed when organic and inorganic compounds found in water react with free chlorine, free bromine, or free iodine. The formation reactions may take place in the treatment plant and in the distribution system.

Reactions between precursors, bromide and iodide ions, and chlorine lead to the formation of a variety of halogenated Disinfection By-Products (DBPs) including Trihalomethanes (THMs) and Haloacetic acids (HAAs). If the ratio of bromide to precursors (measured as TOC) increases, the percentage of brominated DBPs also increases (Krasner, 1999 and references therein).

Chlorine: Most water systems that disinfect use either liquid or gaseous chlorine as their disinfectant. Halogenated byproducts are formed when free chlorine reacts with natural organic matter. In addition, brominated byproducts are formed when source water containing bromide is chlorinated. Chlorine reacts with natural organic matter in the water to form THMs, HAAs and other disinfection byproducts.

Chloramines: Studies have documented that chloramines produce significantly lower THM and HAA levels than free chlorine, and there is no clear evidence that the reaction of precursors and chloramines lead to the formation of THMs (Singer and Reckhow, 1999). The amount of formation of DBP with chloramines varied from 5% to 35% of that calculated for free chlorine, depending on the individual DBP species (Swanson et al., 2001). When chloramination is used, it is possible that DBPs might form if chlorine is added before ammonia or if the mixing process is inefficient. In addition, monochloramine slowly hydrolyzes to release free chlorine in water. Systems using chloramines that have excess ammonia, warm temperatures, long distribution system residence times, and low chloramines residuals may experience nitrification. Systems using chloramines can also change the oxidation reduction potential of the water.

Chlorine Dioxide: The application of chlorine dioxide does not produce significant amounts of THMs and HAAs, unless chlorine is formed as an impurity in the generation process. However, THMs and HAAs will form if excess chlorine is added to water to ensure complete reaction with sodium chlorite during the production of chlorine dioxide.

Chlorine dioxide can also oxidize bromide ions to bromine. The bromine can then react with organic matter to form brominated DBPs. When chlorine dioxide is used as a disinfectant, chlorite is formed. The MCL for chlorite was set at 1.0 mg/L. As much as 70 percent of the chlorine dioxide added to water can break down to form chlorite. This limits the dose of chlorine dioxide that can be used.

Ultraviolet Irradiation: To date, there is no evidence to suggest that ultraviolet irradiation results in the formation of any disinfection byproducts. Studies comparing the effects of UV light followed by chlorination versus chloramination suggest UV does not affect DBP formation in either of these two cases.

At low UV intensities, some microbes have shown the ability to repair damage done by UV light. Any substance that either absorbs or refracts the UV light (e.g. DOC, iron, manganese, calcium, aluminum, and ozone) can interfere with disinfection. Study found no firm evidence that the UV irradiation of water resulted in the formation of any nitrogen containing organic compounds.

Ozone: Ozone does not directly produce chlorinated DBPs. However, if chlorine is added before or after ozonation, mixed bromo-chloro DBPs as well as chlorinated DBPs can form. Ozone can alter the characteristics of precursors and affect the concentration and speciation of halogenated DBPs (THMs and HAAs) when chlorine is subsequently added downstream. In waters with bromide concentrations, ozonation can lead to the formation of bromate and other brominated DBPs. Bromate, like TTHM and HAA5, is a regulated DBP. Some systems that have added ozone without biological filtrations have experienced increased AOC (food for micro-organisms) and microbial growth in the distribution system.

Disinfectant Dose

As the concentration of chlorine or chloramines increases, the production of DBPs increases. Formation reactions continue as long as precursors and disinfectant are present (Krasner, 1999). In general, the impact of chlorine concentration is greater during primary disinfection than during secondary disinfection. The amount of chlorine added during primary disinfection is usually less than the long-term demand; therefore, the concentration of chlorine is often insufficient to react with all DBP precursors in the water. On the contrary, during secondary disinfection, DBP formation is often limited by the concentration of DBP precursors since excess disinfectant is added to the water to maintain a residual concentration in the distribution system (Singer and Reckhow, 1999).

Distribution System

In distribution systems, DBP formation reactions can become limited by the disinfectant concentration when the free chlorine residual drops to low levels. As a rule of thumb, Singer and Reckhow (1999) suggest this event takes place when the chlorine concentration drops below approximately 0.3 mg/L.

Time Dependency

The longer the contact times between disinfectant/oxidant and precursors, the greater the amount of DBPs that can be formed. Generally, DBPs continue to form in drinking water as long as a disinfectant residual and precursors are present. After formation, THMs and HAAs are generally chemically stable as long as a significant disinfectant residual is still present (Singer and Reckhow, 1999). As a consequence, high concentrations of DBPs can accumulate in water with old age.

High THM levels usually occur where the water age is the oldest. Conversely, HAAs cannot be consistently related to water age because HAAs are known to biodegrade over time when the disinfectant residual is low. This might result in relatively low HAAs concentrations in areas of the distribution system where disinfectant residuals are depleted.

Concentration and Characteristics of Precursors

The formation of THMs and HAAs is related to the concentration of precursors at the point of disinfection. In general, greater DBP levels are formed in waters with higher concentrations of precursors. Therefore, removing DBP precursors prior to disinfectant addition is one of the most effective approaches to DBP control.

Natural Organic Matter (NOM) is considered an important DBP precursor. NOM mainly comprises humic and fulvic substances. Humic substances are the organic portion of soil that remains after prolonged microbial decomposition, and that is formed by the decay of leaves, wood, and other vegetable matter. Fulvic acids are water-soluble, natural organic substances of low molecular weight, which are derived from humus, often found in surface water.

UV_{254}, which is generally linked to the aromatic and unsaturated components of NOM, is considered a good predictor of the tendency of source water to form THMs and HAAs (Singer and Reckhow, 1999).

Specific ultraviolet light absorbance (SUVA) is also often used to characterize aromaticity and molecular weight distribution of NOM. This parameter is defined as the ratio between UV_{254} and the dissolved organic carbon (DOC) concentration of water. The more highly aromatic precursors in source waters, characterized by high UV_{254}, are more easily removed by coagulation. Thus, it is the UV_{254} measurement immediately upstream of the point(s) of disinfection within a treatment plant that is more directly related to THM and HAA formation potential.

One significant difference noted on the species distribution of various THMs in samples from desalination and natural sources is that the former contains bromoform as the most predominant haloforms, comprising of more than 80% of the total THMs. This is considered to be due to the presence of bromides in high concentrations in seawater and traces in desalinated water.

Water Temperature

The rate of formation of THMs and HAAs increases with increasing temperature. Consequently, the highest THM and HAA levels may occur in the warm summer months. However, water demands are often higher during these months, resulting in lower water age within the distribution system, which helps to control DBP formation. Furthermore, high temperature conditions in the distribution system promote the accelerated depletion of residual chlorine, which can mitigate DBP formation and promote biodegradation of HAAs unless chlorine dosages are increased to maintain high residuals (Singer and Reckhow, 1999). Higher DBP precursor levels in the fall or spring may also cause the highest THM and HAA levels to be observed in cooler months.

Effect of Season

Seasonal trends affect THM and HAA concentrations differently. For example, when water is colder, microbial activity is typically lower and DBP formation reactions are slower. Under these conditions, the highest THM and HAA concentrations might appear in the oldest water in the system. In warmer water, the highest HAA concentrations might appear in fresher water, which is likely to contain higher disinfectant residuals that can prevent the biodegradation of HAAs.

Water pH

In the presence of DBP precursors and chlorine, THM formation increases with increasing pH, whereas the formation of HAAs decreases with increasing pH. The overall formation of bromate decrease as the pH decreases (Singer and Reckhow, 1999).

Effect of TOC

THM formation rises with increasing soluble humic material content in natural water. The rate of THM formation is equal to that of the TOC consumption, if enough chlorine residual is available.

Effect of Distance from Treatment Plant

In the distribution system, it is an indirect way of measuring the contact time between chlorine dosage and TOC. Hence more the distance from TP more are the chances of formation of THMs.

Effect of Residue Chlorine

Free residual chlorine exists as HOCl and OCl^-. If pH increases, the concentration of HOCl decreases, so the rate of THM formation increases. Thus, whilst the THM concentration leaving the works will have risen, the formation in distribution will have been limited by the fall in chlorine residual. However, if the THM precursor level rises such that the chlorine dose has to be increased to maintain the residual leaving the works then it is likely that the THM concentration at the tap will rise appreciably.

Effect of Turbidity and Ammonia

Simple regression tests indicated no correlation between turbidity and ammonia on the formation of THM.

Formation in Breakpoint Chlorination

The concentrations and distributions of THMs varied among different effluents at different zones of the breakpoint curves. The formation of chloro-only THMs after normalization with the carbon contents of the effluents, increased with increasing specific UV absorbance (SUVA) of the effluents, but the dependency is not valid for bromo- or bromo chloro-DBPs. The formation of THMs showed no significant inclination with increasing chlorine dosages up to the breakpoint, but increased sharply beyond the breakpoint dosing level. Bromine incorporations into THMs increased with an increasing bromide to DOC molar ratio. In addition, the bromine incorporation was also found to be highly dependent on the chlorine dosage and the bromide to ammonia ratio. A longer reaction time increased the yields of THMs.

2.3.2 Health Effects of Disinfection Byproducts

The health effects of halogenated disinfection byproducts can be divided in two groups. They can be carcinogenic or have effects on reproduction and development. Many disinfection byproducts are bio-accumulative. They are not destroyed by the body and can accumulate in body tissues.

Research on health effects of disinfection byproducts aims at the following themes: (1) Health effects on humans that drink disinfected drinking water. Studies are mostly concerned with long-term effects. Humans are exposed to small concentrations of disinfection byproducts for many years. (2) Toxicity of separate disinfection byproducts and mixtures of disinfection byproducts. Research shows that a mixture of disinfection byproducts does not have a higher risk of cancer than the disinfectant with the greatest effect (Hooth, 2002).

Chloroform is normally the trihalomethane (THM) present in drinking water at the highest concentration. The other THMs are expected to be similar in health effects, routes of exposure, and metabolism to chloroform, with a few exceptions. Toxicological research (Larson, 1994) shows that chloroform causes damage to liver and finally causes cancer when it is directly applied daily into the stomach of laboratory animals. The US Environmental Protection Agency (EPA) concludes that as long as exposure to chloroform remains under given threshold values that cause cell damage, the risk for cancer is very low. Standards set for chloroform in drinking water are far below these values.

Subsequently studies on human showed that chlorinated drinking water increases the risk on bladder and anal cancer. The risk did not decrease when other factors, smoking, residence and work were investigated as well. The risk of intestinal cancer was not significant, but increased at higher concentrations disinfection byproducts (Morris, 1992). Studies show there is a relation between drinking water quality and bladder, intestinal and anal cancer (Cantor, 1980).

WHO Study (1991): In 1991 the WHO's International Agency for Research on Cancer (IARC) evaluated the carcinogenic health risk of chlorinated drinking water based on toxicological laboratory studies and human epidemical researches. This study showed that it is hard to find a relation between the development of cancer and drinking of chlorinated water. The risk is small and cannot be proved with epidemical evidence.

Disinfection byproducts and Bladder Cancer: A meta-analysis of several researches shows that there is a positive correlation between exposure to disinfection byproducts in drinking water and human bladder and anal cancer. Nine percent of all cases of bladder cancer and fifteen percent of anal cancer are attributed to chlorinated drinking water and disinfection byproducts. This comes down to 10,000 cases annually (Morris, 1992).

The concentration trihalomethanes, nitrate and residual chlorine were not associated with the risk on bladder cancer (McGeehan, 1993). There is a relation between lengthy exposure to disinfection byproducts and the risk on bladder cancer. Fourteen to sixteen percent of all bladder cancer cases can be attributed to exposure to disinfection byproducts (King, 1996).

For men there was a relation between exposure and the risk on renal cancer. For women this relation was non-significant. For both men and women the connection between exposure and bladder cancer was significant (Koivusalo, 1998). Risk of bladder cancer is important because of the large amount of people exposed to chlorinated drinking water.

Disinfection byproducts and Intestinal Cancer: Research on the connection of intestinal cancer and disinfection byproducts in drinking water shows that there is an elevated risk on intestinal cancer when chlorinated drinking water is used. People who were exposed to concentrations of 50 μg/L or more trihalomethanes in water had 1.5 times bigger risk developing intestinal cancer (Marret en King, 1995). In another study there is too little evidence for a relation between exposure to disinfection byproducts and an elevated risk on intestinal cancer (Mills, 1998).

Disinfection byproducts and Anal Cancer: A study carried out in Iowa (USA) in 1986 and 1989 with data from intestinal and anal cancer patients shows there is no elevated risk on intestinal cancer after long time exposure to chlorinated drinking water or trihalomethanes. For anal cancer there is an elevated risk however. This risk is even bigger for people who eat little fibrous food. A lack of physical exercise also elevates the risk on anal cancer (Hildesheim, 1998).

Disinfection byproducts and Reproduction and Development of Humans: Most attention on health effects of disinfection byproducts is on cancer caused by lengthy exposure to disinfection byproducts in drinking water. Standards that are being used for permitted concentrations of disinfection byproducts are based on carcinogenic abilities of these substances (Singer, 1999).

Connection between exposure to chlorinated drinking water and low birth weight: A research was carried out and showed no connection between exposure to chlorinated drinking water and a risk for low birth weight and small body length. The risk on premature birth was slightly smaller with exposure to chlorinated drinking water than non-chlorinated drinking water (Jaakkola, 2001).

Risk of birth defects after exposure to disinfection byproducts in drinking water: The risk on birth-defects and more specific heart, breathing and urine tract defects were associated with exposure to disinfection byproduct during pregnancy. The risk on abdominal wall defects increases significantly after higher exposure (Bing-Fang, 2002).

Dodds (2001) reported that exposures during pregnancy to bromodichloromethane concentrations of 20 or more µg/L were associated with an elevated risk on defects on the neural tube. Exposure to chloroform points out to an elevated risk of chromosomal defects. Research on the relation between specific disinfection byproducts and birth defects is needed (Dodds, 2001).

Influence of disinfection byproducts on reproduction: Effects that were investigated were birth weight, premature delivery, some congenital defects and early death of the newborn. There was little evidence for defects on the central nervous system, spinal cord, spontaneous abortion and stillbirth. There was sufficient evidence for a relation between growth delay, and defects on urine tracts and exposure to disinfection byproducts (Graves, 2001).

2.3.3 Standards for Disinfectants Disinfection Byproducts

Some disinfection byproducts are considered harmful for public health. Chloroform, dibromochloromethane and bromoform are probably carcinogenic and dichlorobromomethane, dichloroacetonitrile and chloral hydrates are possibly carcinogenic. Health institutions worldwide have set standards for the maximum concentration of disinfection byproducts in drinking water. Some of these standards are shown in Table 2.1.

Table 2.1: Standards for Disinfection Byproducts

Parameter	Unit	Bangladesh Standard	European Union	USEPA	WHO Guideline
Chloroform	µg/L	90	-	-	200
Bromoform	µg/L	-	-	-	100
Bromodichloromethane	µg/L	-	-	-	60
Dibromochloromethane	µg/L			-	100
Trihalomethanes (THMs)	µg/L	-	100	80	-

The United Stated Environmental Protection Agency (USEPA) is regulating both disinfection byproducts and residual disinfectants. For the regulated contaminants, EPA has defined both Maximum Contaminant Levels (MCL) and Maximum Contaminant Level Goals (MCLGs). Compliance criteria are based on the MCL. For the residual disinfectants, EPA has established Maximum Residual Disinfectant Levels (MRDLs) and Maximum Residual Disinfectant Level Goals (MRDLGs). Compliance criteria are based on the MRDL. The Maximum Residual Disinfectant Levels (MRDL) for chlorine and chloramines is 4.0 mg/L as Cl_2. The MRDL for chlorine dioxide is 0.8 mg/L. WHO has guideline values for two disinfectants, Chlorine and Monochloramine; the guideline values are 5 mg/L and 3 mg/L, respectively.

The USEPA issued the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) in 1998 to improve the control of disinfection byproducts (DBPs). This guide provides an overview of the rule along with the essential monitoring requirements. The Washington State Department of Health incorporated the Stage 1 DBPR requirements into the drinking water regulations on April 27, 2003.

The Stage 1 DBPR regulates four DBPs. Since DBPs can continue to form as long as the organic substances and disinfectant are present, the highest concentrations are usually found at the farthest points of the system. The Maximum Contaminant Levels (MCL) and sampling requirements for DBPs are shown in Table 2.2.

Table 2.2: Regulation of USEPA for 4 DBPs

Contaminant	MCL (mg/L)	Compliance
Total Trihalomethanes (TTHM)	0.080	RAA of Quarterly Averages
Five Haloacetic Acids (HAA5)	0.060	RAA of Quarterly Averages
Bromate	0.010	RAA of Monthly Averages
Chlorite	1.0	Daily

RAA: Running Annual Average

2.3.4 Assessment of THMs Formation Potential in Different Countries

Istanbul (Turkey)

The occurrence of THMs in Istanbul (Turkey) surface water resources was investigated by Rizzo et al. (2005). The THMs concentrations in finished water of some Istanbul water treatment plants, measured in November 1999, are shown in Fig 2.9. Total Trihalomethanes (TTHMs) concentration in treatment plants using pre-oxidation was lower (treatment plant 1 and 4) than that using chlorine pre-oxidation (treatment plant 3). The pre-oxidation with ozone as substitute to chlorine in water treatment plant significantly decreased TTHMs concentration in the effluent. Rizzo et al. (2005) concluded that upgrading of the Istanbul water treatment plants in terms of both ozone in place of chlorine (in pre-oxidation) and enhancing coagulation can improve TTHMs control.

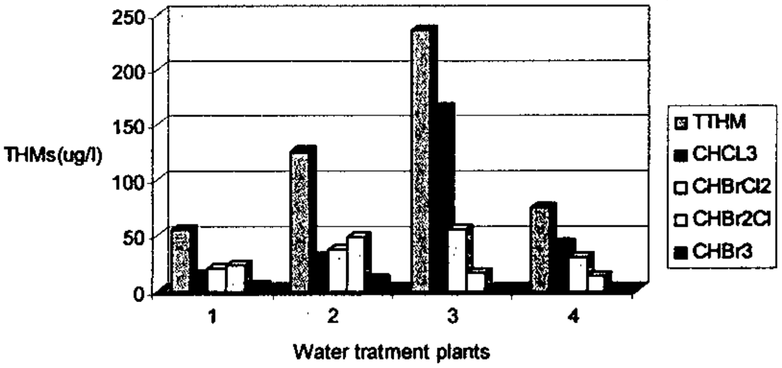

Fig. 2.9: THMs in 4 Istanbul water treatment plants (adapted from Rizzo et al., 2005)

Korea

Shin et al. (1999) reported THMs concentrations and THMs formation potential (THMFP) for a water treatment plant in Korea. The well-validated model of Amy et al. (1998) was for estimating THM formation potential. It was concluded that the source having the highest level of TOC and UV absorbance has the highest level of THMFP. The THMFP level downstream at river source was higher than upstream. It seems that precursors are added as the water flows downstream. Figure 2.10 shows disinfection by-product concentrations in effluent water (from treatment plant) and in tap water. It indicates that the level of THMs increased as their reaction time increased.

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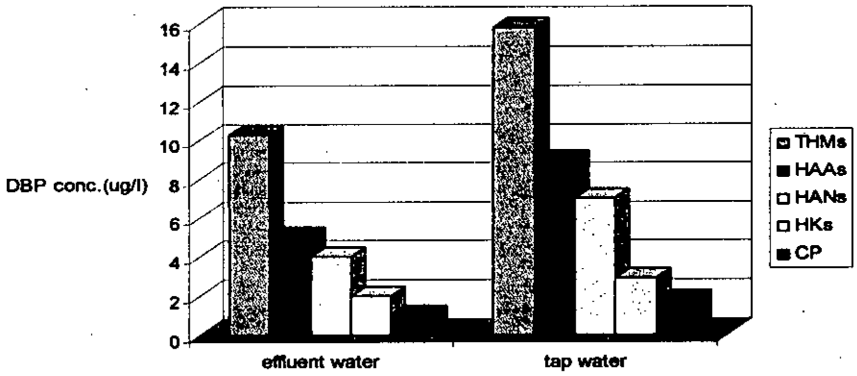


Fig. 2.10: Variation of DBP concentration in effluent and tap water at the end of the distribution system in Korea (adopted from Shin et al., 1999)

Egypt

Pre-chlorination of raw Nile river water is an integral process of water treatment in Egypt. El-Dib and Ali (1994) carried out a research on factors (pH, temperature, contact time, chlorine dose) affecting THMs formation using water from the Nile river. The THMs formation increased with increasing contact time, pH, temperature, and chlorine dose. The reaction rate of THMs progressively increased as the pH value of water was increased from 6 to 9 (Fig. 2.11). THMs concentrations increased as the chlorine dose was increased. However, THMs formation is not directly proportional to the applied chlorine dose. The effect of temperature on THMs yield was rather limited compared to that reported by other investigators. Such variation reflects the differences in the nature of organic precursors liable to be found in raw water. It was concluded that a reduction of 50% in THMs yield could be attained by decreasing the pH value of chlorinated water from 9 to 7.

2.3.5 Management and Control of DBPs

Many of the DBPs are produced by the reaction between the disinfectant and naturally occurring organic matter in the source water. Reducing the amount of organic matter in the source water before disinfection can help control the quantity of DBPs produced. TOC is used as an indicator for natural organic matter (NOM) as the precursor material for DBPs. USEPA requires drinking water systems to demonstrate removal of organic matter measured as total organic carbon. The percentage of the organic carbon that must be removed depends on the alkalinity of the source water. The compliance criterion for TOC is <2.0 mg/L.

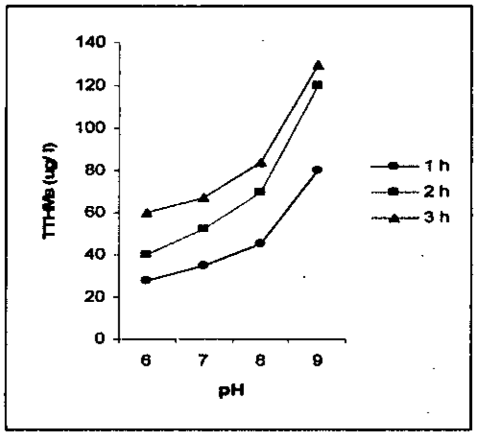


Fig. 2.11: Effect of pH on THMs formation (data from El-Dib and Ali, 1994)

Specific Ultraviolet Absorption (SUVA) is an acceptable alternative measurement of TOC. In some cases, the organic carbon content of the water consists primarily of non-humic materials. Advanced coagulation treatment is not particularly effective at removing non-humic materials, so it can be very difficult to achieve compliance in these cases. Because of this, USEPA has established an alternative compliance criterion based on Specific Ultraviolet Absorption (SUVA). SUVA is a calculated value based on two different methods, ultraviolet absorption at 254 nm (UV_{254}), and dissolved organic carbon (a filtered TOC sample). The SUVA calculation is as follows:

$$SUVA = UV_{254} / DOC \times 100$$

In some cases achieving compliance with the SUVA alternative will be much easier than achieving it through the TOC criterion. Drinking water systems are not required to perform enhanced coagulation or enhanced softening if the SUVA is ≤ 2.0 L/mg-m, even when the TOC is greater than 2.0 mg/L. This can produce substantial savings in treatment costs.

General Approach to Control THM:

Usually involves the following:

- Monitoring THM before, during and after treatment
- Changing pre-chlorination point or stop pre-chlorination
- Improving unit processes, precursors, removal efficiency, change pH, coagulant type, and coagulant dosage
- Ammoniation

- After DBPs have formed it is possible to remove them with a subsequent treatment process. USEPA has specified air stripping and GAC adsorption as techniques for the removal of THMs.
- Ozone, chloramines, chlorine dioxide etc. can be used to reduce the THM levels in drinking water. Both ozone and chloramines are reported to produce low levels of THMs in surface water treatments.
    - Treatment based on pre-ozonation followed by post chloramination became quite popular recently due to effective control of odor and taste in addition to considerable reduction of THMs in the finished water.
    - Chloramines are known to produce the least amount of DBPs but it is costly compared to other disinfectants.
    - Though chlorine dioxide is similar to ozone in its disinfection efficiency and odor/taste control capabilities, it is not very much preferred due to the difficulties in its storage and handling and the formation of toxic inorganic residuals such as chlorite and chlorate.

2.3.6 Treatment for Reducing THMs

Treatment Modifications: Treatment modifications may include:

- Maximizing the efficiency of natural organic matter removal during coagulation, flocculation settling or filtration. NOM has been found to be adsorbed by granular activated carbon (GAC), powdered activated carbon (PAC) and other adsorbing materials. At neutral to basic pH values, much of the NOM present in water exists as negatively charged ions (i.e. anions). These anionic, organic precursors are amenable to removal by anion exchange. Slow sand filters amended with granular media such as anionic resins and GAC can achieve significant removal of organic carbon and THM formation potential, frequently exceeding 75 to 90 percent.
- Changing the chlorination point or dosage. Moving the point of chlorination downstream in the treatment train allows the concentration of disinfection by-product precursors to be reduced before chlorine is added and may be implemented seasonally.
- Organic matter can be selectively removed by coagulation
- Stalling a second chlorination point in the distribution system
- Using chloramines, instead of chlorine, for disinfection

Control Measures at Home: Control measures can be taken at home to reduce TTHM if any one believes that it is an important factor in their lives. Home control measures may include: (i) Filters, (ii) Aeration or Boiling, (iii) Distillation, (iv) Bottled Water, and (v) Activated Carbon

Source Control: It has been found in some watersheds that the adsorption capacity of soils can affect the amount of DOC transport in water. In soils with low exchange capacity, it is possible to improve the adsorption capacity by the addition of adsorbents such as lime, gypsum or alum sludge.

Enhanced Coagulation: This is among the simplest strategies for utilities already using conventional coagulation. Enhanced coagulation may involve any of the following: An increase in coagulant dose, pH adjustment and alternate coagulants. There are concerns associated with enhanced coagulation, including turbidity removal, corrosion and increases in contaminant concentrations, such as aluminum, in the finished water.

Alum Coagulation: Alum coagulation tends to remove more monohaloacetic acids (XAAs) and trihaloacetic acids (X_3AAs) precursors than that of dihaloacetic acids (X_2AAs). Alum coagulation treated water had a lower HAA_9/TTHM ratio compared with that of the raw water. In alum coagulated water brominated THMs or HAAs formed faster than the chlorinated species in the initial period.

Reverse osmosis: The reverse osmosis (RO) process is effective in reducing concentrations of nonvolatile organics. RO treatment of waters with high concentrations of THM precursors prior to chlorination can significantly reduce the level of THMs in the final potable water.

CHAPTER 3

ASSESSMENT OF WATER AND SEDIMENT QUALITIES OF THE DND CONVEYANCE CANAL

3.1 INTRODUCTION

The DND canal conveys raw water from the Sitalakhya river to the Saidabad Water Treatment Plant (SWTP). Poor quality of water in the Sitalakhya river is a major concern for the SWTP during the dry season (January-April). Possible change in quality of raw water within the DND conveyance canal is an important issue with regard to controlling algae and ammonia problem in the SWTP. Ideally, raw water quality should improve within the DND canal due to sedimentation and biodegradation processes. However, the DND canal is widely used by people for bathing, washing of clothes and utensils, etc. which may deteriorate water quality within the DND canal. Sediment of the DND canal is likely to accumulate trace contaminants such as heavy metals with passage of time, and may act as a source of such contaminants. Therefore, it is important to assess water and sediment qualities of the DND conveyance canal.

This Chapter presents an assessment of water quality of the DND conveyance canal. The assessment is based on a systematic collection and analysis of the water samples from the DND conveyance canal during both dry and wet seasons. This chapter also presents the analysis of sediment quality within the DND canal.

3.2 METHODOLOGY

For assessment of water quality within the DND canal, water samples were collected during both dry and wet seasons. Dry season monitoring of water quality of DND conveyance canal was carried out over a period of nine weeks, starting on 29 January 2007 and ending on 27 March 2007. Water quality was monitored once a week at 6 locations along the DND canal; water quality at the Sarulia intake was also monitored once a week along with those in the DND canal. In addition, three sampling programs were carried out during the wet season – at the end of June, at the end of July and at the beginning of September. Sediment samples were also collected from three locations within the DND canal on September 2007.

3.2.1 Sampling Locations and Schedule

The six water quality monitoring locations along the DND canal is shown in Fig. 1; the locations are identified as DND-1 through DND-6. In addition, water samples were also collected from the Sarulia intake (Photograph 3.1). The geographic coordinates of the sampling locations (including the Sarulia intake) is shown in Table 1. There are 9 bridges on the DND canal and for ease of sample collection, the sampling points were selected at 6 bridge locations. Photographs 3.2 to 3.7 show the sampling locations along the DND canal. Water samples from the DND canal and the Sarulia intake were collected during dry season once a week for 9 weeks on 29 January, 5 February, 12 February, 19 February, 26 February, 5 March, 12 March, 19 March and 27 March of 2007. Water samples from the DND canal were also collected during wet season once a month for three months on 29 June, 27 July and 10 September of 2007. During each sampling campaign, samples were collected in the morning (between 8:00 to 10:00 a.m.) starting from the upstream end of the DND canal (i.e., DND-1), with 1 hour interval between sampling from each location. Photographs 3.2 to 3.7 show the 6 sampling locations along the DND conveyance canal.

Table 3.1: Location of sampling points along DND canal

Sampling Location	GPS Position (Deg Min Sec)		Distance from the starting point of DND canal (km)
	Latitude	Longitude	
Sarulia	23° 43′ 02.6″	90° 30′ 0.4″	
DND-1	23° 43′ 03.8″	90° 29′ 40.9″	0.215
DND-2	23° 43′ 09.7″	90° 29′ 25.5″	0.695
DND-3	23° 43′ 06.2″	90° 29′ 04.1″	1.312
DND-4	23° 43′ 02.4″	90° 28′ 28.1″	2.344
DND-5	23° 42′ 58.8″	90° 27′ 56.8″	3.240
DND-6	23° 42′ 50.8″	90° 27′ 23.1″	4.226

For monitoring of sediment quality of DND canal, sediment samples from the top 20 centimeters (approximately) of the canal bed were collected on 10 September 2007 from three sampling points: DND-1, DND-3 and DND-5. The sediment samples were stored in plastic sampling bags at 4°C in a refrigerator before analysis. The top 20 cm represent the most biologically active depositional layer in relatively slow flowing streams (Hickey, 1998).

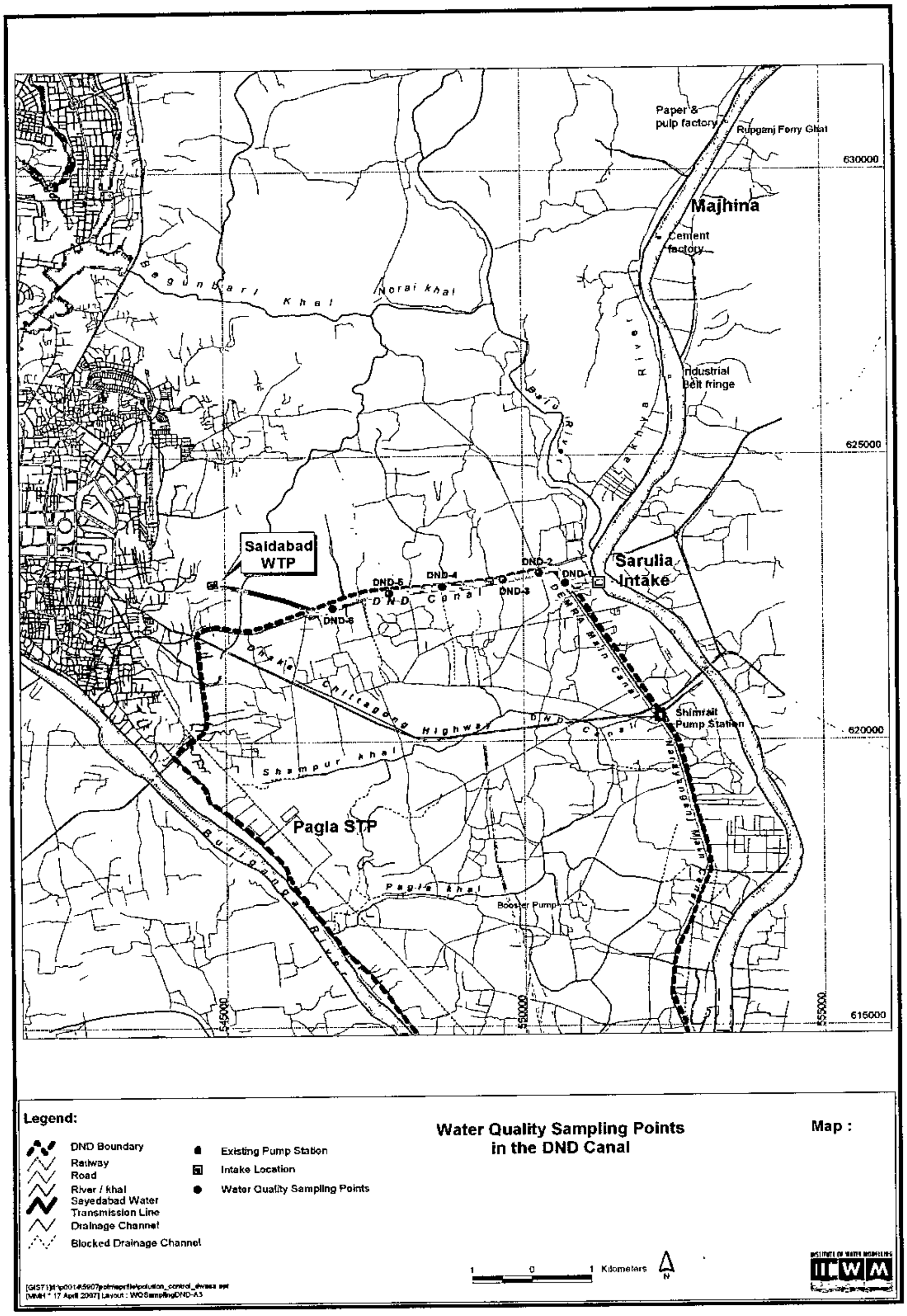
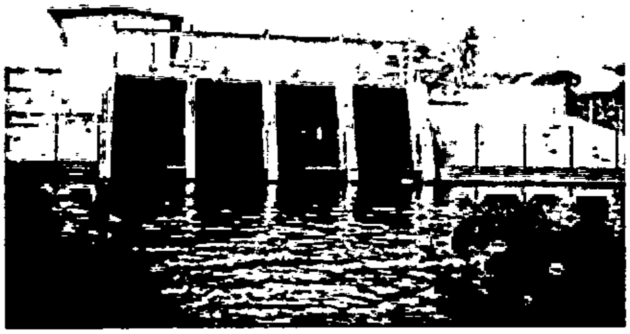


Figure 3.1: Sampling locations along DND canal
(Courtesy: Institute of Water Modeling, Dhaka)

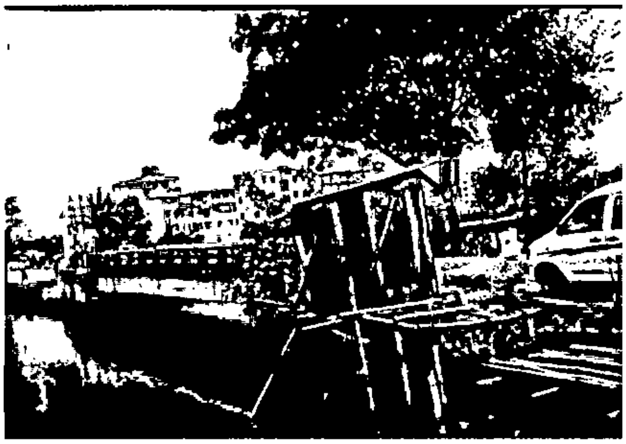


Photograph 3.1: A view of the Sarulia intake on Sitalakhya river

Photograph 3.2: Water samples being collected from DND-1 location

Photograph 3.3: A view of the DND-2 location

Photograph 3.4: A view of the DND-3 location



Photograph 3.5: A view of the DND-4 location

Photograph 3.6: A view of the DND-5 location

Photograph 3.7: A view of the DND-6 location

3.2.2 Analysis of Water Sample

The water samples collected from the Sarulia intake and DND canal were analyzed for pH, Chloride, DO, BOD_5, TOC, EC, Suspended Solids, TDS, Ammonia, Nitrate, Nitrite, Phosphate, Alkalinity, Chlorophyll-A and Temperature. Selected water samples were also analyzed for COD, Sulfate, Color, Turbidity, Total Chlorine, DOC, Bromide and UV_{254}. The pH, DO and Temperature measurements were carried out in the field. TOC analysis was carried out on samples collected during the dry season on every alternate week beginning from the second week of sampling. Water samples collected during the wet season from DND-1, DND-3 and DND-5 locations were also tested for four heavy metals Copper, Lead, Cadmium and Chromium. The DOC concentrations were measured for three samples collected from DND-1, DND-3 and DND-5 locations on 10 September 2007.

During sampling, pH was measured by a pH meter (Geotech) attached with a pH electrode (WTW, Sen Tix 41), Conductivity was measured by a Conductivity meter (Hach), and Turbidity by a Turbidimeter (Hach, 2100P). In the Environmental Engineering Laboratory of BUET, Ammonia, Nitrate, Nitrite, Phosphate, and Sulfate concentrations were measured with a Spectrophotometer (HACH, DR4000U). Ammonia was measured by the Nessler method, Nitrate by the Cadmium Reduction Method, Nitrite by the Diazotization method, Phosphate by the Molybdenum Blue method and Sulfate by the Sulfa Ver 4 method. The Total Organic Carbon (TOC) concentration was also measured by the Spectrophotometer using the Direct Method (Method 10129). Copper (Cu), Lead (Pb), Cadmium (Cd) and Chromium (Cr) concentrations were determined with an Atomic Absorption Spectrophotometer (Shimadzu, AA6800). Other parameters (e.g. TDS, TSS, Alkalinity) were measured following Standard Methods. Chlorophyll-A (algae) and phytoplankton concentrations were measured by the Environmental Microbiological Laboratory of ICDDR,B, Dhaka. The DOC concentrations were measured from the Plasma Plus Laboratory located in Uttara, Dhaka. Bromide concentrations were measured from EAWAG, Switzerland.

3.2.3 Analysis of Sediment Sample

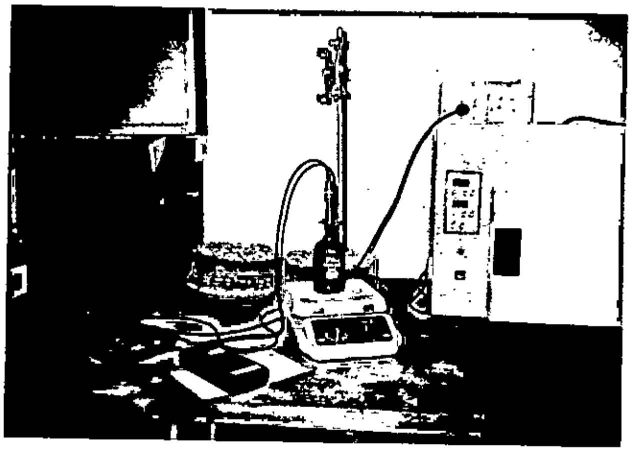
The sediment samples were analyzed for total concentration of Copper, Lead, Cadmium and Chromium after digestion with aqua-regia. Sediment Oxygen Demand (SOD) of the collected sediments was measured using an ex-situ method. Specific gravity, moisture content and organic matter content of the sediment samples were also determined.

Digestion of Sediment Samples

For determination of aqua-regia extractable heavy metals (Cu, Pb, Cd, Cr), the selected soil sample was dried in an oven at 110 °C for 24 h. After drying, the sample was ground and sieved before digestion. For digestion, 5 g of soil sample was weighed into a 500 mL flask to which 2.5 mL concentrated nitric acid and 7.5 mL concentrated hydrochloric acid were added. The suspension was kept overnight in the flask and then it was refluxed for 2 h, followed by dilution with deionized water to 500 mL, stirring for 5 min and filtering (0.80 μm) after cooling. The filtrate was stored in a plastic bottle for analysis of Cu, Pb, Cd and Cr using an AAS attached with a graphite furnace (Shimadzu, Japan, AA6800).

Ex Situ SOD Measurement

The sediment oxygen demand (SOD) was estimated using the ex-situ method outlined by Matlock et al. (2003). For measurement of SOD, the sediment samples were divided into 5 and 10 gram increments and placed into a 300 ml BOD bottle, which was then filled with aerated distilled water saturated with oxygen (Photograph 3.8). The DO was measured with a DO meter probe at roughly one-minute increments for 30 minutes while stirring the sediment in the bottle with a magnetic stirrer. After the initial reading, the BOD bottle was continuously stirred and DO concentrations were measured after fixed time periods for 24 hours or until the oxygen was driven to below detection level of 0.02 mg/L.



Photograph 3.8: Ex-situ measurement of sediment oxygen demand (SOD)

The overall oxygen consumption in the bottle was measured for the given sample size resulting in a measurement of oxygen consumed in "mg O_2/gram of sediment/day". Using specific gravity, these values were converted into "mg O_2/m^3 sediment /day".

3.3 RESULTS AND DISCUSSION

This section provides an assessment of water quality and sediment quality of DND canal, based on the test results of samples collected during this study. Detail test results of water samples are presented in Annex A, while those of sediment samples are presented in Annex B.

3.3.1 Variation of Water Quality within the DND Canal

As mentioned earlier, water samples from the DND conveyance canal and Sarulia intake were analyzed for pH, chloride, DO, BOD_5, TOC, EC, suspended solids, TDS, sulfate, ammonia, nitrate, nitrite, phosphate, alkalinity, Chlorophyll-A and temperature. Selected water samples were also analyzed for COD, copper, cadmium, lead, chromium, color, turbidity, total chlorine, DOC, bromide and UV_{254}. The DOC, bromide, and UV_{254} concentrations of water samples were used in estimating trihalomethane (THM) formation potential and have been presented and discussed in Chapter 4.

pH:

The pH value of water samples along the DND canal on a particular sampling date did not vary significantly. During the study period January to March (dry season) and June to September (wet season), no particular trend in the variation of pH could be observed. Some lowering of pH occurred during the wet season. Figure 3.2 shows the variation of pH value at the Sarulia intake and along the DND canal during the monitoring period.

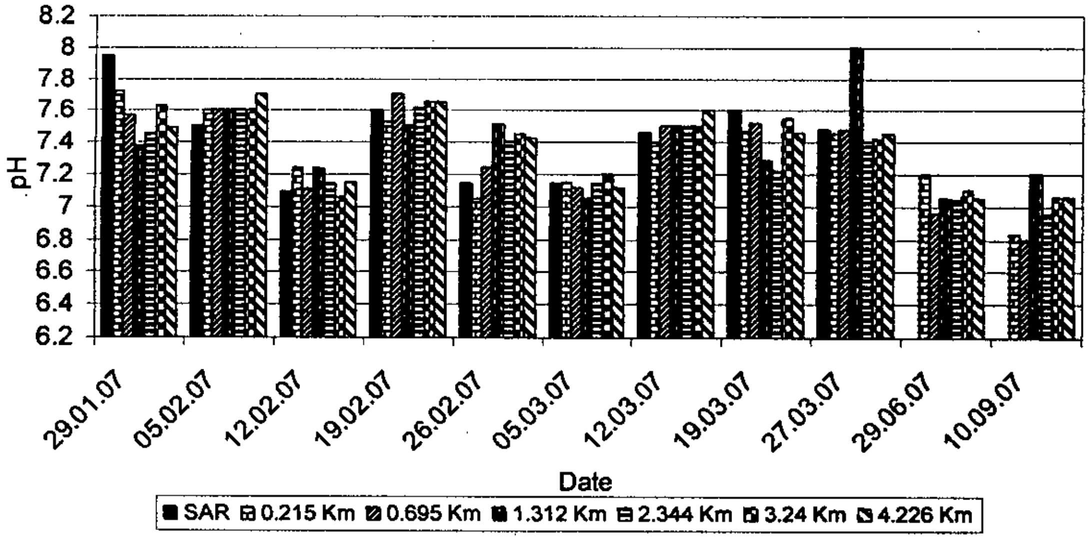


Figure 3.2: Variation of pH of water at Sarulia intake and along the DND canal

During the dry season, the pH value varied from a low of 7.05 to a high of 8.00. The minimum pH value of 7.05 was recorded at DND-3 location on 5 March 2007, while the maximum pH value of 8.00 was also recorded at the same location on 27 March 2007. Mean pH values of different sampling dates varied over a narrow range of 7.13 on 5 March 2007 to 7.62 on 5 February 2007. The pH value at Sarulia intake was similar to those found along DND canal.

During the wet season the pH value varied from a low of 6.8 to a high of 7.2. The minimum pH value of 6.8 was recorded at DND-2 location on 10 September 2007, while the maximum pH value of 7.2 was recorded at DND-1 location on 29 June 2007 and at DND-3 location on 10 September 2007. Mean pH values of different sampling dates varied over a narrow range of 6.99 on 10 September 2007 to 7.07 on 29 June 2007. Thus, slight lowering of pH value is observed during the wet season, compared to dry season.

Chloride:

Figure 3.3 shows the variation of chloride concentration at the Sarulia intake and along the DND canal during the monitoring period. During the dry season (January to March 2007), Chloride concentration varied from a low of 38 mg/L to a high of 96 mg/L. The minimum Chloride concentration of 38 mg/L was recorded at DND-3 location on 29 January 2007, while the maximum concentration of 96 mg/L was recorded at several locations on 27 March 2007. Mean Chloride concentration of different sampling dates varied over a wide range of 42.8 mg/L on 29 January 2007 to 95 mg/L on 27 March 2007. Relatively high concentration of Chloride was recorded during March 2007 (compared to Chloride concentrations recorded in January and February). Figure 3.3 shows that Chloride concentration increases gradually from January to March as dry season progressed. The Chloride concentration of water samples along the DND canal on a particular sampling date did not vary significantly. This indicates no significant input of Chloride along the DND canal. Chloride concentration at Sarulia intake during dry season were found similar (mean Chloride concentration was 71 mg/L) to those of water samples along DND canal.

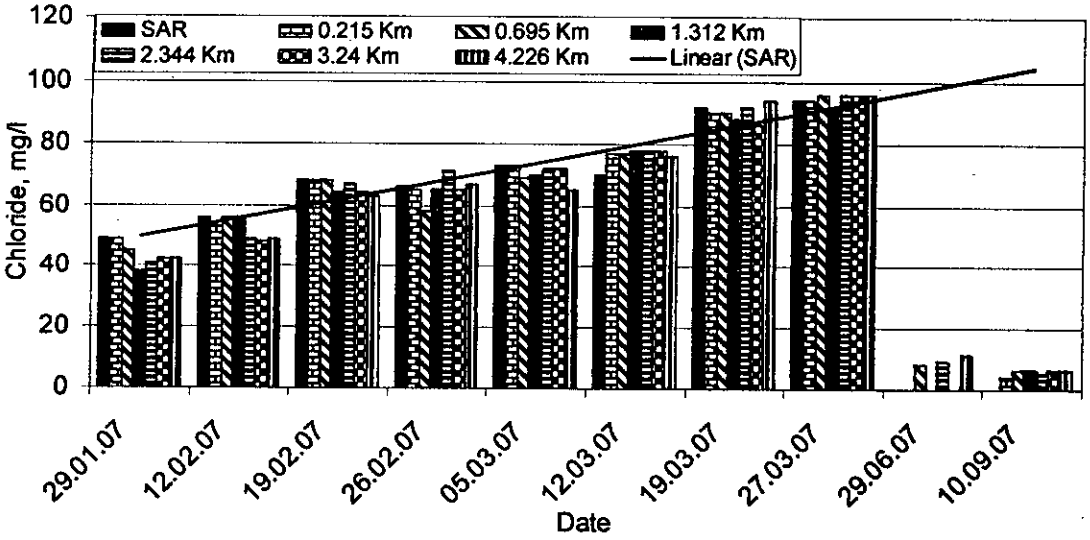


Figure 3.3: Variation of Chloride concentration of water at the Sarulia intake and along the DND canal

During the wet season (June and September 2007), Chloride concentrations decreased significantly along the DND canal. Chloride concentrations varied from a low of 4 mg/L to a high of 11 mg/L. The minimum Chloride concentration of 4 mg/L was recorded at

DND-1 location on 10 September 2007, while the maximum Chloride concentration of 11 mg/L was recorded at DND-6 location on 29 June 2007. Mean Chloride concentration of different sampling dates varied over a narrow range of 5.5 mg/L on 10 September 2007 to 9.3 mg/L on 29 June 2007.

Alkalinity:

On any particular sampling day, Alkalinity concentration along the DND canal did not change significantly. Figure 3.4 shows the variation of Alkalinity at the Sarulia intake and along the DND canal during the monitoring period. Relatively high concentration of Alkalinity was recorded during March 2007 (compared to Alkalinity recorded in January and early February). During the dry season (January to March 2007), Alkalinity varied from a low of 165 mg/L to a high of 275 mg/L. The minimum Alkalinity of 165 mg/L was recorded at DND-6 location on 12 March 2007, while the maximum Alkalinity of 275 mg/L was recorded at DND-3 location on 12 March 2007. Mean Alkalinity of different sampling dates varied from a low of 214 mg/L on 29 January 2007 to a high of 265 mg/L on 19 March 2007. Except for a couple of cases, Alkalinity concentrations of water at the end of the DND canal (i.e., DND-6 location) have been found to be slightly higher than those at the Sarulia intake point.

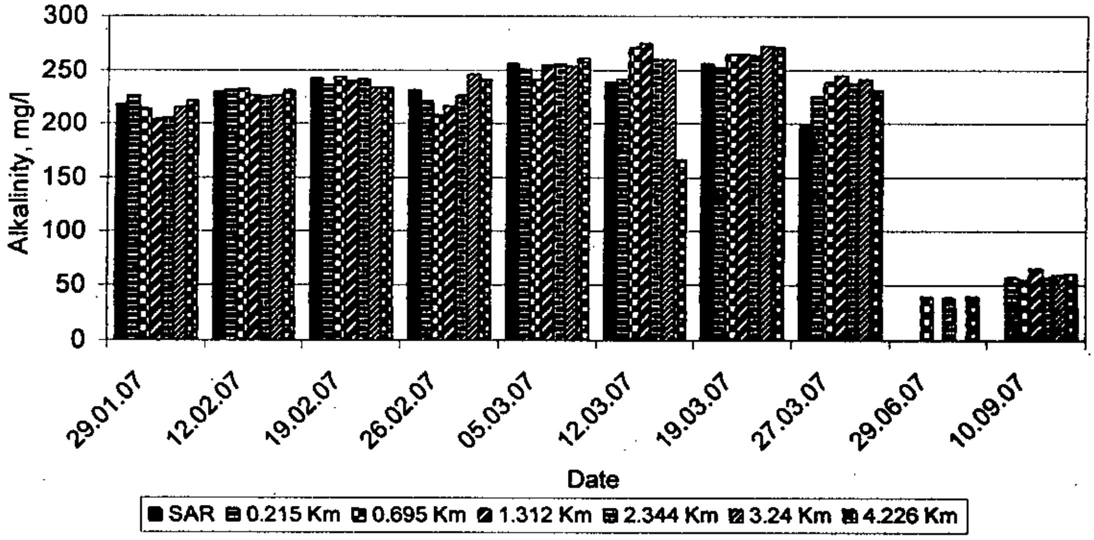


Figure 3.4: Variation of Alkalinity of water at the Sarulia intake and along the DND canal

During the wet season (June and September 2007), Alkalinity decreased significantly along the DND canal. Alkalinity varied from a low of 37 mg/L to a high of 65 mg/L. The minimum Alkalinity of 37 mg/L was recorded at DND-4 location on 29 June 2007, while the maximum Alkalinity of 65 mg/L was recorded at DND-3 location on 10 September 2007. Mean Alkalinity of different sampling dates varied from a low of 38 mg/L on 29 June 2007 to a high of 58 mg/L on 10 September 2007.

TDS and EC:

As expected, the variation of total dissolved solids (TDS) and electrical conductivity (EC) was similar. The TDS of water samples along the DND canal on any particular sampling day did not change significantly. Figure 3.5 shows the variation of TDS concentration at the Sarulia intake and along the DND canal during the monitoring period.

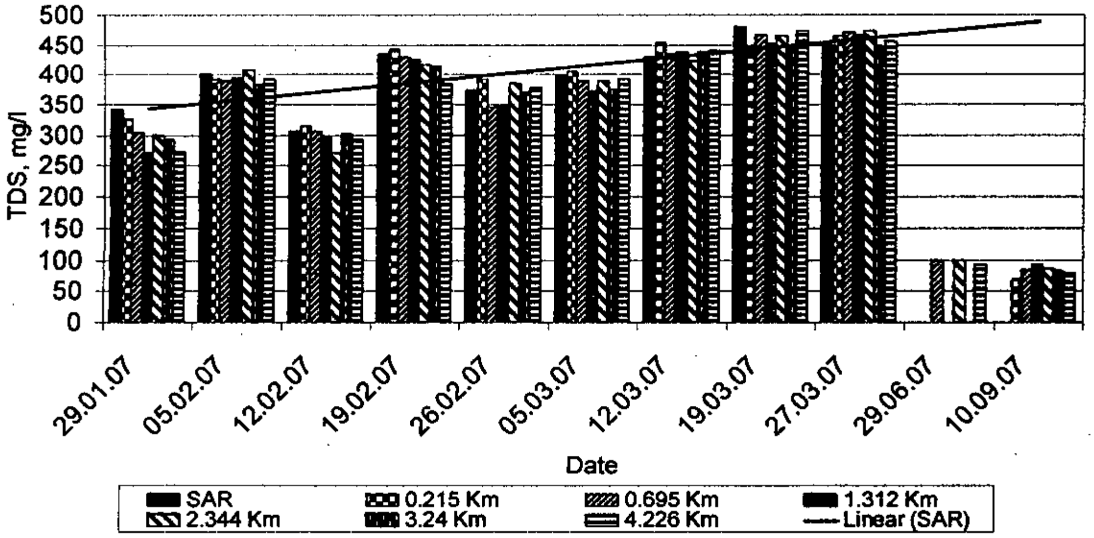


Figure 3.5: Variation of TDS of water at the Sarulia intake and along the DND canal

During dry season, the TDS varied from a low of 271 mg/L to a high of 474 mg/L. The minimum TDS of 271 mg/L was recorded at DND-4 location on 12 February 2007, while the maximum TDS of 474 mg/L was recorded at DND-6 location on 19 March 2007. Mean TDS of different sampling dates varied over a wide range of 295 mg/L on 29 January 2007 to 463 mg/L on 27 March 2007. An increasing trend of TDS is observed from January to March as dry season progressed. The TDS at Sarulia intake was found to be similar to those along DND canal, indicating no significant input of dissolved materials along the canal.

Significant lowering of TDS occurred during the wet season; TDS varied from a low of 68 mg/L to a high of 100 mg/L. The minimum TDS concentration of 68 mg/L was recorded at DND-1 location on 10 September 2007, while the maximum TDS concentration of 100 mg/L was recorded at DND-2 location on 29 June 2007. Mean TDS concentration of different sampling dates varied over a narrow range of 82 mg/L on 10 September 2007 to 97 mg/L on 29 June 2007.

Figure 3.6 shows the variation of EC at the Sarulia intake and along the DND canal during the monitoring period; relatively high EC was recorded during March 2007. During the dry season (January to March), EC varied from a low of 515 µs/cm to a high of 850 µs/cm. The minimum EC of 515 µs/cm was recorded at DND-3 location on 29 January 2007, while the maximum of 850 µs/cm was recorded at DND-6 location on 19 March 2007. The EC values did not vary significantly along the DND canal on a particular sampling date. Mean EC of different sampling dates varied over a wide range of about 542 µs/cm on 29 January 2007 to 839 µs/cm on 19 March 2007. Like the case for Chloride, the EC also showed an increasing trend from January to March as dry season progressed.

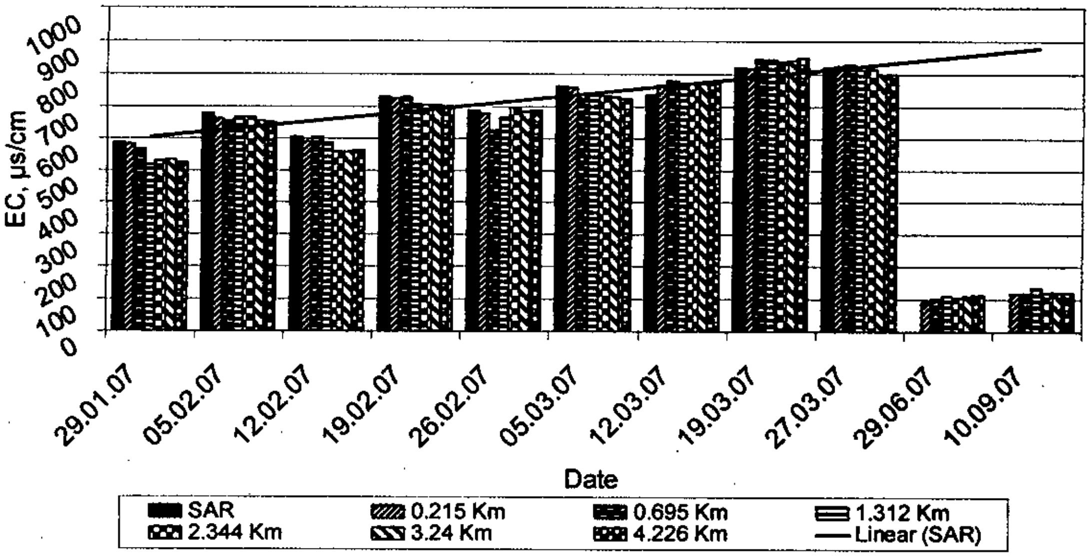


Figure 3.6: Variation of EC of water at the Sarulia intake and along the DND canal

During the wet season (June and September 2007), EC decreased significantly. EC varied from a low of 93.7 µs/cm to a high of 137.5 µs/cm. The minimum EC of 93.7 µs/cm was recorded at DND-1 location on 29 June 2007, while the maximum conductivity of 137.5 µs/cm was recorded at DND-3 location on 10 September 2007. Mean conductivity on different sampling dates varied over a narrow range of about 104 µs/cm on 29 June 2007 to 122 µs/cm on 10 September 2007.

TSS and Turbidity:

During dry season, Suspended Solids (SS) concentration in the DND canal varied from a high of 58 mg/L to a low of 4 mg/L. Mean Suspended Solids concentration of different sampling dates during dry season varied over a wide range of about 16 mg/L on 19 February and 27 March 2007 to 37 mg/L on 5 February 2007 (Fig. 3.7). The Suspended Solids concentration increased significantly during the wet season (measured for samples collected on 29 June and 10 September 2007); up to 110 mg/L at DND-1 location on 10 September.

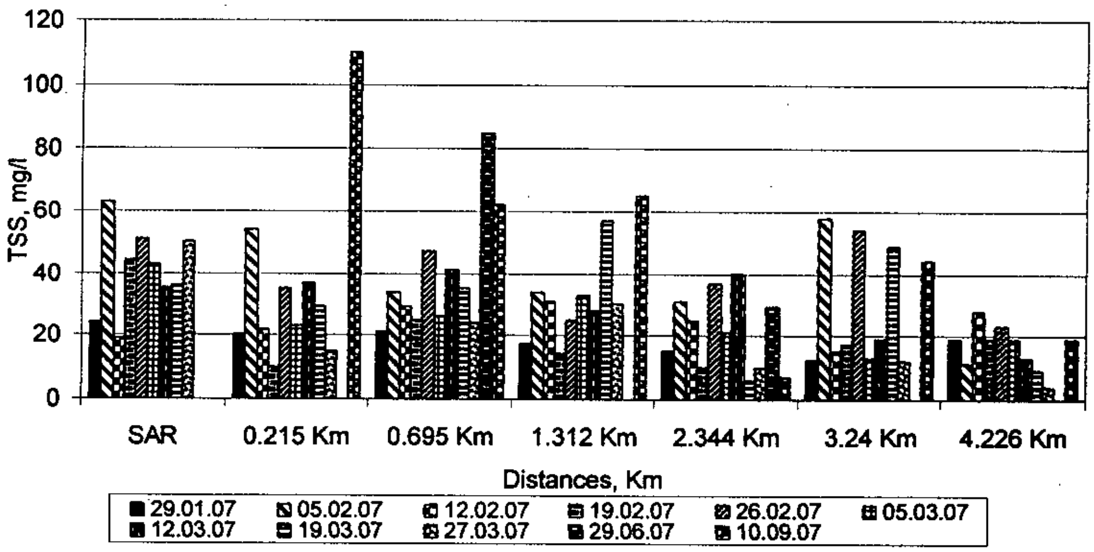


Figure 3.7: Variation of TSS concentration of water at the Sarulia intake and along the DND canal

Since the DND conveyance canal acts as a sedimentation basin, the SS concentration is likely to be reduced in the canal. However, reduction in SS concentration during the dry season does not appear to be significant except at the end of DND canal (DND-6 location) (see Fig. 3.8). Over the 9 weeks of monitoring, average TSS was about 27 mg/L at DND-1 location and 16 mg/L at DND-6 location, showing a 40% reduction on an average. Average TSS at the intermediate sampling points (DND-2 to DND-5) did not change significantly.

On the other hand, reduction in TSS during the wet season was quite significant; over 80% removal within the canal, as shown in Fig. 3.8. This is consistent with turbidity values measured for the samples collected on 10 September 2007. Figure 3.9 shows significant reduction of turbidity from 73 NTU to 20 NTU within the DND canal, indicating significant reduction of suspended solids within the canal during wet season.

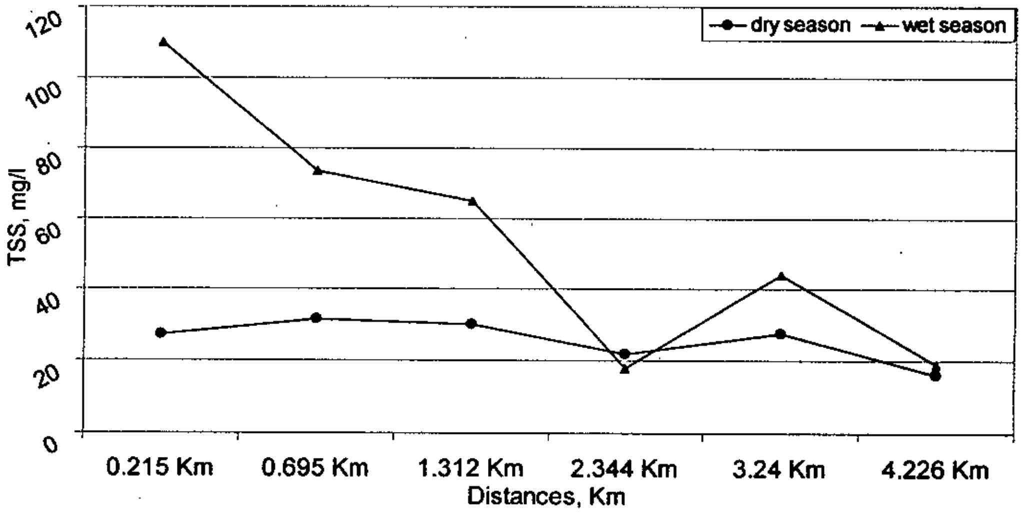


Figure 3.8: Variation of mean TSS concentration along the DND canal during dry and wet seasons

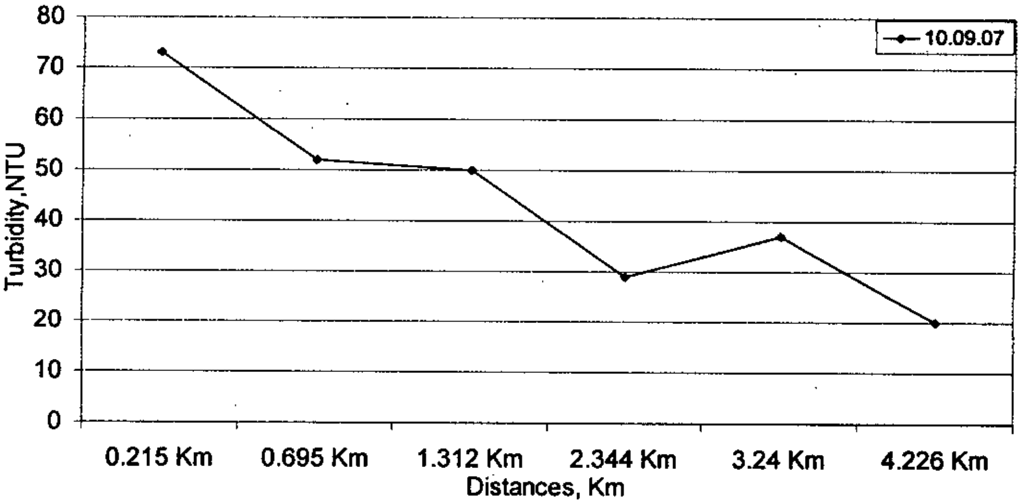


Figure 3.9: Variation of Turbidity of water along the DND canal on 10 September 2007 (wet season)

Color:

Color concentration was measured only for samples collected on 29 June and 10 September 2007 (i.e. during wet season); Fig. 3.10 shows the variation of color concentration. Relatively high color concentrations were recorded on 10 September 2007. Color concentration varied from a low of 42 Pt-Co Unit to a high of 202 Pt-Co Unit.The minimum Color concentration of 42 Pt-Co was recorded at DND-6 location on 29 June, while the maximum Color concentration of 202 Pt-Co unit was recorded at DND-2 location on 10 September of 2007. Mean Color concentration was 83 Pt-Co Unit on 29 June 2007 and 181 Pt-Co Unit on 10 September 2007.

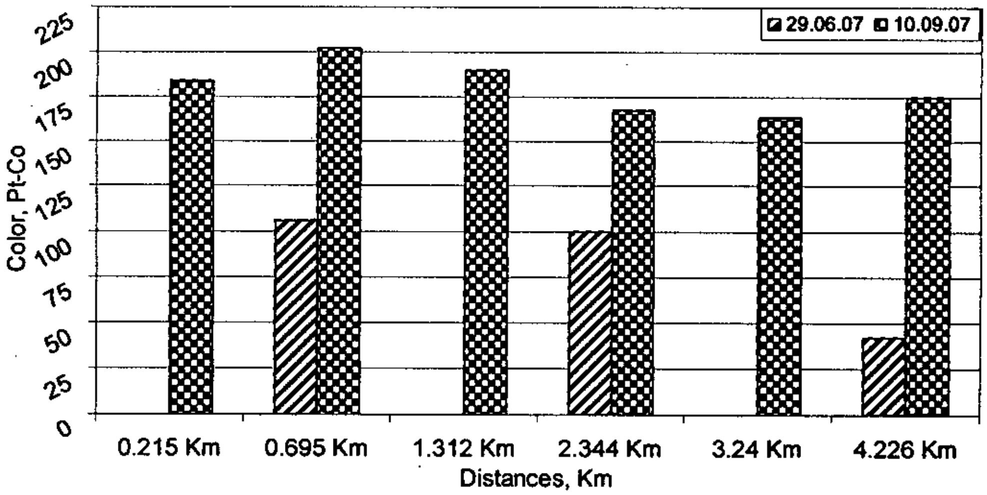


Figure 3.10: Variation of Color concentration of water along the DND canal

Dissolved Oxygen (DO):

During dry season, water in the DND canal contained relatively low DO, mostly below 2 mg/L (Fig. 3.11a). Only on a couple of sampling days (19 and 27 March 2007), relatively high DO values (exceeding 3 mg/L) were recorded at some sampling points. Except for a couple of cases, DO values of water at the end of the DND canal (i.e. DND-6 location) have been found to be slightly lower than those at the Sarulia intake point. The DO concentration of water increased significantly during wet season. All the water samples collected on 10 September 2007 contained DO of close to 4 mg/L and higher.

Figure 3.11b shows the variation of temperature water at the Sarulia intake and along the DND canal, which were measured along with DO in the field. It shows increasing water temperature as dry season progressed.

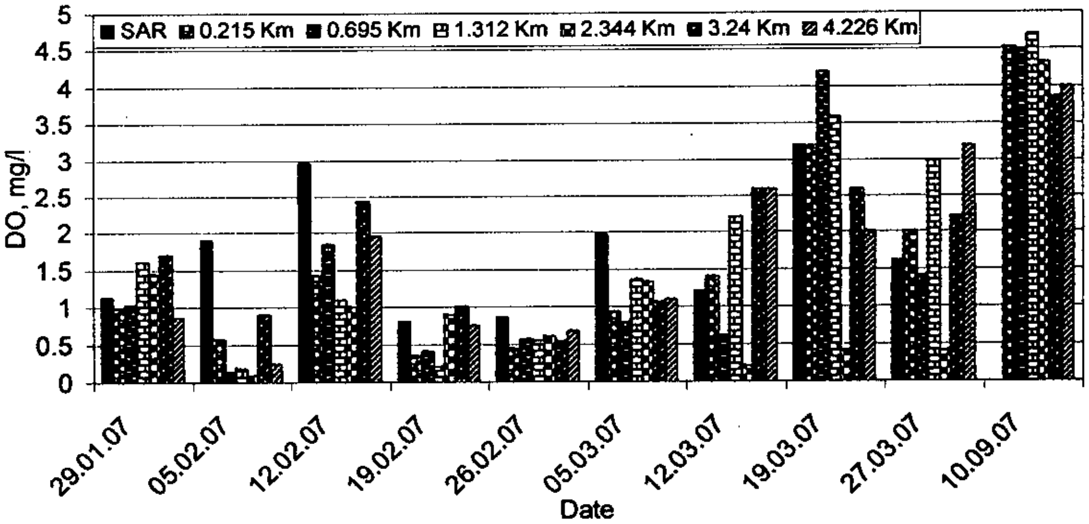


Figure 3.11a: Variation of DO of water at the Sarulia intake and along the DND canal

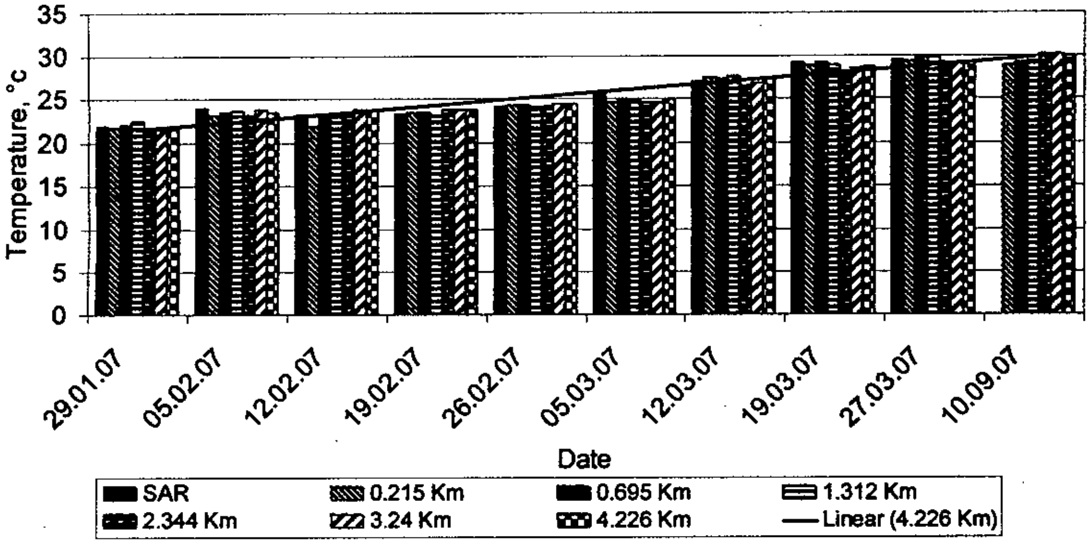


Figure 3.11b: Variation of temperature of water at the Sarulia intake and along the DND canal

BOD$_5$:

Except for a few instances, BOD$_5$ values of water samples did not vary significantly along the DND canal during dry season. Most BOD$_5$ values are within 10 to 20 mg/L (Fig. 3.12). Mean BOD$_5$ value varied from a low of 9.1 mg/L on 29 January 2007 to a high of 18.9 mg/L on 27 March 2007. Relatively high mean BOD values were also recorded for samples collected during 19 February to 5 March 2007. The BOD$_5$ values of water samples at the Sarulia intake were similar to the BOD$_5$ values of samples collected from the downstream end (DND-6) of the canal.

BOD$_5$ concentration decreased significantly during the wet season. Most BOD$_5$ values were within the range of 2 to 4 mg/L. Mean BOD$_5$ value varied from a low of 1.9 mg/L on 10 September 2007 to a high of 3.8 mg/L on 29 June 2007. Figure 3.12 and Figure 3.13 show the variation of BOD$_5$ concentration at the Sarulia intake and along the DND canal during the monitoring period.

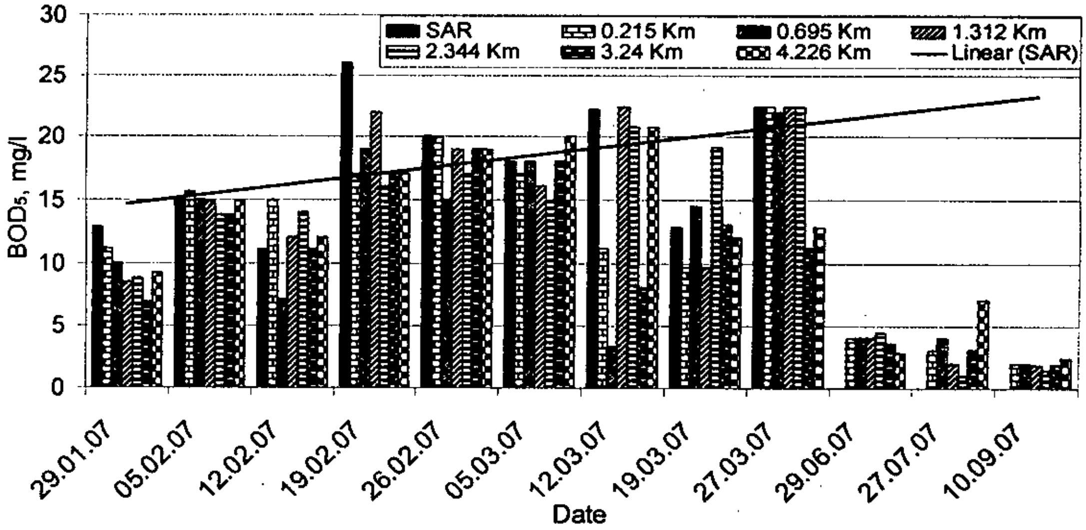


Figure 3.12: Variation of BOD$_5$ of water at the Sarulia intake and along the DND canal

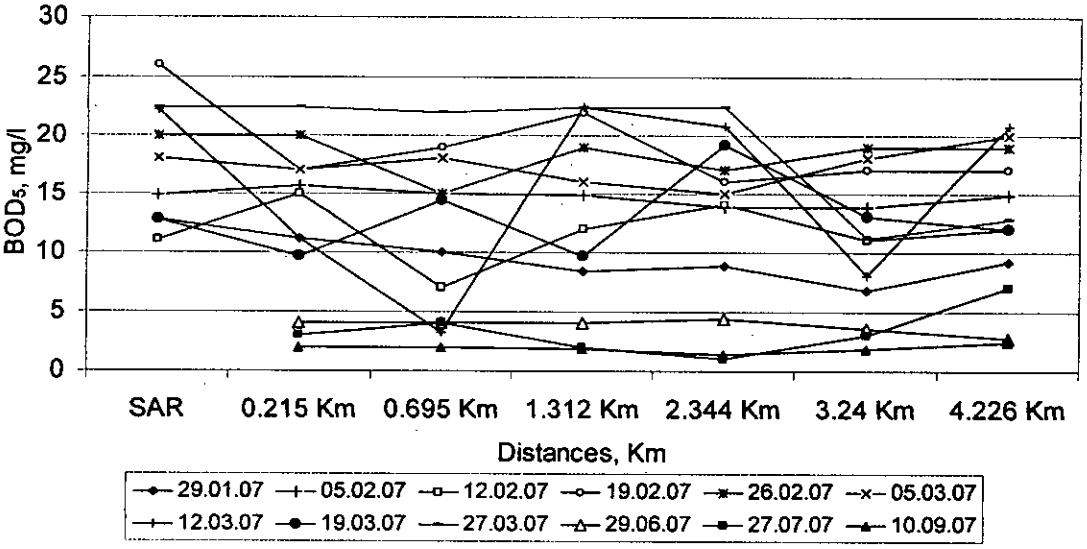


Figure 3.13: Variation of BOD$_5$ of water at the Sarulia intake and along the DND canal

Since residence time of water within the DND canal is relatively short (about 12.9 hours), BOD reduction by biodegradation is likely to be insignificant along the canal (Fig. 3.13). For the water sample collected from DND-4 location on 27 March 2007, it was estimated that BOD_5 of water would reduce by about 1 mg/L (due to biodegradation) from entry to exit point of the DND canal [based on the BOD rate constant of 0.27 day $^{-1}$, estimated from BOD_3 and BOD_5 measurements].

Reduction in BOD, however, may result from removal of particulate BOD within the DND canal. Measurement of filtered BOD of three samples collected on 27 March 2007 (from DND-2, 4 and 6 locations) suggest that particulate BOD could make up 40% of total BOD, which could be removed due to sedimentation. However, no significant BOD reduction within the canal suggest that any reduction in BOD due to settling of particulate BOD (and also biodegradation) is probably accompanied by addition of BOD of similar magnitude from the surrounding areas and from the sediment.

These data suggest that input of biodegradable organics into the DND canal from surrounding areas is probably not very significant. Contribution of sediment BOD into the water column is probably also not very significant.

COD:

COD analysis was carried out on one set of samples collected on 5 March 2007 (dry season) and on all three set of samples collected during the wet season. The water samples collected on 5 March 2007 were found to contain relatively high concentrations of COD. On 5 March 2007, the COD of the water sample from the Sarulia intake was 57 mg/L, while that of water samples along the DND canal varied from 57 to 61 mg/L. Mean COD concentration of water samples was 58.8 mg/L. BOD_5 to COD ratio of the water samples collected on 5 March 2007 (dry season) varied from 0.25 to 0.33. BOD_5 to COD ratio of typical domestic sewage varies from 0.4 to 0.8 (Metcalf and Eddy, 1991). The lower BOD_5 to COD ratio of the samples probably indicate presence of industrial effluent containing relatively higher percentage of non-biodegradable material.

COD concentration decreased significantly during the wet season and varied from a low of 1 mg/L to a high of 12 mg/L. The minimum COD concentration of 1 mg/L was recorded at DND-3 location on 10 September 2007, while the maximum COD concentration of 12 mg/L was recorded at DND-4 location on 29 June and at DND-5 location on 27 July 2007. Mean COD of different sampling dates varied from a low of 3.4 mg/L on 10 September 2007 to a high of 8.7 mg/L on 29 June 2007. Figure 3.14 shows the variation of COD along the DND canal during the monitoring period. The BOD_5 to COD ratio of the samples collected during the wet season were relatively high (compared to those of the samples collected during dry season), varying from about 0.2 to 0.9.

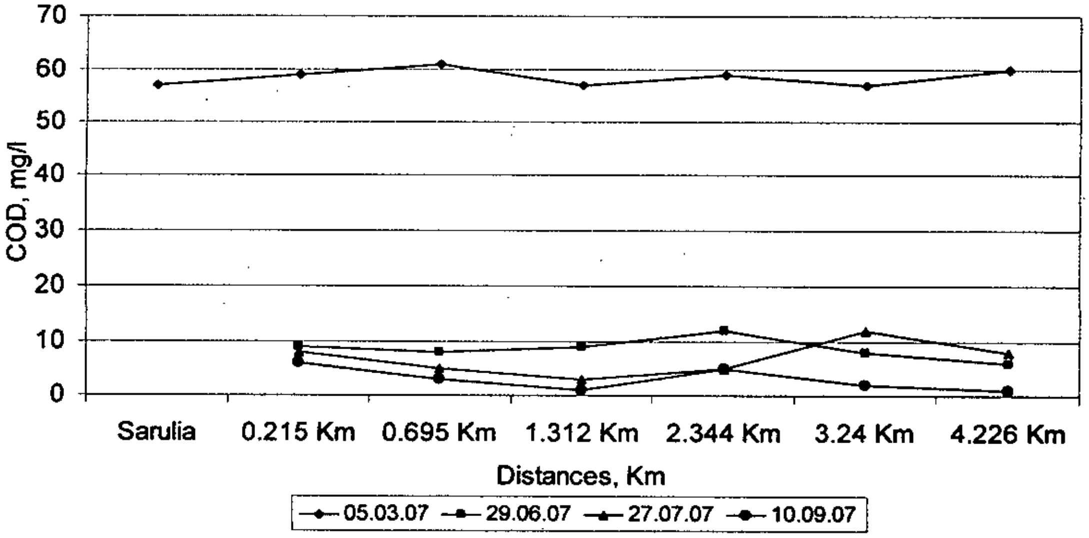


Figure 3.14: Variation of COD value of water at Sarulia intake and along the DND canal

TOC:

The Total Organic Carbon (TOC) concentrations were determined for samples collected on four different sampling date during the dry season. On 5 and 19 February 2007, TOC concentrations of water along the DND canal were mostly within 20 to 40 mg/L. However, on 5 March 2007, very high TOC concentrations of around 75 mg/L were found in all water samples along the DND canal. Figure 3.15 shows the variation of TOC concentration along the DND canal during the monitoring period. The BOD_5 to TOC ratio of typical domestic waste water varies from 1.0 to 1.6 (Metcalf and Eddy, 1991). However, very low BOD_5 to TOC ratios were found for almost all the samples. Except for one sample, all BOD_5 to TOC ratios were less than 1.0; many samples had BOD_5 to TOC ratio of around 0.2. The very low BOD_5 to TOC ratios possibly indicate the presence of high concentration of non-biodegradable organic matter, possibly from industrial sources.

Ammonia:

Figure 3.16 shows the variation of total ammonia concentration at the Sarulia intake and along the DND canal during the monitoring period. On any particular sampling day, ammonia concentration along the DND canal did not change significantly. Ammonia concentration showed an increasing trend as dry season progressed. On 12 March 2007, highest ammonia concentrations, varying from 10.5 to 11.1 mg/L, were recorded along the DND canal. Mean ammonia concentration of water samples varied from a low of 6.2 mg/L on 29 January 2007 to a high of 10.8 on 12 March 2007.

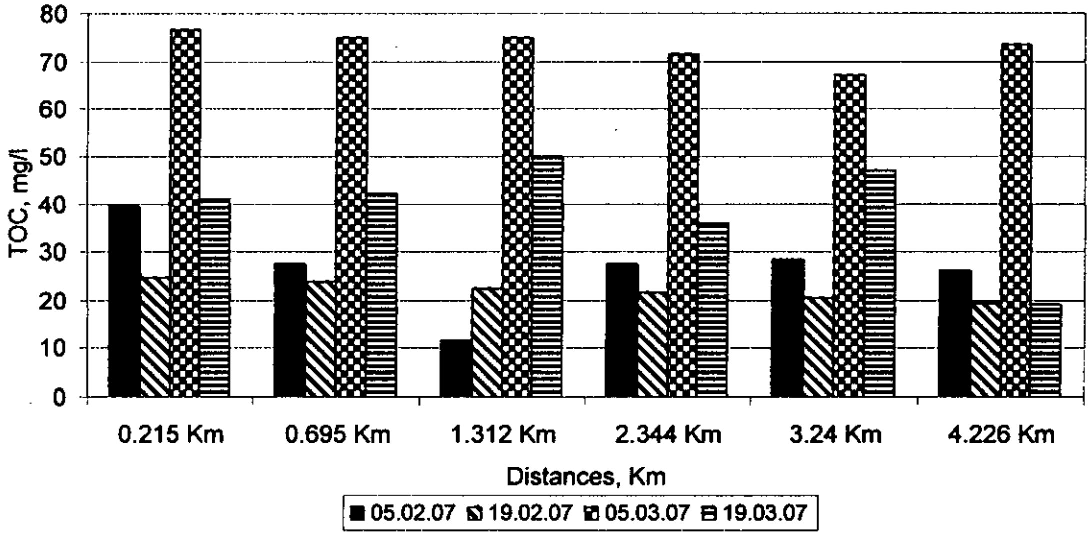


Figure 3.15: Variation of TOC concentration of water along the DND canal

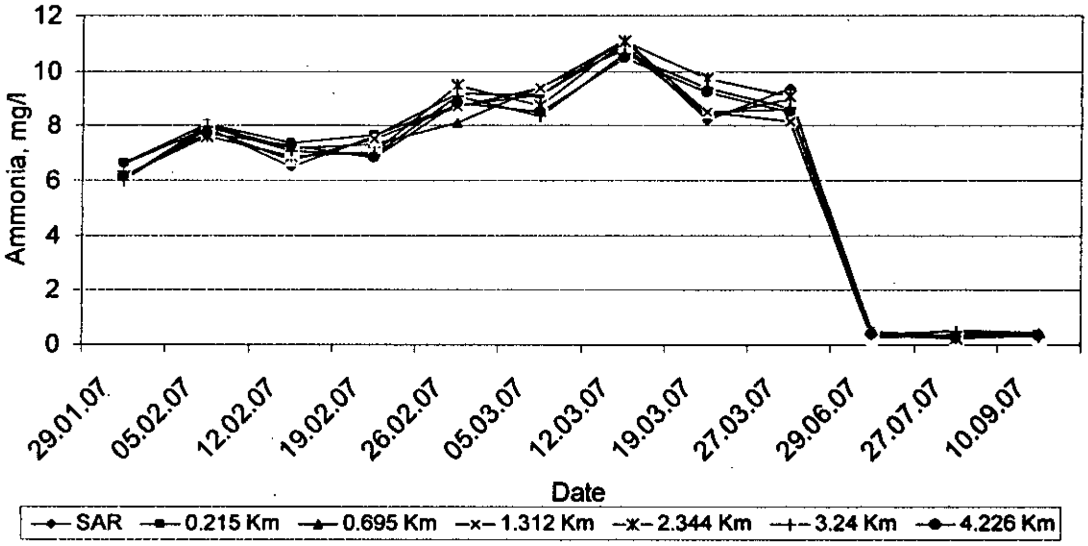


Figure 3.16: Variation of Ammonia concentration of water along the DND canal

Ammonia concentration along the DND canal decreased significantly during wet season (June to September); most Ammonia concentrations were around 0.3 mg/L during this period. Mean Ammonia concentration of different sampling dates varied over a narrow range of 0.36 on June 2007 to 0.37 on 27 July 2007.

As noted earlier, on a particular sampling date, Ammonia concentration did not change significantly along the canal; Ammonia concentration of water sample at the end of the DND canal (i.e. DND-6 location) is comparable to that of the sample collected from the Sarulia intake. It appears that conversion of ammonia to nitrate (through nitrification) within the DND canal is not significant (which is also supported by lack of change of nitrate concentration along the DND canal), and also there is no significant input of ammonia (e.g., from wastewater discharge) to the water along the DND canal. High ammonia concentration is a major concern at the SWTP during the dry season.

Nitrate:

Except for a couple of sampling dates, Nitrate concentration along the canal was low (below 0.3 mg/L). Relatively high concentrations were detected on 5 February (up to 1.2 mg/L), and on 27 March 2007 (up to 5.2 mg/L). Mean Nitrate concentration of water varied from a low of 0.1 mg/L on 19 February to a high of 2.6 mg/L on 27 March 2007.

During wet season, Nitrate concentration varied from a low of 0.4 to a high of 0.7 mg/L. Mean Nitrate concentration of different sampling dates varied over a narrow range of 0.47 mg/L on 29 June 2007 to 0.67 mg/L on 27 July 2007. Figure 3.17 shows the variation of Nitrate concentration at the Sarulia intake and along the DND canal during the monitoring period. In general, Nitrate concentration of water on a particular sampling date did not vary significantly along the DND canal, indicating insignificant conversion of ammonia to nitrate within the canal.

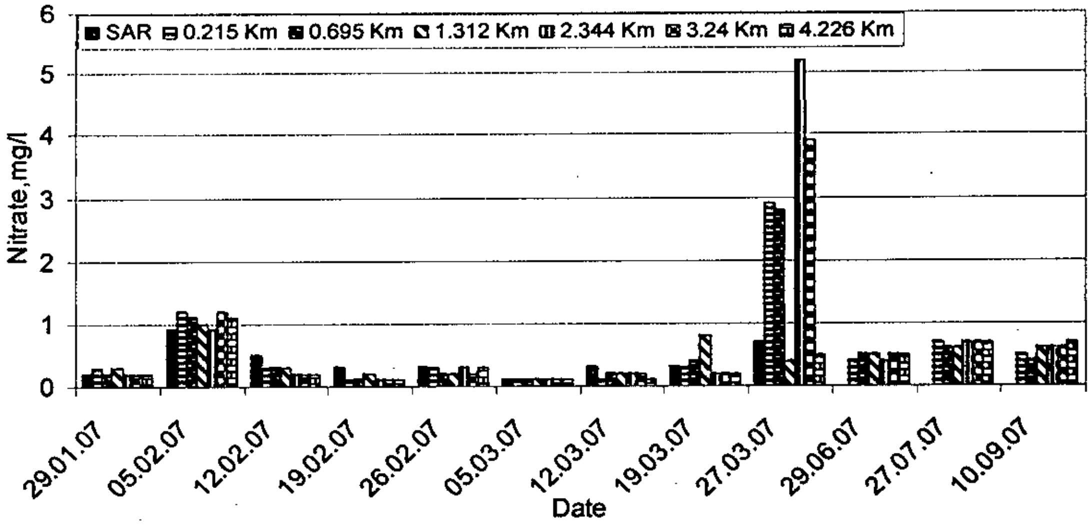


Figure 3.17: Variation of Nitrate concentration of water along the DND canal

Nitrite:

During dry season, Nitrite concentration along the DND canal, though mostly low, varied over a wide range (from 0.003 to 0.415 mg/L). Relatively high concentrations were recorded on 19 February, 19 and 27 March, 2007. Mean nitrite concentration of samples varied from 0.005 mg/L on 5 and 26 February 2007 to 0.208 mg/L on 27 March 2007. In general, nitrite concentrations at the end of the DND canal (i.e. DND-6 location) are comparable to those obtained for the samples collected from the Sarulia intake.

In wet season, Nitrite concentration increased slightly along the DND canal. The minimum Nitrite concentration of 0.028 mg/L was recorded at DND-1 location on 29 June 2007, while the maximum Nitrite concentration of 0.082 mg/L was recorded at DND-6 location on 10 September 2007. Mean Nitrite concentration on different sampling dates varied over a narrow range of 0.039 mg/L on 29 June 2007 to 0.062 mg/L on 10 September 2007. Figure 3.18 shows the variation of Nitrite concentration at the Sarulia intake and along the DND canal during the monitoring period.

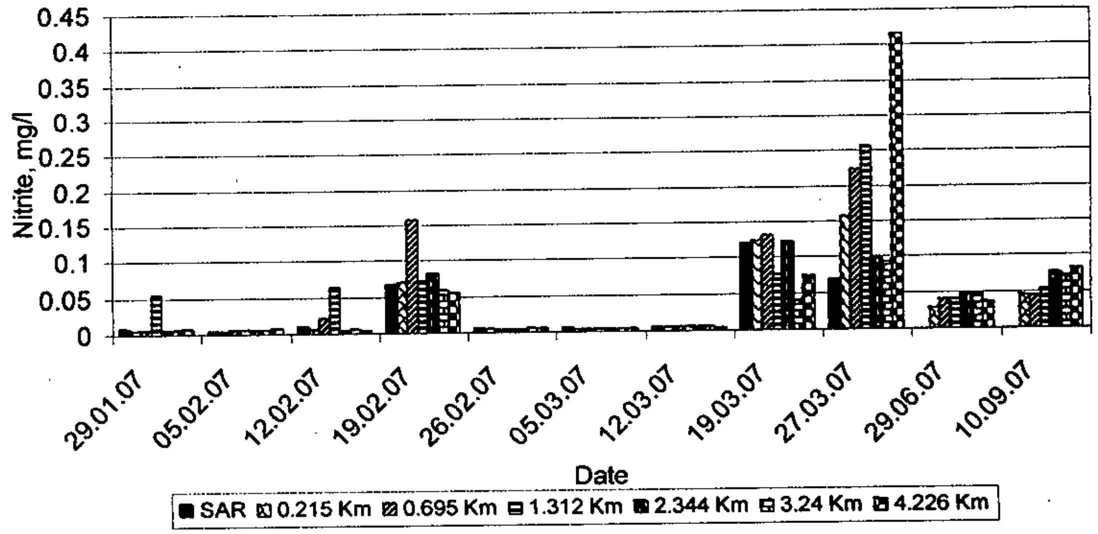


Figure 3.18: Variation of Nitrite concentration of water along the DND canal

Phosphate:

During dry season, Phosphate concentration along the DND canal varied from a low of 0.167 mg/L to a high of 2.95 mg/L; most phosphate concentrations were above 1 mg/L (Fig. 3.19). Except for one sampling date (5 February), phosphate concentration did not vary significantly along the canal. Since the DND canal is widely used for bathing and washing of clothes, some addition of phosphate from soap/detergent is anticipated. This is probably counteracted by phosphate removal from water column through sedimentation of suspended solids containing adsorbed phosphate. Phosphate concentration shows an increasing trend from January to March as dry season progresses (Figure 3.19). Mean phosphate concentration of water samples varied from a low of 0.45 mg/L on 5 February 2007 to a high of 2.23 mg/L on 27 March 2007.

Phosphate concentration along the DND canal decreased significantly during wet season. The maximum Phosphate concentration of 0.398 mg/L was recorded at DND-5 location on 29 June 2007. Mean Phosphate concentration of water samples varied from a low of 0.001 mg/L on 10 September to a high of 0.305 mg/L on June 2007.

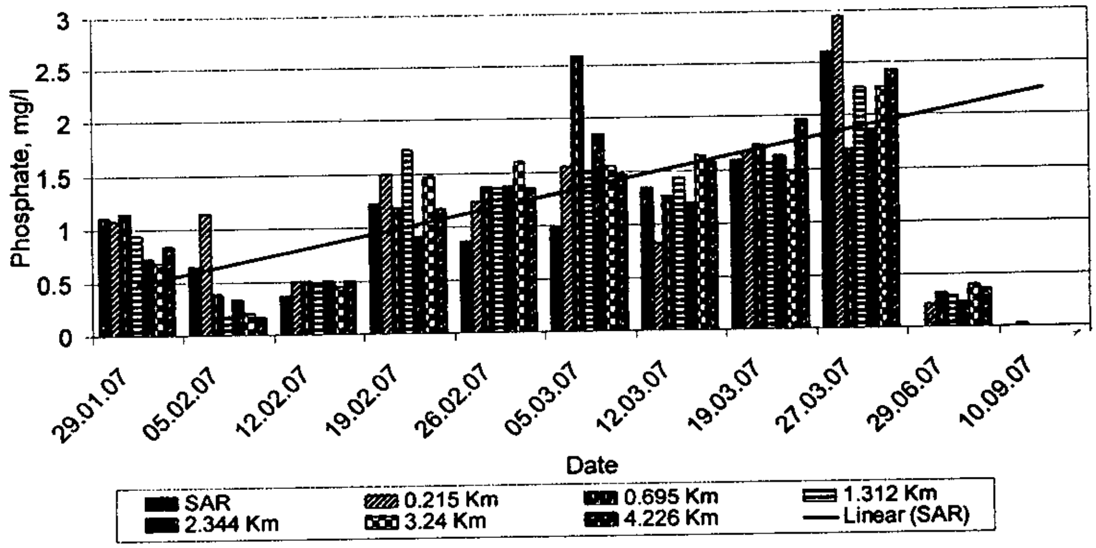


Figure 3.19: Variation of Phosphate concentration of water along the DND canal

Sulfate:

Sulfate concentration was measured only for samples collected on 27 March 2007. Sulfate concentration of water sample from the Sarulia intake was 47.3 mg/L, while those of water samples along the DND canal varied from 44.4 to 46.2 mg/L (Fig. 3.20). The minimum Sulfate concentration of 44.4 mg/L was recorded at DND-5 location, while the maximum Sulfate concentration of 46.2 mg/L was recorded at DND-1 location. Mean Sulfate concentration of different sampling points was 45.3 mg/L.

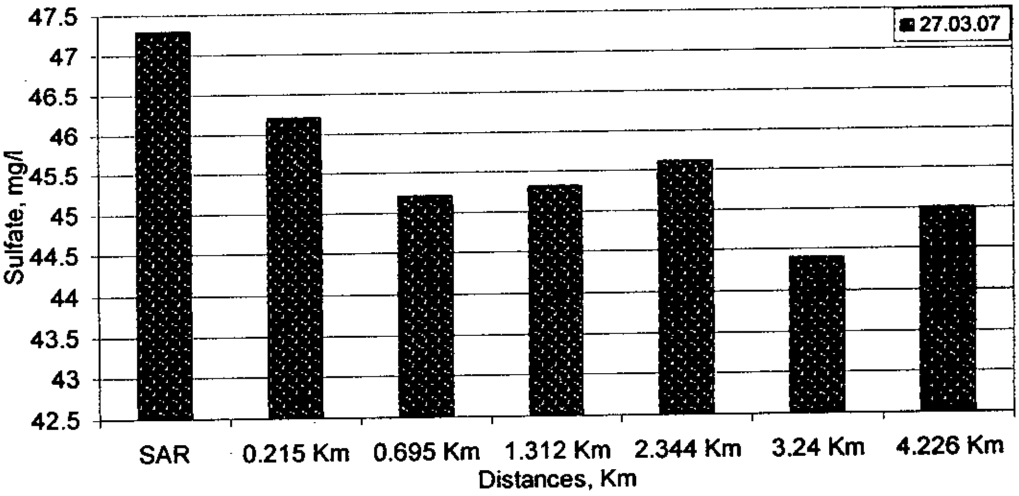


Figure 3.20: Variation of Sulfate concentration of water along the DND canal

Chlorophyll-A:

Water of DND canal contained very high concentrations of Chlorophyll-A during the dry season (January to March) and Chlorophyll-A concentration increased along the DND canal (Figs. 3.21a, b). On a number of sampling dates Chlorophyll-A concentration at DND-6 location was over three times that at DND-1 location. The minimum Chlorophyll-A concentration of 12.02 μg/L was recorded at DND-1 location on 29 January 2007, while the maximum Chlorophyll-A concentration of 116.8 μg/L was recorded at DND-6 location on 12 March 2007. Mean Chlorophyll-A concentration over the sampling period varied from a low of 36.7 μg/L at DND-1 location to a high of 61.4 μg/L at DND-6 location (Figure 3.21b). The significant increase of Chlorophyll-A within the DND canal is a major cause of concern.

As shown in Fig. 3.21a, Chlorophyll-A concentration shows an increasing trend during January to March as dry season progresses. With high ammonia and phosphate concentrations in water, the DND conveyance canal appears to be a fertile ground for algae growth during dry season.

Chlorophyll-A concentration along the DND canal decreased significantly in September (wet season). The minimum Chlorophyll-A concentration of 2.67 μg/L was recorded at DND-2 and DND-5 locations, while the maximum Chlorophyll-A concentration of 5.34 μg/L was recorded at DND-1 location on 10 September 2007. Mean Chlorophyll-A concentration on 10 September was 3.73 μg/L.

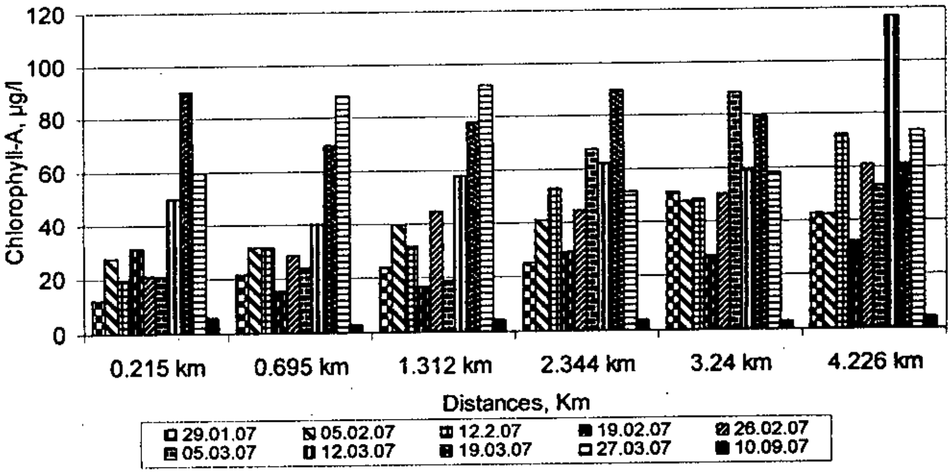


Figure 3.21a: Variation of Chlorophyll-A concentration of water along the DND canal during dry season

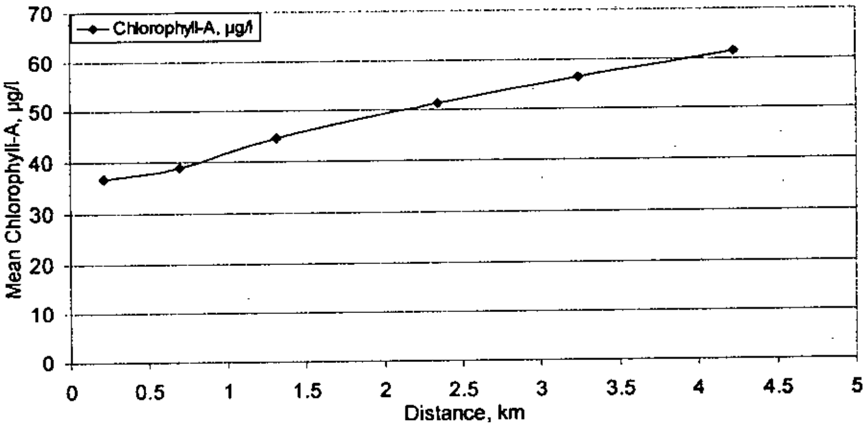


Figure 3.21b: Variation of mean Chlorophyll-A concentration along DND canal during the dry season

Heavy Metals:

Concentrations of four heavy metals (Copper, Cadmium, Lead and Chromium) were measured only for three water samples collected from the DND canal (DND-1, DND-3 and DND-5) locations on 10 September 2007. Heavy metal concentrations of the water samples are presented in Table 3.2

Copper: The water samples contained very low concentration of Copper and the concentrations appear to decrease progressively downstream of the canal. The Copper concentrations are much below the Bangladesh drinking water standard of 1 mg/L (DoE, 1997) as well as the WHO recommended health-based guideline value of 2 mg/L (WHO, 2004).

Cadmium: Cadmium concentration of the water samples were very low (Table 3.2), much lower than the Bangladesh drinking water standard of 0.005 mg/L (DoE, 1997) and the WHO recommended guideline value of 0.003 mg/L (WHO, 2004) based on health consideration.

Lead: Lead concentration of samples appears to decrease progressively along the canal. Lead concentrations at DND-1, DND-3 and DND-5 were 1.11, 0.55 and 0.18 µg/L, respectively. These Lead concentrations satisfy both the Bangladesh drinking water standard of 0.05 mg/L and the WHO guideline value of 0.01 mg/L (2004) based on health consideration.

Chromium: Chromium concentration of water at DND-1 location was 3.85 μg/L, while at DND-3 and DND-5 locations Cr concentration was below detection limit. Thus, the Chromium concentrations of water samples were well within the Bangladesh drinking water standard and the WHO guideline value of 0.05 mg/L.

Table 3.2: Metals concentration of water along DND canal

Metal	Unit	Concentration in water		
		DND-1	DND-3	DND-5
Copper (Cu)	mg/L	0.018	0.012	0.008
Cadmium (Cd)	mg/L	0.001	< 0.001	0.001
Lead (Pb)	μg/L	1.1	0.6	0.2
Chromium (Cr)	μg/L	3.9	< 1	< 1

3.3.2 Assessment of Sediment Quality of DND Canal

Sediment samples from the DND conveyance canal were collected from DND-1, 3 and 5 locations on 10 September 2007 and were analyzed for total (aqua-regia extractable) concentrations of 4 heavy metals - Copper, Cadmium, Lead and Chromium. Organic matter content and specific gravity of sediment samples were also determined. Besides, Sediment Oxygen Demand (SOD) of the samples was also estimated using an ex-situ method.

Organic Matter, Moisture Content and Specific Gravity:

Organic matter contents of sediment samples were varied from 1.05 to 4.35 (%). The sandy sediment from DND-3 location had the lowest organic content (1.05%), while the clayey samples from DND-1 and DND-5 location had relatively high organic contents (4.35 and 2.70%, respectively). Moisture content of the sediment samples varied from 25.7 to 40.2%, while specific gravity varied over a limited narrow range of 2.67 to 2.73.

Heavy Metals:

Copper (Cu), Cadmium (Cd), Lead (Pb) and Chromium (Cr) concentrations of the sediment samples are presented in Table 3.3. Copper concentrations of sediment samples at locations DND-1, DND-3 and DND-5 were found 57.8, 426 and 39.0 mg/kg, respectively. Common range of Cu concentration in natural soils is 2 to 100 mg/kg, while reported average concentration is 30 mg/kg (USEPA). Copper concentrations of sediment samples from location DND-1 and DND-5 are well within the common range but higher than the average concentration in natural soils; while very high Cu concentration is recorded for the DND-3 location. The significant variation of Cu concentration in the three samples suggest the necessity of more intensive sampling and analysis for better understanding of Cu concentration in sediments along the DND canal.

Cadmium concentrations at location DND-1, DND-3 and DND-5 were 0.5, 0.4 and 0.7 mg/kg, respectively. Common range of Cd concentration in natural soils is 0.01 to 0.7 mg/kg, while average concentration is 0.06 mg/kg (USEPA). Thus, Cd concentrations of sediment samples along the DND canal were much higher than the average concentration in natural soils, possibly indicating Cd accumulation in sediment from polluted water of Sitalakhya river.

Lead concentrations at location DND-1, DND-3 and DND-5 were 325, 8.8 and 22.4 mg/kg, respectively. Common range of Pb concentration in natural soils is 2 to 200 mg/kg, while average concentration is 10 mg/kg (USEPA). Lead concentration of sediment sample at the DND-1 location was significantly higher than the common range. Thus, like Cu, the wide variation of Pb concentration in sediment samples suggest the necessity of more intensive sampling and analysis for better understanding of Pb concentration in sediments.

Chromium concentrations at location DND-1, DND-3 and DND-5 were 13.63, 4.55 and 7.64 mg/kg, respectively. Common range of Cr concentration in natural soils is 1 to 1000 mg/kg , the average concentration is 100 mg/kg (USEPA). Thus, Cr concentrations of sediment samples along the DND canal are well below the average concentration in natural soils.

Table 3.3: Sediment quality along DND canal

Paramcter	Unit	DND-1	DND-3	DND-5
Organic Matter (%)	%	4.35	1.05	2.70
Moisture Content (%)	%	40.2	25.7	32.2
Specific Gravity	--	2.71	2.73	2.67
Copper (Cu)	mg/kg	57.8	426	39
Cadmium (Cr)	mg/kg	0.5	0.4	0.7
Lead (Pb)	mg/kg	325	8.8	22.4
Chromium (Cr)	mg/kg	13.6	4.55	7.64

Sediment Oxygen Demand (SOD):

Sediment Oxygen Demand (SOD) is the sum of all biological and chemical processes in sediment that utilize (take up) oxygen. SOD is useful in measuring the depletion of oxygen in waters. Sediment oxygen demand (SOD) has been defined as the rate of oxygen consumption, biologically or chemically, on or in the sediment at the bottom of a water body. SOD measurements have been demonstrated to vary between sites. In some rivers, SOD accounts for as much as 50 percent of the total oxygen depletion, making SOD a critical element in water quality modeling studies. SOD is therefore an integral part of assessing the quality of water in a system. The sources of oxygen demand in sediment include organic and inorganic molecules that can be oxidized biologically and chemically in the sediment. The rates of oxygen diffusion through sediment typically limit SOD in a system at base flow when sediment is at steady state, but during storm flow, sediment is re-suspended, resulting in dramatic increases in SOD and associated low DO in the water column. Oxygen demand from sediment (SOD) for a river typically has two states – diffusion limited SOD (SOD) and potential SOD (pSOD), expressed when sediment is re-suspended through increased flow or other disturbances. Sites with high sediment deposition potential had high SOD. Potential SOD can serve as an indicator of the possible impact of SOD from re-suspended sediment in stream systems.

The laboratory SOD measurements of sediment samples following the procedure outlined by Matlock et al. (2003) differ from traditional ex-situ measurement in that the sediment was intentionally suspended in the measurement vessel to remove diffusion limitations. This suspension allowed oxygen to be consumed at a maximum rate, much like it would in a re-suspension event in the canal. The oxygen concentration versus time curve for sediment samples from 3 different locations (DND-1, 3 and 5) are shown in Figs. 3.22 to 3.24. These figures show that there is a large initial consumption of oxygen followed by a decreased rate of consumption as oxygen becomes limiting.

As noted earlier, the sediment samples from DND-1 and DND-5 were clayey in nature having relatively higher organic matter content, while that from DND-3 was sandy having relatively low organic content (Table 3.3). The rate of oxygen consumption was much faster for the clayey sediments collected from DND-1 and DND-5 location, compared to that for the sandy sample collected from DND-3 location. The initial rate of oxygen demand, commonly referred to as potential SOD (pSOD), is the SOD that is generally not realized in a stream because sediment is oxygen diffusion limited. Potential SOD was calculated by expressing the rate of oxygen demand of the sediment sample in g O_2 consumed / m^3 sediment/day.

The calculated mean pSOD values of the three sediment samples (Table 3.4) varies from 639 (DND-3 sediment) to 6977 (DND-5 sediment) g O_2/m^3 sediment/day. These values can be compared to the pSOD values of Arroyo Colorado river reported by Matlock et al. (2003). Matlock et al. (2003) reported pSOD of sediment from Colorado river ranged from 19.2 to 2779.2 g O_2/m^3 sediment/day. Table 3.4 shows that the pSOD of the clayey sediment of DND canal (DND-1 and DND-5) are much higher than the highest value reported for Colorado river, indicating very high oxygen demand of sediments of the DND conveyance canal.

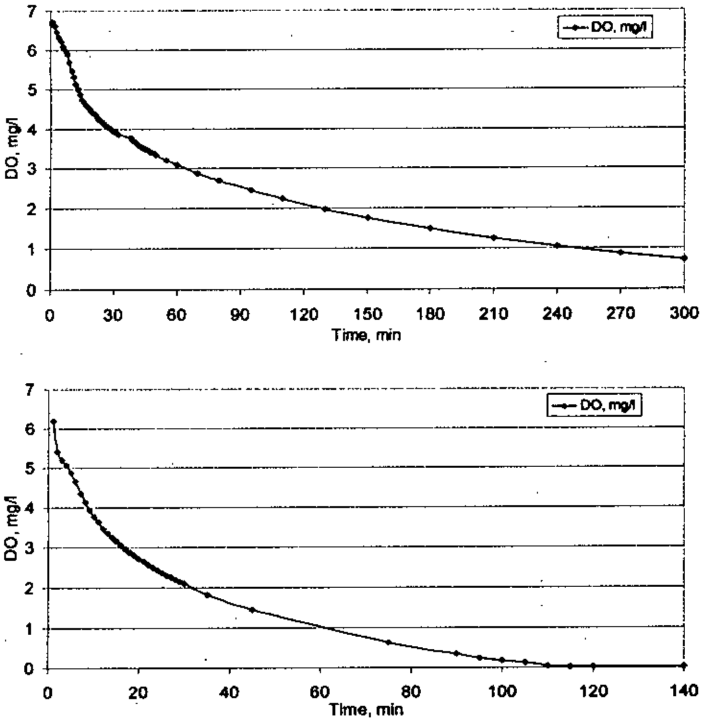


Figure 3.22: Dissolved oxygen concentration versus elapsed time curve for sediment from DND-1 location: (a) 5 gm sediment, (b) 10 gm sediment

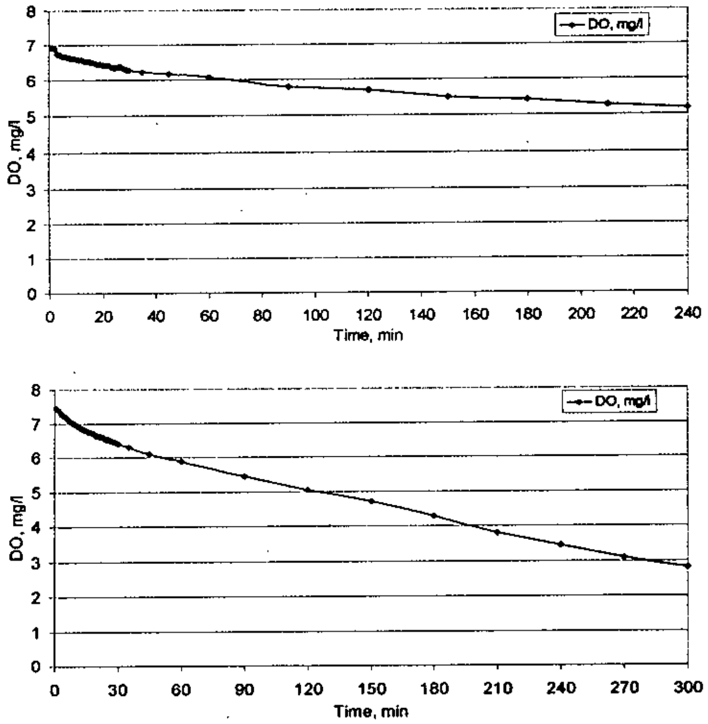


Figure 3.23: Dissolved oxygen concentration versus elapsed time curve for sediment from DND-3 location: (a) 5 gm sediment, (b) 10 gm sediment

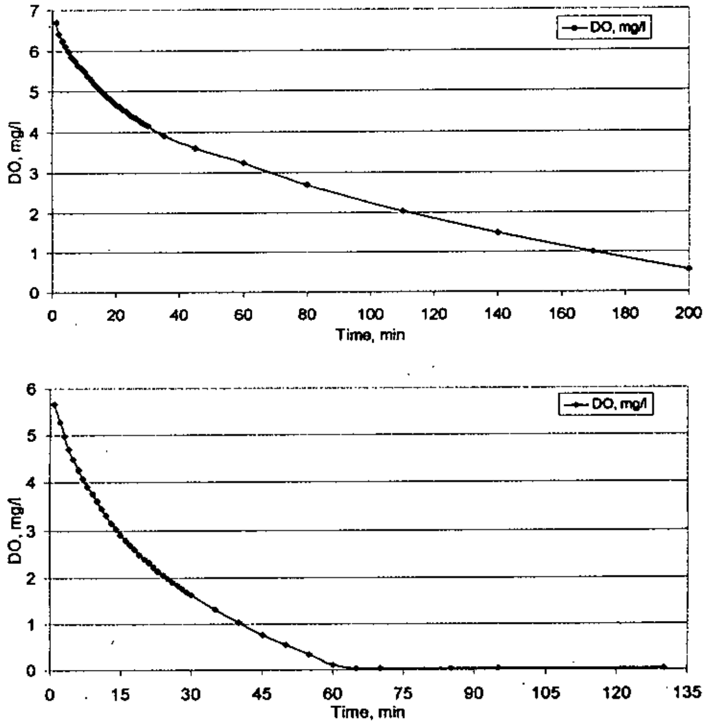


Figure 3.24: Dissolved oxygen concentration versus elapsed time curve for sediment from DND-5 location: (a) 5 gm sediment, (b) 10 gm sediment

Table 3.4: Sediment Oxygen Demand (SOD) along the DND canal

Location	SOD, mg O_2/g sediment/day (5 gm sample)	SOD, mg O_2/g sediment/day (10 gm sample)	Mean SOD	
			mg O_2/g sediment/day	g O_2/m^3 sediment/day
DND-1	1.728	1.907	1.818	4927
DND-3	0.246	0.222	0.234	639
DND-5	2.66	2.565	2.613	6977

Many variables such as sediment size, subsurface flow, heterogeneity of sediment and variability in SOD are not considered during pSOD measurements. When the limits of diffusion no longer exist (as occurs during a re-suspension event), very large oxygen consumption events can occur very rapidly. The utility of measuring pSOD is the ability to estimate the DO demand of a reach of stream during a re-suspension event. While several gross simplifications, such as assumptions of homogeneity of stream sediment and suspension mass would be required, this approach provide increased insight into the temporal and spatial impact of SOD on stream oxygen demands (Matlock et al., 2003). The very high pSOD values estimated in this study is a cause of concern.

3.4 SUMMARY

The water quality of Sitalakhya river and the DND canal becomes very poor during the dry season (January to March), and is characterized by high concentrations of BOD_5, COD, TOC, Ammonia and Chlorophyll-A (algae); and low concentrations of DO. Water quality appears to deteriorate progressively from January to March as dry season progresses. Concentrations of a number of water quality parameters increases during this period; these parameters include BOD_5, Ammonia, Phosphate, Chloride and Dissolved Solids. Water quality within the DND canal does not appear to change significantly during the dry season, except for Chlorophyll-A. The concentration of Chlorophyll-A increases by a factor of 2 to 3 within the 4.6 km stretch of the canal.

During the wet season (June to September), water quality of Sitalakhya river and DND canal improves significantly due to rainfall and freshwater inflow from upstream, which results in significant reduction of BOD_5, COD, Ammonia and Chlorophyll-A concentrations and an increase in DO concentration. For example, compared to March

2007, concentrations of BOD and Ammonia were reduced by factors of about 10 and 30 respectively in September 2007. Concentrations of a number of other water quality parameters are also reduced significantly during this period due to dilution by rainwater and upstream flow. These parameters include Chloride, Alkalinity, Total Dissolved Solids, Phosphate; pH value of water also drops during the wet season. Low concentration of Cu, Cd, Pb and Cr were detected in the water samples collected from the DND canal.

The Suspended Solids concentration in the Sitalakhya river increases significantly during the wet season. However, the DND canal appears to be very effective in reducing the SS concentration, up to 80% reduction of SS concentration was recorded within the DND canal.

The potential sediment oxygen demand (pSOD) of sediments estimated for the sediment samples of the DND canal was found to be very high. The sediments of the canal therefore could exert significant oxygen demand on the water, especially during re-suspension events.

CHAPTER 4

ASSESSMENT OF TREATMENT PROCESSES AND THM FORMATION POTENTIAL AT SWTP

4.1 INTRODUCTION

At the Saidabad water treatment plant (SWTP), the processes involved in the treatment include: (i) pre-chlorination and pH adjustment (with lime, if necessary) of the raw water, (ii) coagulation with alum in a pulsating clarifier; (iii) filtration of the water coming from the clarifier; and finally (iv) post-chlorination and pH-adjustment (if necessary) of the water before its introduction in the distribution system (Fig. 4.1).

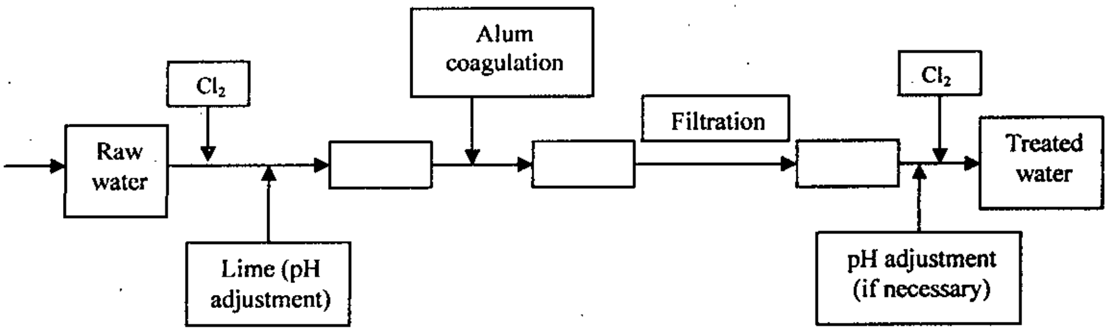


Figure 4.1: Treatment process at SWTP

As discusses in Chapter 2, the quality of the raw water drawn through the intake structure varies significantly over the year and this affects the efficiency of treatment at the plant and the quality of treated water. Doses of alum and chlorine used at the plant also depend on the quality of raw water. At the SWTP, the inflow rate of raw water is 10100 m^3/hr and outflow rate of treated water is 9800 m^3/hr. The detention time of water within the treatment plant is about 1.94 hours, which include 1.70 hrs in the clarifier and 0.18 hrs in the filter.

As discussed in Chapter 2, the raw water quality deteriorates significantly during the dry season (January to March) and during this period high alum dose of up to 60 mg/L is used in the coagulation process. During wet season, when water quality improves, the alum dose comes down to below 30 mg/L. Chlorine dose also varies depending on the water quality.

As discussed in Chapter 2, chlorination of raw surface water is a general practice in conventional water treatment to control bacterial and algal growth. A number of studies have revealed the formation of trihalomethanes (THMs) during chlorination of drinking water (Symons et al., 1975; El-Dib and Ali, 1994; Shin et al., 1999; Rizzo et al., 2005). THMs have carcinogenic properties and could affect public health (WHO, 1984). Consequently, potential formation of THMs is a major concern at the SWTP.

This Chapter presents an assessment of the efficiency and impacts of applied treatment processes on the water quality at the SWTP through intensive sampling and analysis of water samples from different points within the treatment plant during the critical dry season. Trihalomethane Formation Potential (THMFP) at the SWTP water were also evaluated employing different available models and also through limited laboratory measurements.

4.2 METHODOLOGY

For assessment of treatment processes at the SWTP, raw and treated water qualities were intensively monitored during the dry season (January to March) of 2007. The monitoring of water quality at the SWTP was carried out over a period of nine weeks, starting on 31 January 2007 and ending on 28 March 2007. Within the SWTP, water quality was monitored once a week at the raw water intake point, at three locations within the treatment processes and at treated water tap after post-chlorination. For evaluating THMFP, THM precursors (e.g., TOC, DOC, bromide and UV_{254}) of water samples collected from the DND conveyance canal were measured in both dry and wet seasons. THMFP was estimated following the model of Amy et al. (1998), which is based on concentrations of DOC, Cl_2, Bromide, temperature, pH and contact time with chlorine dose. In addition, THMFP was also estimated using UV_{254} and DOC concentrations, following the method used by Yoon et al. (2003).

4.2.1 Sample Collection and Analysis

Collection of Water Samples

Water samples were collected from 5 locations within the SWTP. Raw water samples entering the SWTP were collected from the raw water intake pit of the plant (Photograph 4.1) and treated water samples (after post-chlorination) were collected from the tap located at the plant laboratory (Photograph 4.6). In addition, the water quality at the treatment plant was monitored at the following three locations, once a week for nine weeks.

(1) After alum dose, just before water flows into the blue distribution pipe to the pulsators (sampling point SWTP-1, Photograph 4.3);

(2) After the pulsators, just before water enters one of the filter beds, fed by the same pulsator (sampling point SWTP-2, Photograph 4.4); and

(3) Filtrate of the above filter (sampling point SWTP-3, Photograph 4.5). It was ensured that the specific filter has been in operation for more than one hour after backwash.

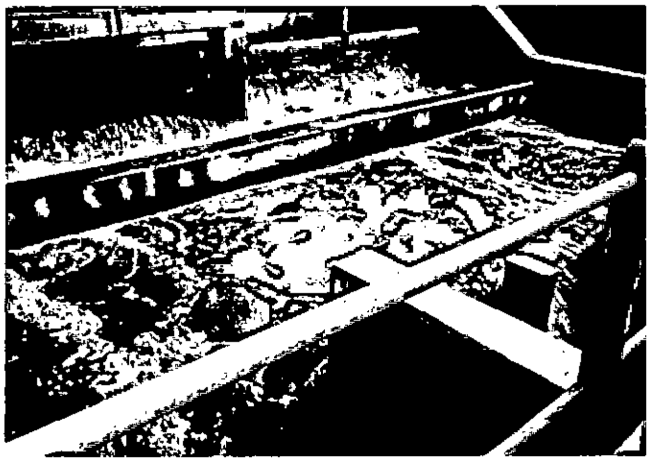
During each sampling campaign, water samples were collected in the morning (between 8:00 to 10:00 a.m.) from the first point (i.e. after alum dose), then from the second point (i.e. before filter) after about 30 minutes, and then from the third point (i.e. after filter) after about 20 minutes. These water samples were tested for pH, Chloride, DO, COD, TOC, EC, Suspended Solids, TDS, Sulfate, Sulfide, Ammonia, Nitrate, Nitrite, Phosphate, Alkalinity, Chlorophyll-A, Phytoplankton, Aluminum, Chromium, Nickel, Temperature, Total Chlorine and Free Chlorine. The pH and DO measurements were carried out in the field. TOC analysis was carried out on samples collected on every alternate week beginning from the second week of sampling.

Water samples collected from the intake pit and treated water tap of the SWTP during each sampling campaign were analyzed for pH, DO, Suspended Solids, Ammonia, Nitrate, Nitrite, Phosphate and Chlorophyll-A. The pH and DO measurements were carried out in the field.

Water samples from the SWTP were collected once a week for 9 weeks on 31 January, 6 February, 13 February, 20 February, 27 February, 6 March, 13 March, 20 March and 28

March of 2007. In addition, for estimation of THM formation potential water samples were collected from the DND canal on 29 June 2007 (wet season) and 26 February 2008 and analyzed for Bromide; samples collected on 10 September 2007 were analyzed for DOC; and samples collected on 10 September 2007 and 26 February 2008 were analyzed for UV_{254}.

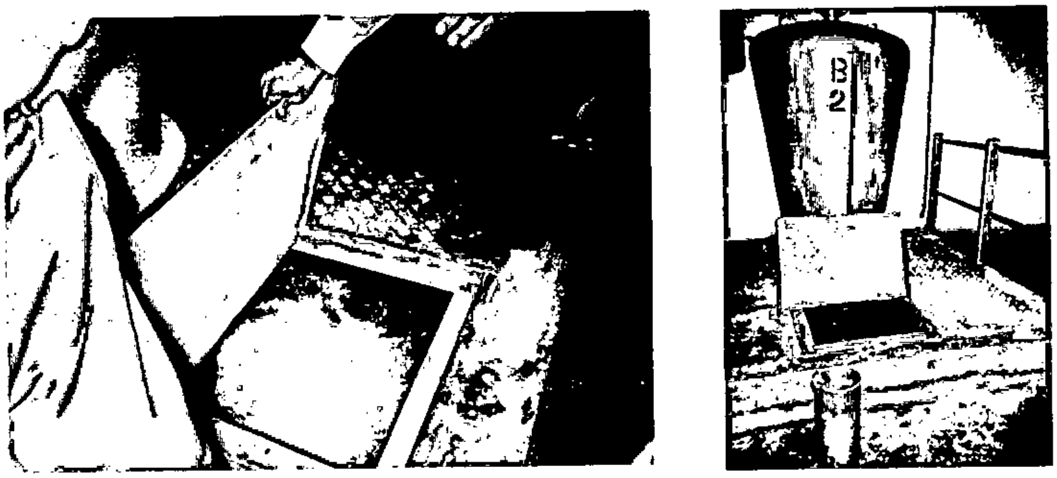
Photograph 4.1: Raw water intake pit at SWTP



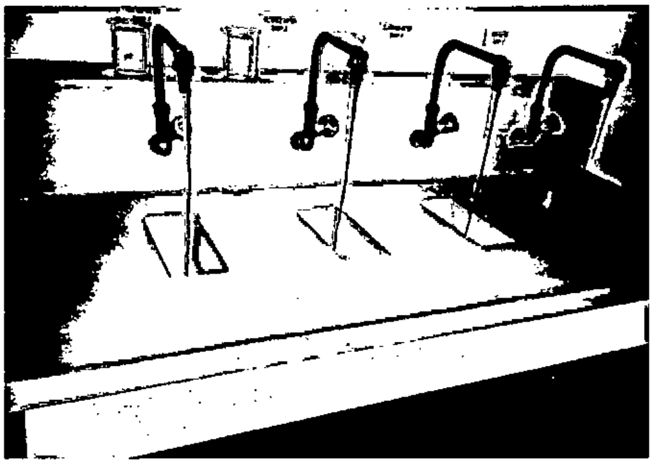
Photograph 4.2: Alum mixing at SWTP

Photograph 4.3: After alum dose (sampling point SWTP-1)

Photograph 4.4: After the pulsators (sampling point SWTP-2)



Photograph 4.5: Filtered water (sampling point SWTP-3)



Photograph 4.6: Treated water after post-chlorination-1st tap from left

Analysis of Water Samples

In the field, pH was measured with a pH meter (Geotech) attached with a pH electrode (WTW. SenTix 41); DO was measured with a DO meter (Hach). In the Environmental Engineering Laboratory of BUET, Ammonia, Nitrate, Nitrite, Phosphate, Sulfate Sulfide and UV_{254} concentrations were measured with a Spectrophotometer (HACH, DR4000U). Ammonia was measured by the Nessler method, Nitrate by the Cadmium Reduction Method, Nitrite by the Diazotization method, Phosphate by the Molybdenum Blue method, Sulfate by the Sulfa Ver 4 method, and sulfide by the Methylene Blue method. The Total Organic Carbon (TOC) concentration was also measured by the Spectrophotometer using the Direct Method (Method 10129). Electrical Conductivity was measured with a conductivity meter (Hach). Aluminum (Al), Nickel (Ni), and Chromium (Cr) concentrations were determined with an Atomic Absorption Spectrophotometer (Shimadzu, AA6800). Other parameters were measured following Standard Methods. UV_{254} absorbance was measured with a Spectrophotometer (HACH, DR 4000U) by the Direct Reading Method (Method 10054).

Chlorophyll-A (algae) and phytoplankton concentrations were measured by the Environmental Microbiological Laboratory of ICDDR,B, Dhaka. Water samples collected for Bromide analysis were sent to EAWAG, Switzerland for analysis of Bromide, as facilities for bromide measurements are not available at the Environmental Engineering Laboratory of BUET. These samples were measured after 0.45 μm filtration (Nylon) by ion chromatography with chemically suppressed conductivity using a Dionex AS19 column fitted with a pre-column. The hydroxide eluent was generated online (RFIC-Technology). DOC concentrations were measured at the Plasma Plus Laboratory located in Uttara using a TOC analyzer.

THM concentration in 4 water samples was measured on 5 April 2008. Three of these water samples were collected from SWTP; two were treated water samples (after post chlorination) and one was filtered water (before post chlorination). The other sample was collected from a residence at 42 Siddeswari Road, Dhaka, an area receiving water from the SWTP. In the Environmental Engineering Laboratory of BUET, THM concentrations of these water samples were measured with a Spectrophotometer (HACH, DR 4000U) following THM Plus^{TM} method. In addition, Ammonia and Total Chlorine concentrations of these water samples were also measured.

Break Point Chlorination

Break Point Chlorination experiments were carried out to determine the characteristics of chlorine demand of raw water at the SWTP. For this purpose, water samples were collected from the raw water intake pit of the SWTP on 6 March and 13 March of 2007.

4.2.2 Evaluation of THM Formation Potential

Trihalomethanes (THMs) are formed during the chlorination of drinking water. THM formation potential at the SWTP may be assessed based on information on raw water quality and chlorination process used. This section briefly describes the various models for evaluation of THM formation potential as well as chlorination process at SWTP.

Chlorination at SWTP

At the SWTP, the treatment process employs pre-chlorination and post-chlorination for disinfection. Chlorine dose varies with raw water quality. During dry season when water quality becomes worse, pre-chlorination dose varies from 6 to 7 mg/L and post-chlorination dose is maintained at about 0.30 mg/L. In the wet season when water quality improves, pre-chlorination dose varies from 3 to 4.5 mg/L and post-chlorination dosage is maintained at about 0.50 mg/L.

THM Formation Potential based on Amy et al. (1998) Method

Amy et al. (1998) present statically-based empirical models for predicting the total trihalomethanes (TTHM) formation, as well as formation of individual trihalomethane species in raw/untreated waters. These predictive models for raw/untreated sources are based on data derived from eleven source waters. DOC provided better correlations than UV absorbance as a precursor parameter. Other parameters in the models are chlorine dose, bromide concentration, temperature, pH and contact time. Predictive raw water models for Total THMs (TTHM) and THM species are presented below (Amy et al., 1998).

$$[\mathrm{TTHM}] = 10^{-1.385}[\mathrm{DOC}]^{1.098}[\mathrm{Cl_2}]^{0.152}[\mathrm{Br^-}]^{0.068}\mathrm{Temp}^{0.609}\mathrm{pH}^{1.601}t^{0.263} \tag{4.1}$$

$$[\mathrm{CHCl_3}] = 10^{-1.205}[\mathrm{DOC}]^{1.617}[\mathrm{Cl_2}]^{0.094}[\mathrm{Br^-}]^{-0.175}\mathrm{Temp}^{0.607}\mathrm{pH}^{1.403}t^{0.306} \tag{4.2}$$

$$[\mathrm{CHBrCl_2}] = 10^{-2.874}[\mathrm{DOC}]^{0.901}[\mathrm{Cl_2}]^{0.017}[\mathrm{Br^-}]^{0.733}\mathrm{Temp}^{0.498}\mathrm{pH}^{1.511}t^{0.199} \tag{4.3}$$

$$[\mathrm{CHBr_2Cl}] = 10^{-5.649}[\mathrm{DOC}]^{-0.226}[\mathrm{Cl_2}]^{0.108}[\mathrm{Br^-}]^{1.81}\mathrm{Temp}^{0.512}\mathrm{pH}^{2.212}t^{0.146} \tag{4.4}$$

$$[\mathrm{CHBr_3}] = 10^{-7.83}[\mathrm{DOC}]^{-0.983}[\mathrm{Cl_2}]^{0.804}[\mathrm{Br^-}]^{1.765}\mathrm{Temp}^{0.754}\mathrm{pH}^{2.139}t^{0.566} \tag{4.5}$$

The boundary conditions for the TTHM and THM species models are listed below.

[TTHM] = Total Trihalomethanes (μg/l)

$[\mathrm{CHCl_3}]$, $[\mathrm{CHBrCl_2}]$, $[\mathrm{CHBr_2Cl}]$, $[\mathrm{CHBr_3}]$ = Individual concentrations of THM species (μg/L)

[DOC] = Dissolved Organic Carbon (mg/L); $1.2 \leq [\mathrm{DOC\ (mg/L)}] \leq 10.6$

$[\mathrm{Cl_2}]$ = Applied Chlorine (mg/L); $1.51 \leq [\mathrm{Cl_2\ (mg/L)}] \leq 33.55$

$[\mathrm{Br^-}]$ = Concentration of Bromide (μg/L); $7 \leq [\mathrm{Br^-}\ (\mu g/L)] \leq 600$

Temp = Incubation Temperature (°C); $15 \leq \mathrm{Temp} \leq 25$

pH: $6.5 \leq \mathrm{pH} \leq 8.5$

t = Incubation Reaction Time (hour); $2 \leq t \leq 168$

The weight-based model for predicting Total THM (TTHM) formation in raw /untreated water is presented in Eq. 4.1. The model is based on 11 source waters and a total of 786 cases. It includes six independent variables; dissolved organic carbon (DOC), chlorine dose ($\mathrm{Cl_2}$), ambient/spiked bromide levels ($\mathrm{Br^-}$), temperature (Temp), pH and reaction time (t). Based on the exponents associated with the models, each of the independent variables exerts a positive influence on total THM formation. The TTHM model exhibited a good coefficient of determination, $R^2 = 0.90$.

The development of THM speciation models can provide an indirect means of estimating Total THM formation (summation of individual species), can help describe the relative importance of each THM component behaviour under various conditions, and can elucidate the influence of bromide ion on THM species distribution. Equations 4.2 to 4.5 show weight-based models for predicting individual THM species formation. The R^2 values for the three models which predict chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$) and dibromochloromethane ($CHBr_2Cl$) formation range from 0.87 to 0.90, while for bromoform ($CHBr_3$), the R^2 was only 0.61.

From the relationship between the summation of predicted THM individual species (from individual species models) versus TTHM from the overall models, it is apparent that both approaches have merit, although the TTHM model is superior in predictive capability based on its R^2 (0.90) compared to the R^2 (0.61-0.90) values for each of the four species models. The summation approach tends to over predict.

THM Formation Potential from UV_{254}

THM formation potential from both DOC concentration and UV_{254} were developed by Yoon et al. (2003) from relationship of THMFP7 with UV_{254} and DOC for water supplies of US and Korea.

UV_{254} absorbance indicates the extent of aromaticity and has been considered a measure of THMFP (Korshin et al., 1997; Najm et al., 1994). Figure 4.2 shows the graph from Yoon et al. (2003), which has been plotted using the US data from Amy et al. (1987), Edzwald et al. (1985) and Singer et al. (1981). For assessing THM formation potential from this relationship, a straight line has been drawn through the data to describe the relationship between UV_{254} and THM formation; the line can be described as:

$$THMFP7 = 1875 * UV_{254} \qquad (4.6)$$

If UV_{254} absorbance of a sample is measured, then using Eq. 4.6 THM formation potential level at 7 days (THMFP7) can be calculated.

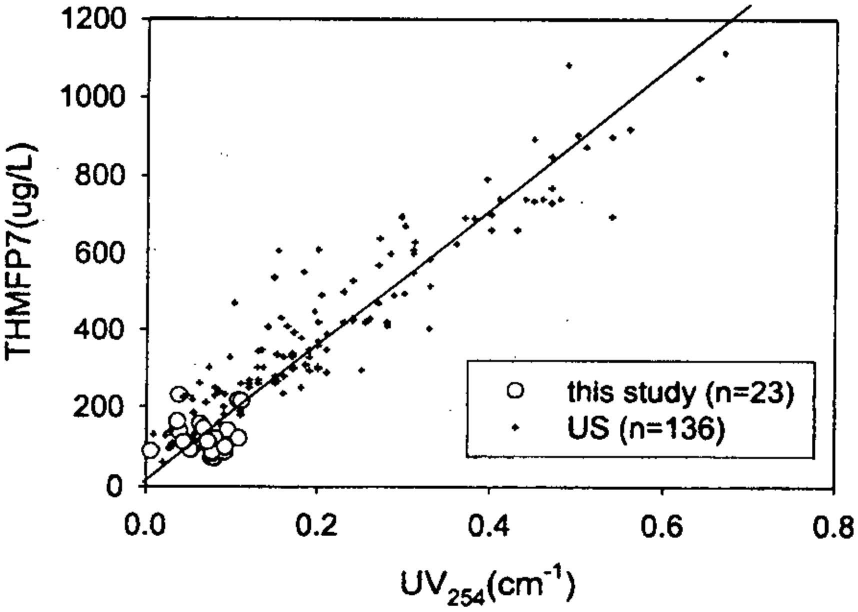


Figure 4.2: THMFP7 as a function of UV_{254} absorbance (Yoon et al., 2003)

THM Formation Potential from DOC Concentration

Figure 4.3 shows the graph from Yoon et al. (2003), which has been plotted using the US data from Amy et al. (1987), Edzwald et al. (1985) and Singer et al. (1981). For assessing THM formation potential from this relationship, a straight line has been drawn through the data to describe the relationship between DOC and THM formation; the line can be described as:

$$THMFP7 = 71.67 * DOC \qquad (4.7)$$

If DOC concentration of a sample is measured, then using Eq. 4.7, THM formation potential level at 7 days (THMFP7) can be calculated.

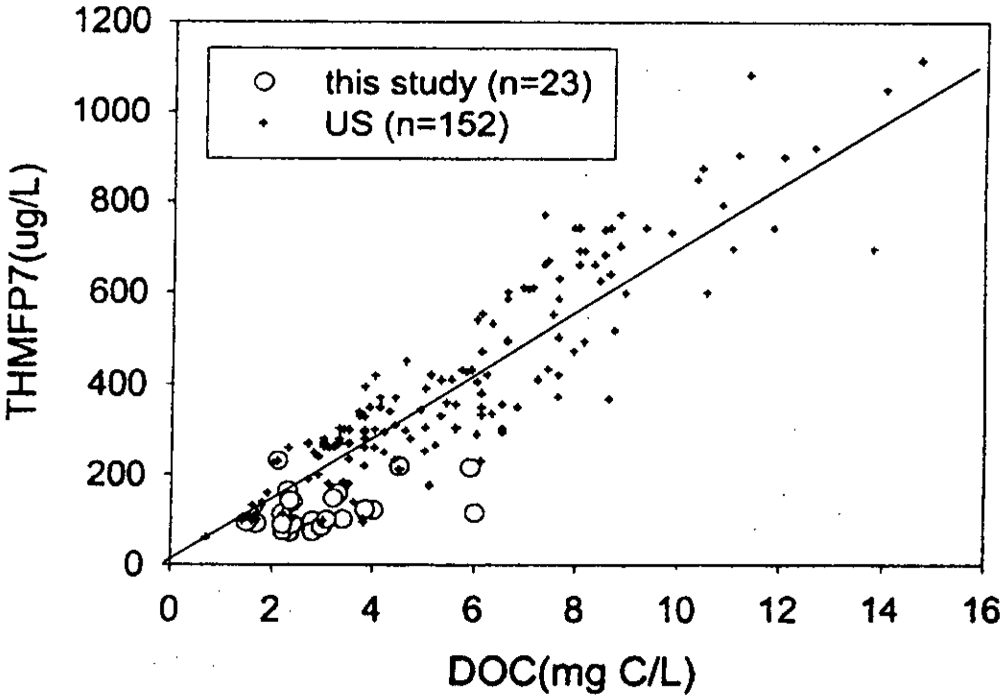


Figure 4.3: THMFP7 as a function of DOC (Yoon et al., 2003)

4.3 RESULTS AND DISCUSSION

The test results of water samples collected from the SWTP over the sampling period are presented in Appendix C; results of water quality analysis made in connection with estimating THMFP are presented in Appendix D. The following sections provide analyses of these test results.

4.3.1 Water Quality at SWTP

As noted earlier, the water quality at the treatment plant was monitored once a week for nine weeks at 5 locations: (i) intake pit (SWTPI); (ii) After alum dose, just before water flows into the distribution pipe to the pulsators (SWTP-1); (iii) After the pulsators, just before water enters one of the filter beds fed by the same pulsator (SWTP-2); (iv) Filtrate of the above filter (SWTP-3); and (v) treated water after post-chlorination (SWTPO). This section provides an assessment of the treatment processes at the SWTP based on the result of analysis of water samples collected from different points within the treatment plant.

pH:

Table 4.1 shows the pH values of water samples collected from different points within the monitoring period. The pH values of water samples of the inlet pit varied from 7.20 to 7.81. Some lowering of pH occurred during the treatment processes (e.g., due to chlorination and alum coagulation) in the SWTP. The pH values of water samples collected from SWTP-1 (after alum coagulation) varied from 6.72 to 7.60; for SWTP-2 and SWTP-3, pH varied from 6.11 to 7.60 and 6.96 to 7.7, respectively. The pH values of treated water samples (after post chlorination) varied from 6.86 to 7.7. Since pH for treated water samples lied within the range of 6.5 to 8.5, it satisfied both the Bangladesh drinking water standard and the WHO guideline value (not based on health consideration).

Table 4.1: pH value of water at the SWTP

Sampling Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	7.81	7.44	7.23	7.65	7.22
06.02.07	7.60	7.60	7.60	7.70	7.70
13.02.07	7.20	6.91	6.89	6.97	6.86
20.02.07	7.38	7.11	7.08	7.13	7.08
27.02.07	7.54	6.97	6.93	6.98	6.94
06.03.07	7.50	6.75	6.74	7.18	6.98
13.03.07	7.50	6.72	6.67	6.96	7.12
20.03.07	7.68	7.19	6.11	7.24	7.34
28.03.07	7.53	6.96	6.78	7.01	7.21

Chloride:

Chloride concentration was measured only for samples collected on 31 January 2007 (dry season). Chloride concentration within the SWTP did not change significantly. Raw water (inlet pit) had a Chloride concentration of 43 mg/L. Chloride concentration of water samples within the treatment plant were 52 mg/L at all 3 sampling locations within the plant (SWTP-1 to 3). The slight increase in Chloride concentration is most likely due to addition of Chlorine in the form of Chlorine gas ($Cl_2 + H_2O = HOCl + H^+ + Cl^-$). Treated water sample (after post-chlorination) contained Chloride concentration of 50 mg/L.

The chloride concentration of treated water sample satisfied both the Bangladesh drinking water standard of 150 to 600 mg/L (DoE, 1997) and the WHO (2004) recommended guideline value of 250 mg/L (based on taste threshold consideration). Figure 4.4 shows the variation of chloride concentration at the SWTP during the monitoring period.

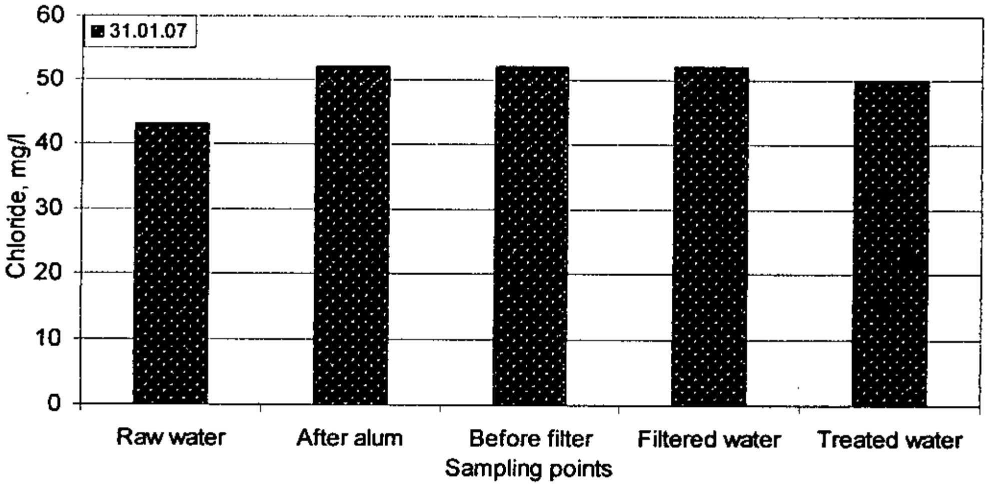


Figure 4.4: Variation of Chloride concentration of water at the SWTP

Alkalinity:

Alkalinity was measured only for water samples collected on 31 January 2007 (dry season). Alkalinity of water samples within the SWTP did not change significantly. On 31 January 2007, alkalinity of water samples within the treatment plant was 195 mg/L at all 3 sampling locations within the plant (SWTP-1 to 3). Slightly higher alkalinity of 211 mg/L was observed in the water sample at the inlet pit. The reduction of Alkalinity is possibly due to addition of alum; Treated water sample (after post chlorination) contained alkalinity of 180 mg/L. Figure 4.5 shows the variation of alkalinity concentration at the SWTP during the monitoring period.

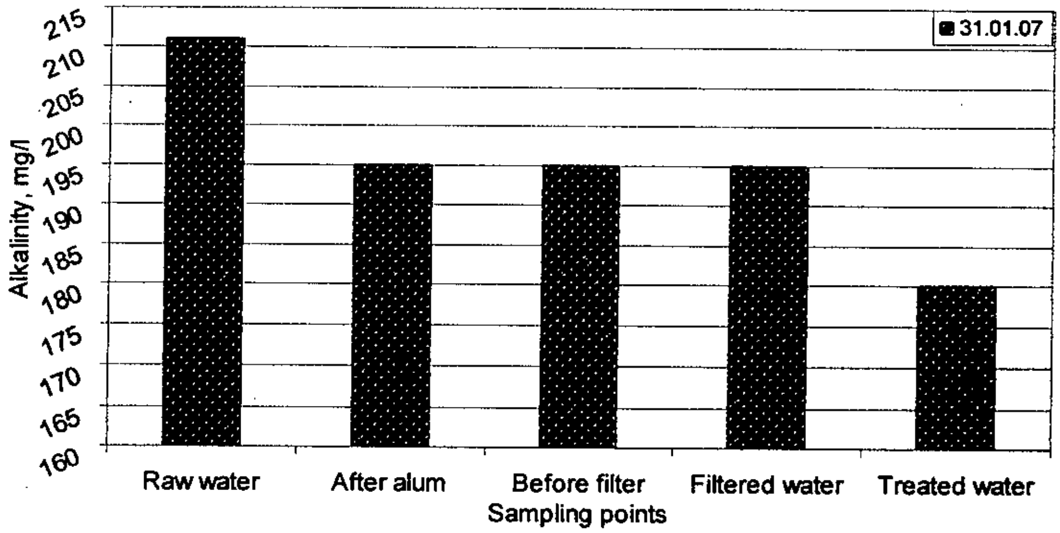


Figure 4.5: Variation of Alkalinity of water at the SWTP

TDS and EC:

Table 4.2 shows the variation of total dissolved solid concentration at the SWTP during the monitoring period. TDS concentration of water samples within the SWTP did not change significantly and were comparable to the TDS concentrations in the water samples at the inlet pit. The TDS concentration of water sampled after filtration varied from 286 mg/L to 497 mg/L, while those of water samples after post chlorination (treated water samples) varied from 284 mg/L to 476 mg/L. Thus, the TDS concentrations of treated water samples satisfied both the Bangladesh drinking water standard of 1000 mg/L (DoE, 1997) and the WHO (2004) recommended guideline value of 1000 mg/L (based on taste threshold consideration).

Table 4.2: TDS concentration in mg/L of water at the SWTP

Sampling Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	302	304	303	286	284
06.02.07	361	375	394	383	376
13.02.07	358	370	352	359	-
20.02.07	461	453	451	454	448
27.02.07	395	412	406	416	403
06.03.07	276	449	461	468	457
13.03.07	439	457	456	450	427
20.03.07	462	476	462	453	465
28.03.07	483	484	492	497	476

Figure 4.6 shows the variation of electrical conductivity at the SWTP during the monitoring period. On any particular sampling day, conductivity of water samples within the SWTP did not change significantly and were comparable to the conductivity of the water samples at the inlet pit. Relatively high conductivity was recorded during March 2007 (compared to concentrations recorded in January and February). On 20 March 2007, high conductivity of around 850 μs/cm was recorded at all sampling locations. Lower conductivity of around 550 μs/cm was recorded on 31 January 2007 at all sampling locations. Conductivity of treated water samples (after post chlorination) of different sampling dates varied over a wide range of 545 μs/cm on 31 January 2007 to 856 μs/cm on 20 March 2007.

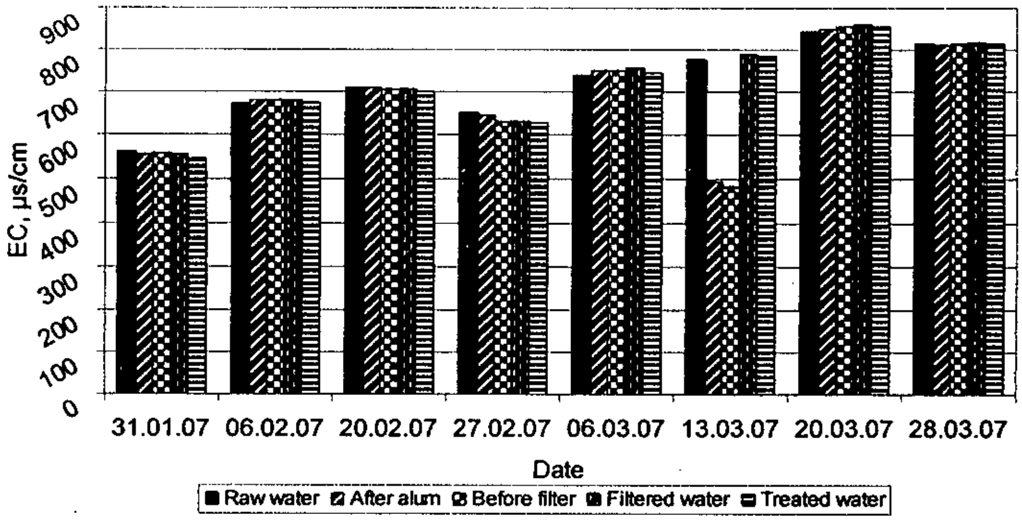


Figure 4.6: Variation of Conductivity of water at the SWTP

TSS:

Figure 4.7 shows the variation of total suspended solid concentration at the SWTP during the monitoring period. The suspended solids concentration decreased significantly in the treatment processes. The suspended solids concentration of water after filtration varied from 5 to 18 mg/L. After post chlorination, treated water samples contained suspended solids from 6 to 14 mg/L. Except for three sampling dates (on 6 February, 20 February and 13 March 2007), suspended solid concentrations of treated water samples satisfied the Bangladesh drinking water standard of 10 mg/L (DoE, 1997).

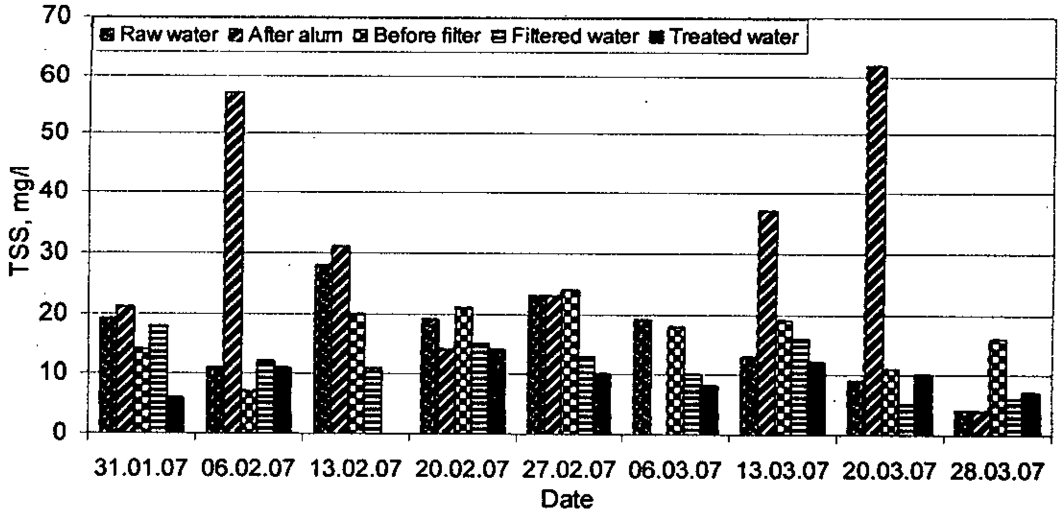


Figure 4.7: Variation of TSS concentration of water at the SWTP

Dissolved Oxygen:

The dissolved oxygen (DO) concentrations of water samples of the inlet pit were relatively low varied from 0.6 to 2.4 mg/L. The dissolved oxygen concentration of water increased significantly (due to aeration) as water moved through the treatment processes. The water samples collected after the filtration process contained DO of close to 6 mg/L and higher. For treated water samples collected after post chlorination, DO concentration varied from 5.85 mg/L (on 20 February 2007) to 8.2 mg/L (on 6 March 2007). Mean DO concentration of treated water samples after post chlorination was 6.93 mg/L. Except for one sampling day (20 February 2007), DO concentrations of treated water samples were higher than the Bangladesh drinking water standard of 6 mg/L (DoE, 1997). Figure 4.8 shows the variation of DO concentration at the SWTP during the monitoring period; Fig. 4.9 shows the temperature of water recorded during the DO measurement. It shows that water temperature increased from January to March as dry season progressed.

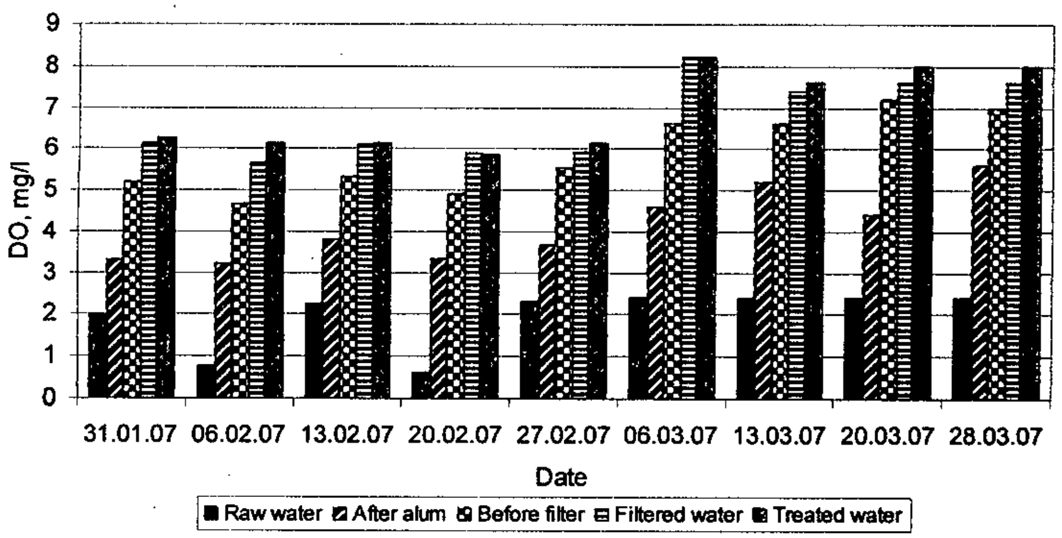


Figure 4.8: Variation of DO concentration of water at the SWTP

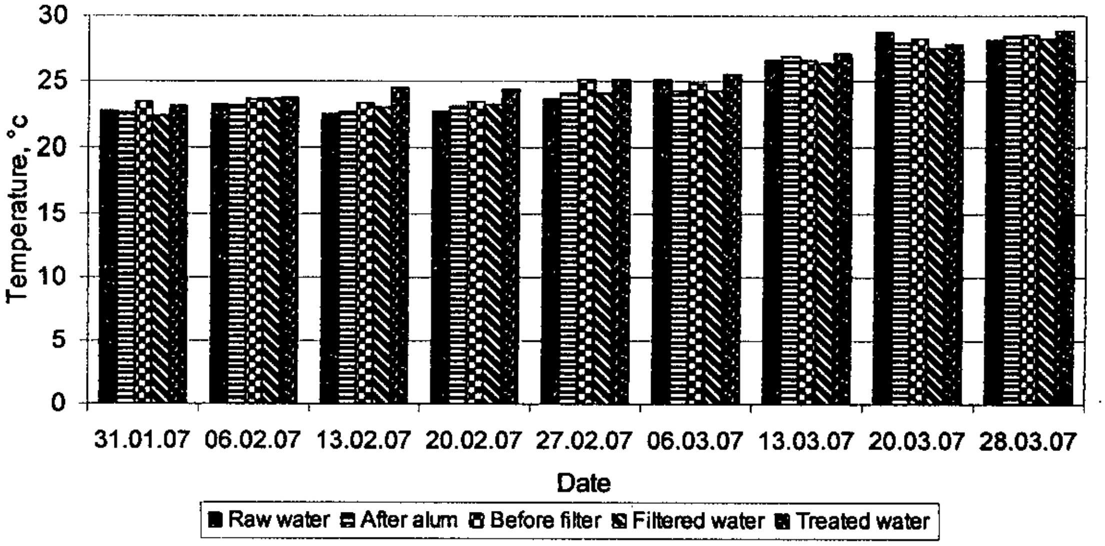


Figure 4.9: Temperature variation of water at the SWTP

COD:

Figure 4.10 shows the variation of chemical oxygen demand (COD) at the SWTP during the monitoring period. Water samples from the inlet pit and three locations within the SWTP were found to contain high concentrations of COD. The COD of water samples from the inlet pit varied from 25 to 57 mg/L, while that of water samples within the SWTP varied from 10 to 64 mg/L. Possible presence of non-biodegradable organic materials in raw water from industrial discharges may contribute to the high COD values. The COD of filtered water varied from 10 to 37 mg/L. In all cases, COD of filtered water was lower than that of the raw water. The reduction may result due to (i) removal of organics through the coagulation-filtration processes; and (ii) oxidation of organic matter by chlorine applied during pre-chlorination.

TOC:

Figure 4.11 shows the variation of total organic carbon (TOC) concentration at the SWTP during the monitoring period. The TOC values of water samples were very high, particularly for samples collected on 20 February and 6 March, 2007. The TOC concentrations of water after filtration varied from 16.4 to 68 mg/L. As noted earlier, possible presence of non-biodegradable organic materials in raw water from industrial discharges may contribute to the high TOC values. In all cases, the TOC values of the filtered water were less than those immediately after alum coagulation, possibly indicating some removal of organic material through coagulation-filtration processes and through oxidation (by chlorine added during pre-chlorination).

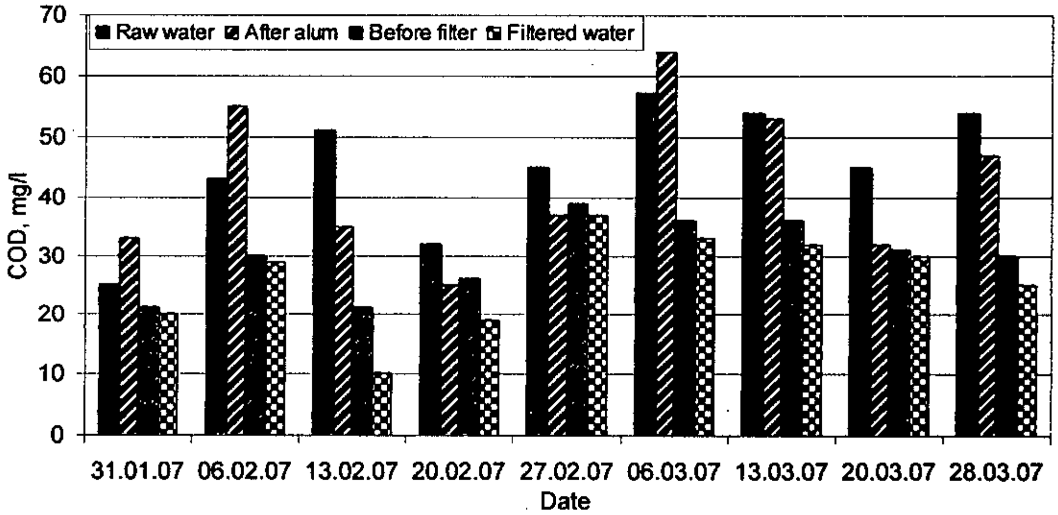


Figure 4.10: Variation of COD concentration of water at the SWTP

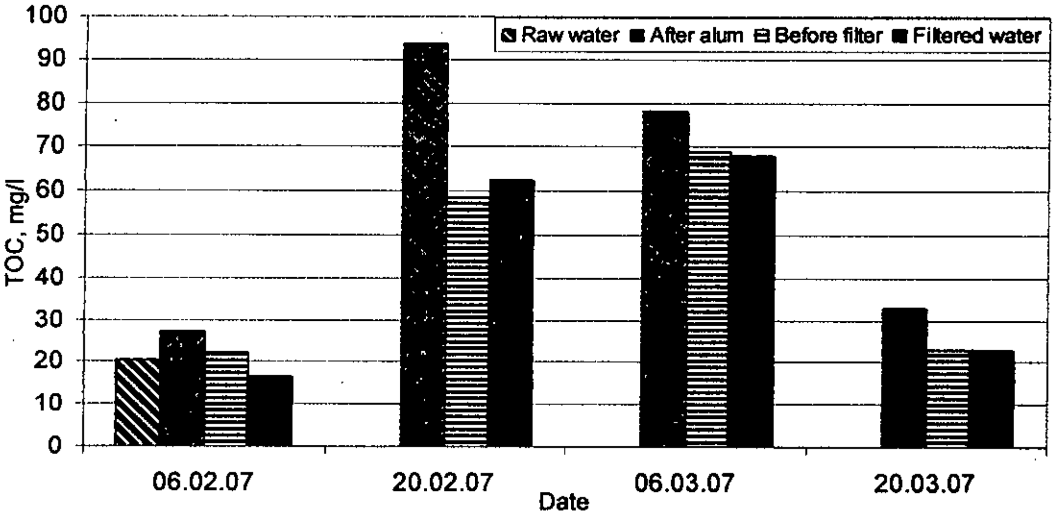


Figure 4.11: Variation of TOC concentration of water at the SWTP

Ammonia:

Figure 4.12 shows the variation of total Ammonia concentration at the SWTP during the monitoring period. Total Ammonia concentration of water did not change significantly within the treatment plant and were comparable to the total Ammonia concentrations of the water samples at the inlet pit. Mean Ammonia concentration within the SWTP (i.e., SWTP-1 to 3) varied from 5.80 mg/L on 31 January 2007 to 10.14 mg/L on 13 March 2007. In all cases, Ammonia concentration in treated water was slightly lower than that in raw water. Ammonia concentrations of the treated water samples (after post chlorination) varied from 5.58 mg/L on 31 January 2007 to 9.75 mg/L on 13 March 2007.

Over most of the dry season, the concentration of Ammonia (in mg/L) present in raw water is higher than the applied chlorine dose (~ 6.5 mg/L) added in the pre-chlorination step. Hence Chlorine to Ammonia concentration ratio is mostly below 1. At such low Chlorine to Ammonia ratios, Monochloramine (NH_2Cl) is the predominant chloramines species. The relatively high pH during the dry season would also favor Monochloramine formation. Hence the portion of Ammonia that would react with the applied chlorine most likely exists as Monochloramine, the remaining Ammonia is likely to exist as free Ammonia (i.e., NH_3 and NH_4^+). For example, if chlorine dose is 6.5 mg/L, then theoretically it could be entirely converted into Monochloramine with the consumption of about 1.3 mg/L NH_3-N. The remaining NH_3-N would exist as free Ammonia. Thus, a significant portion of Ammonia in the treated water likely to exist as Monochloramine, while the rest as free Ammonia.

Dry season is the critical period when Ammonia concentration in both raw and treated water remains above the Bangladesh drinking water standard of 0.5 mg/L (DoE, 1997) as well as the threshold odor concentration limit of 1.5 mg/L according to 2004 WHO guidelines. Based on taste threshold consideration, the WHO recommended guideline value (2004) for ammonia is 35 mg/L. Ammonia is an important indicator of pollution as it can be formed as an intermediate product in the breakdown of nitrogen-containing organic compounds, or of urea from human or animal excrement. Although, ammonia has particularly no toxic effect, unacceptable odor and color in drinking water has major social implications.

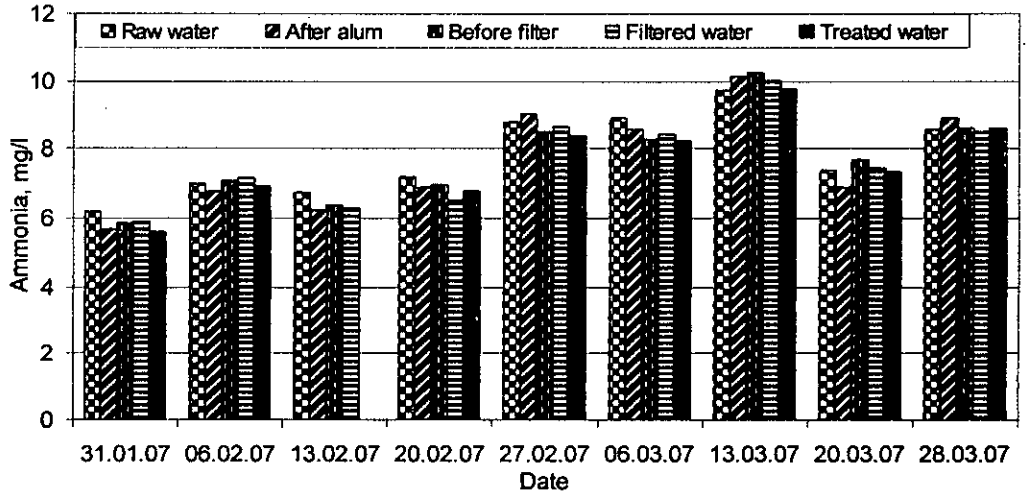


Figure 4.12: Variation of Ammonia concentration of water at the SWTP

Total Chlorine:

Figure 4.13 shows the variation of total Chlorine concentration at the SWTP during the monitoring period. Total Chlorine concentration of water samples within the SWTP (SWTP-1 to 3 locations) were found to be about 4 mg/L. Total Chlorine concentration of the treated water after post-chlorination increased to some extent and varied from 4.2 to 5.95 mg/L.

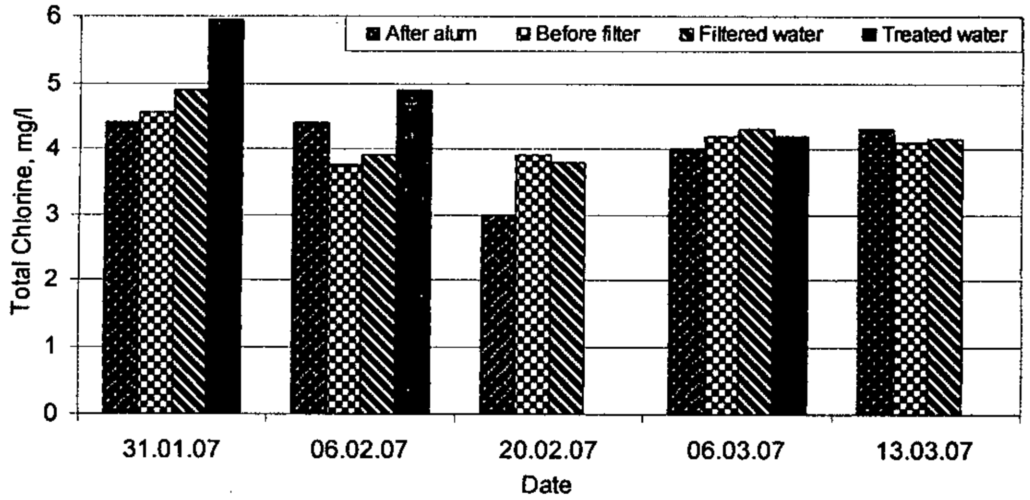


Figure 4.13: Variation of total Chlorine concentration of water at the SWTP

As noted earlier, since raw water contains high concentrations of Ammonia in the dry season and the applied chlorine dose (in mg/L) in most cases is comparable to or lower than the ammonia concentration (in mg/L), the applied chlorine is likely to get converted into chloramines within the treatment plant. Table 4.3 shows chlorine dose required for NH_3-Cl_2 reactions. It shows that below a chlorine to ammonia ratio of 4.2, Monochloramine would be the dominant chloramine species. Table 4.4 shows the calculated reaction times for Monochloramine formation at different pH values at 25°C, and at a chlorine:ammonia ratio of 3:1 (White, 1992). It shows that in the pH range of 7 to 8, conversion of chlorine to monochloramine is essentially complete in ≤ 0.2 seconds. The chlorine to ammonia ratio at the Saidabad treatment during the dry season is far below 4.2, and the pH is also relatively high (7.20 to 7.81 in raw water). Hence the applied chlorine is likely to be converted to Monochloramine immediately, and majority of the residual chlorine is likely to exist as Monochloramine.

Table 4.3: Chlorine dose required for NH_3-Cl_2 reaction

Reaction	mg Cl_2 / mg NH_3
Monochloramine (NH_2Cl)	4.2
Dichloramine ($NHCl_2$)	8.4
Nitrogen Trichloride (NCl_3)	12.5
Nitrogen (N_2)	6.3
Nitrate (NO_3)	16.7
Free residual reaction	9

Source: AWWA and ASCE (1990), as reported in EPA, 1999

Table 4.4: Time to 99% conversion of chlorine to Monochloramine

pH	Time (seconds)
2	421
4	147
7	0.2
8.3	0.069
12	33.2

Source: EPA, 1999

As discussed earlier in Chapter 2, the USEPA standard for chloramines in drinking water is 4.0 mg/L (as Cl_2). On the other hand, the WHO guideline value for Monochloramine is 3 mg/L. Hence, the residual chlorine at SWTP appears to exceed these standards during the dry season.

It should be noted that Monochloramine is the preferred chloramine species with regard to disinfecting drinking water because of taste and odor problems associated with dichloramine and nitrogen trichloride. To ensure that these compounds are not formed, common practice is to limit the chlorine to ammonia ratio to 3:1 (EPA, 1999). However, because of problems such as nitrification and biofilm growth, which can be caused by excess Ammonia, current practice in the United States is to use a Cl_2:N ratio in the range of 3:1 to 5:1, with a typical value of 4:1. It should be noted that Ammonia concentration in the raw water of the SWTP comes down significantly during the wet season and remains below 0.5 mg/L in most cases. The chlorine dose usually employed at the SWTP during the wet season varies from 3 to 4.5 mg/L, which would result in Chlorine to Ammonia ratio significantly in excess of 4.2. Such high Chlorine to Ammonia ratio may promote formation of dichloramine and nitrogen trichloride and give rise to taste and odor problem during the wet season.

Free Chlorine:

Figure 4.14 shows the variation of free chlorine concentration at the SWTP during the monitoring period. Free Chlorine concentration of water samples within the treatment plant varied from 0.26 to 2.24 mg/L. However, the high free Chlorine concentration found in the samples collected on 20 February and 10 March 2007 should be treated with caution. In the presence of high concentration of Ammonia in raw water, the applied Chlorine is likely to form chloramines (Monochloramine) and such high concentration (exceeding 1 mg/L) of free Chlorine is questionable.

Free available Chlorine is much more effective as a disinfectant than combined available chlorine (existing as chloramines). It should be noted that the Bangladesh drinking water standard for free residual chlorine is 0.2 mg/L (DoE, 1997) and WHO recommended guideline value (based on health consideration) is 5 mg/L (2004).

Nitrate:

Figure 4.15 shows the variation of Nitrate concentration at the SWTP during the monitoring period. Nitrate concentrations of water samples within the SWTP were much higher than those for the samples collected from the inlet pit. While nitrate concentrations of water samples from the inlet pit were around 0.2 mg/L, those from within the SWTP (i.e., SWTP-1 to 3) were around 1.0 mg/L. This is possibly due to oxidation of some

Ammonia into Nitrate by Chlorine added during pre-chlorination. Mean Nitrate concentration of the treated water samples (after post chlorination) was 0.96 mg/L. Nitrate concentrations of treated water samples collected after post-chlorination were below the Bangladesh drinking water standard of 10 mg/L (DoE) and the WHO (2004) recommended guideline value of 50 mg/L (based on health consideration).

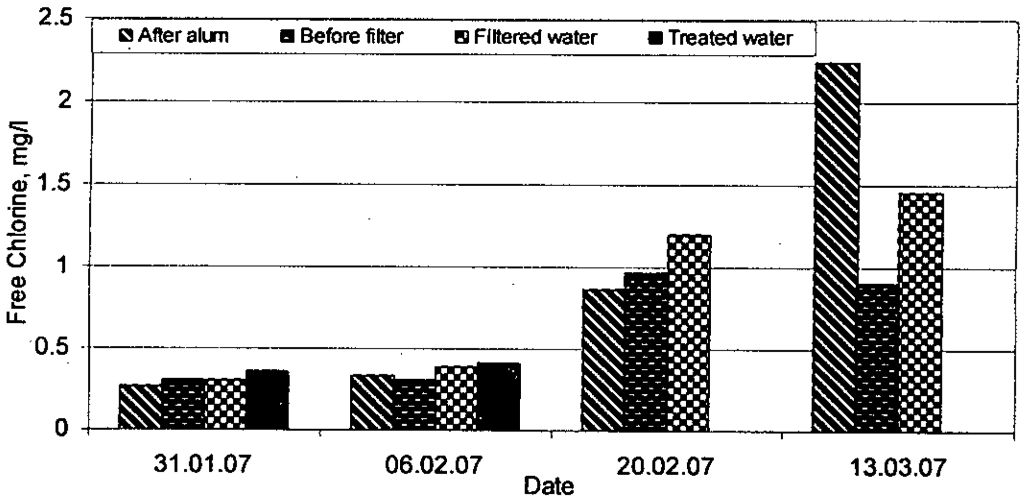


Figure 4.14: Variation of Free Chlorine concentration of water at the SWTP

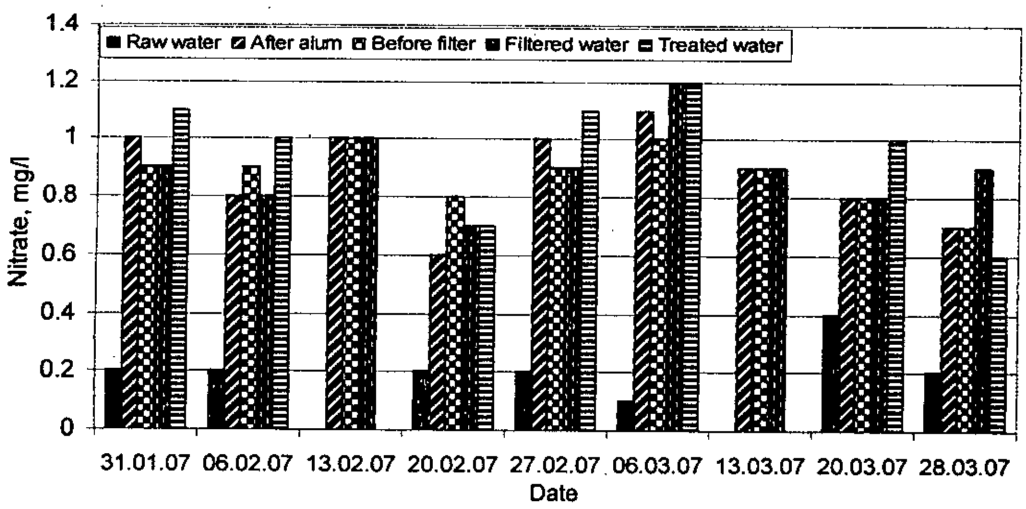


Figure 4.15: Variation of Nitrate concentration of water at the SWTP

Nitrite:

Figure 4.16 shows the variation of nitrite concentration at the SWTP during the monitoring period. Nitrite concentrations at the SWTP were relatively low and with a few exceptions did not change significantly during the treatment processes. Nitrite concentrations of the treated water samples after post-chlorination varied over a narrow range of 0.012 mg/L on 31 January 2007 to 0.030 mg/L on 20 March 2007; these values are well within the Bangladesh drinking water standard (<1 mg/L) as well as the WHO guideline value of 3 mg/L (based on health consideration) and 0.2 mg/L (based on health consideration for long-term exposure).

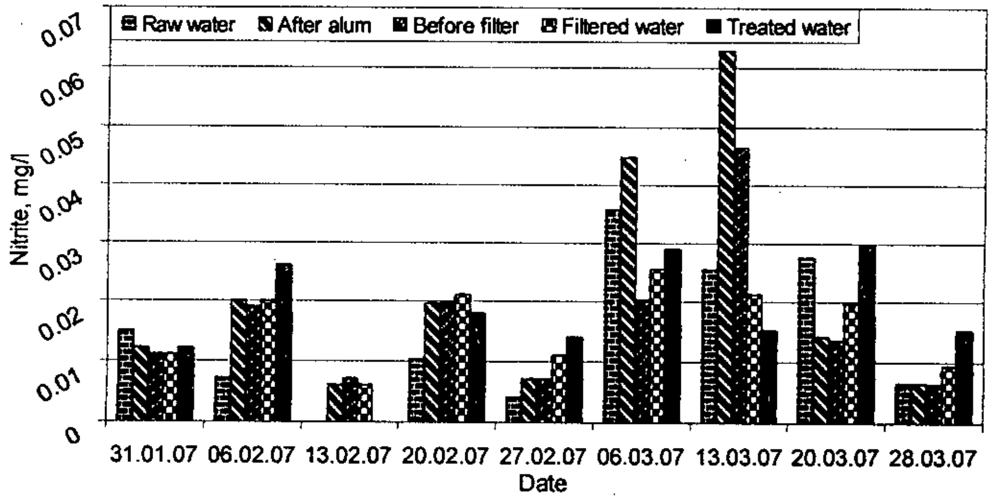


Figure 4.16: Variation of Nitrite concentration of water at the SWTP

Phosphate:

Figure 4.17 shows the variation of Phosphate concentration at the SWTP during the monitoring period. Compared to the raw water at the inlet pit, Phosphate concentration of within the SWTP were relatively low, possibly due to its co-precipitation with aluminum hydroxide flocs. Phosphate concentration of water samples after the filtration process varied from 0.202 mg/L to 1.56 mg/L. Mean phosphate concentration of the treated water samples (after post chlorination) was 0.838 mg/L. Phosphate concentrations of treated water are much lower than the Bangladesh drinking water standard of 6 mg/L (DoE, 1997).

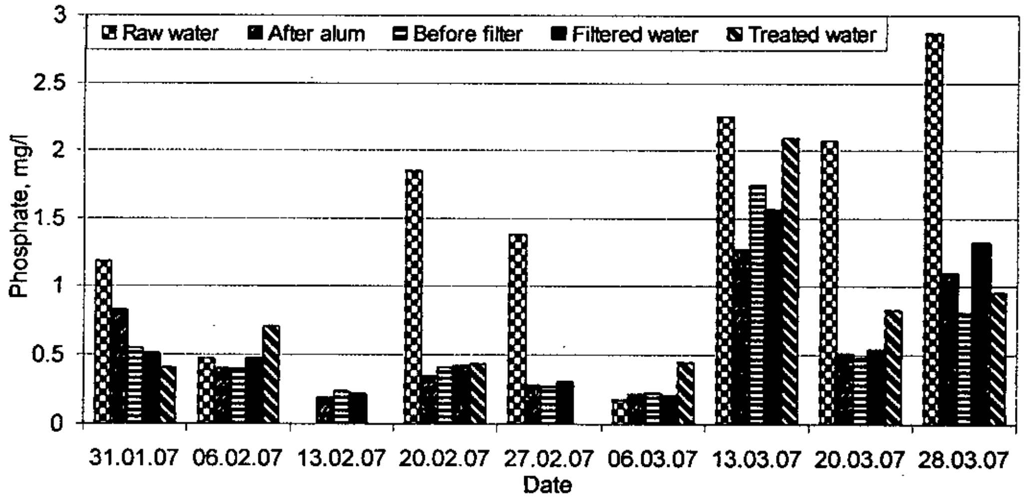


Figure 4.17: Variation of Phosphate concentration of water at the SWTP

Sulfate:

Figure 4.18 shows the variation of sulfate concentration at the SWTP during the monitoring period. The high concentration of sulfate in the water samples collected from the SWTP compared to that in raw water is due to addition of Alum [$Al_2(SO_4)_3.24H_2O$]. Sulfate concentration did not change significantly within the treatment plant (i.e., from SWTP-1 to 3 location). The variation of sulfate concentration on different sampling dates is possibly reflects the variation of Alum doses employed at the SWTP. Sulfate concentrations of the treated water after post-chlorination varied from 35.3 to 74 mg/L, which are much below the Bangladesh drinking water standard of 400 mg/L (DoE, 1997) as well as the WHO recommended guideline value (2004) of 250 mg/L, which is based on taste threshold consideration.

Sulfide:

Figure 4.19 shows the variation of sulfide concentration at the SWTP during the monitoring period. Sulfide concentrations of the water samples from the SWTP were relatively low, varying from 2 μg/L to 19 μg/L. Sulfide concentrations of the treated water samples after post-chlorination varied from 6 μg/L to 18 μg/L, well within the WHO recommended guideline value of 0.05 to 0.1 mg/L based on both odor and taste threshold considerations. It may be noted that the Bangladesh standard for sulfide in drinking water is zero mg/L (DoE, 1997).

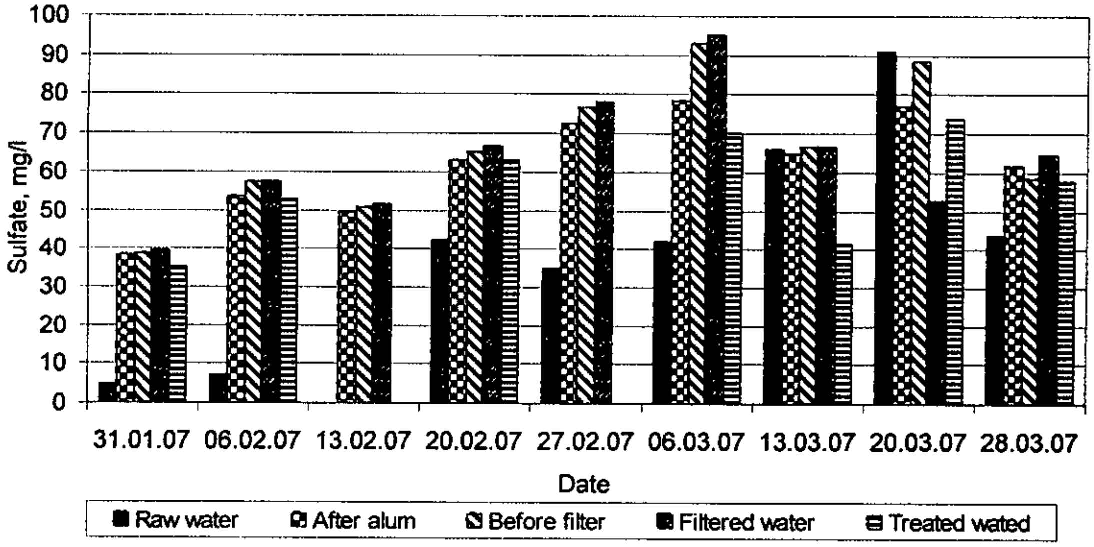


Figure 4.18: Variation of Sulfate concentration of water at the SWTP

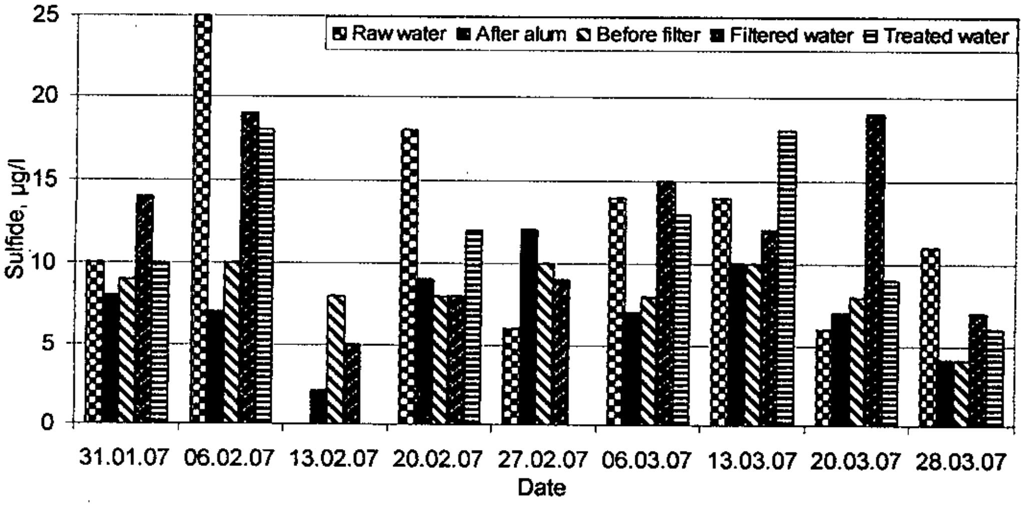


Figure 4.19: Variation of Sulfide concentration of water at the SWTP

Chlorophyll-A and Total Phytoplankton:

The treatment processes at the SWTP lowered Chlorophyll-A concentration significantly compared to levels in the raw water (i.e., water from the inlet pit). Raw water of the SWTP contained very high concentrations of Chlorophyll-A, varying from 15.6 to 92.8 µg/L. These concentrations decreased progressively as water moved through the SWTP. Mean Chlorophyll-A concentration in the raw water over the monitoring period was 46.6 µg/L, while that of the filtered water was about 6.9 µg/L. Figure 4.20 shows the variation of chlorophyll-A concentration at the SWTP during the monitoring period.

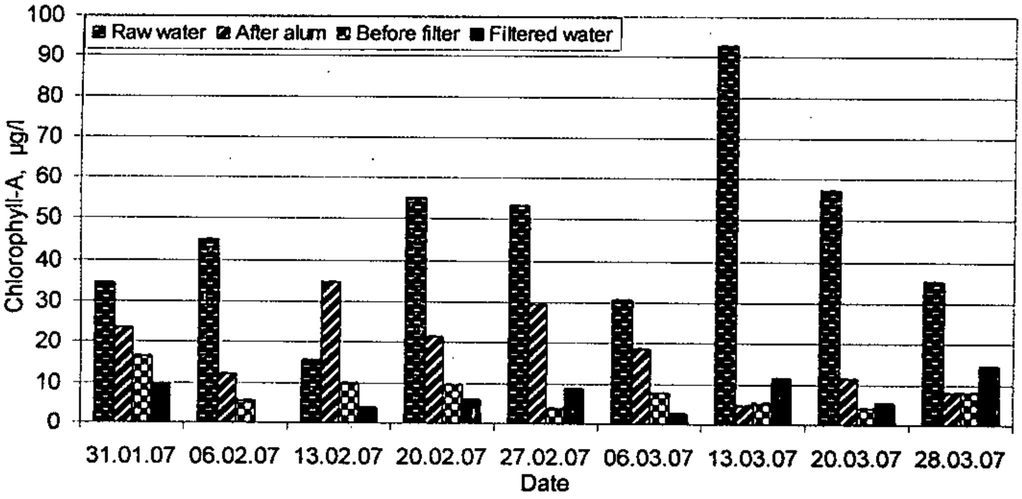


Figure 4.20: Variation of Chlorophyll-A concentration of water at the SWTP

Figure 4.21 shows the variation of total Phytoplankton concentration (sum of concentrations of 29 different species) at the SWTP during the monitoring period. In most cases, total phytoplankton concentration decreased after filtration at the SWTP. Relatively high concentrations of Phytoplankton were detected in both raw and treated water during March 2007. This possibly indicates that high concentration of Phytoplankton in raw water would possibly result in elevated concentrations of Phytoplankton in the treated water.

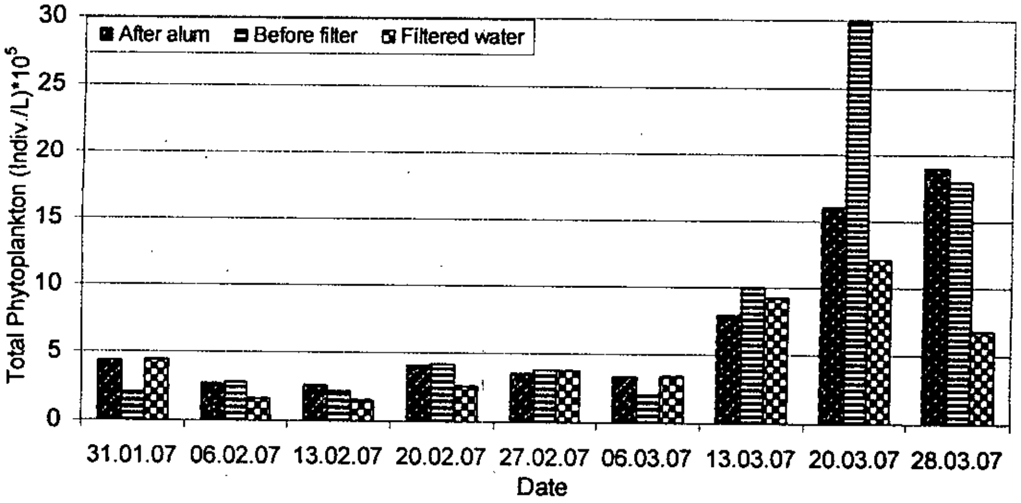


Figure 4.21: Variation of total Phytoplankton concentration of water at the SWTP

Aluminum:

Figure 4.22 shows the variation of Aluminum (Al) concentration at the SWTP during the monitoring period. Dissolve Al concentration of water at the SWTP decreased as water moved from SWTP-1 to SWTP-3 location. The variation of Al concentration among sampling dates most likely reflects the changes in alum dose employed at the SWTP. During the monitoring period of nine weeks, mean Al concentrations at SWTP-1, 2 and 3 locations were 4.01, 1.35 and 0.54 mg/L, respectively. The high dissolved Aluminum concentration in treated water during the dry season is possibly due to very high doses of Alum (up to 60 mg/L) used during this period. Thus, mean Al concentration of water collected after the filtration process is higher than the Bangladesh drinking water standard and the WHO guideline value (not based on health considerations) of 0.2 mg/L. Presence of Al in excess of 0.1 to 0.2 mg/L often leads to consumer complaints as a result of deposition of aluminum hydroxide flocs in distribution system and the exacerbation of discoloration of water by iron (WHO, 2004). It is therefore important to optimize treatment processes in order to minimize any residual aluminum entering the distribution system. Under good operating conditions, aluminum concentrations of less than 0.1 mg/L are achievable in many circumstances (WHO, 2004).

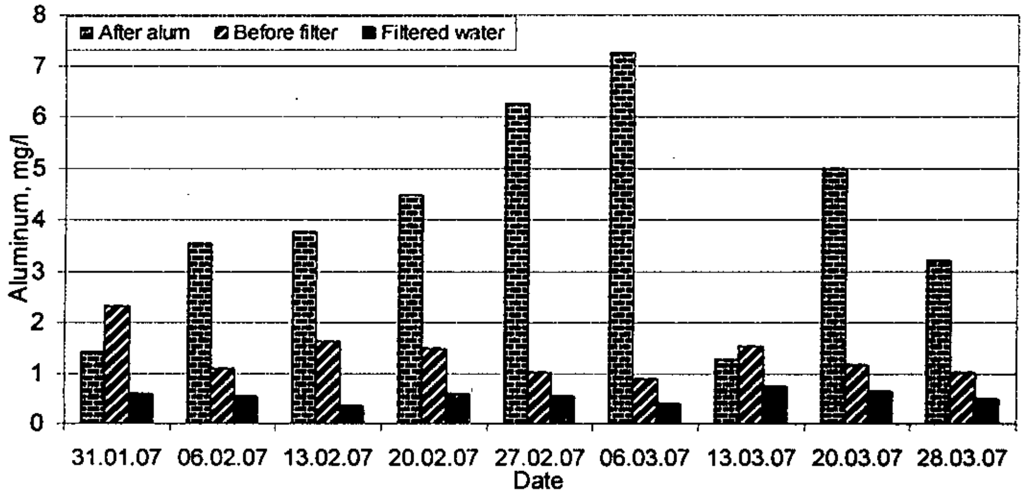


Figure 4.22: Variation of Aluminum concentration of water at the SWTP

Chromium and Nickel:

Chromium concentrations of all 27 water samples collected from the SWTP were relatively low, varying from 0.005 mg/L to 0.039 mg/L (Fig. 4.23). Chromium concentrations of water samples collected after the filtration process varied from 0.005 to 0.013 mg/L, well within the Bangladesh drinking water standard and WHO guideline value of 0.05 mg/L.

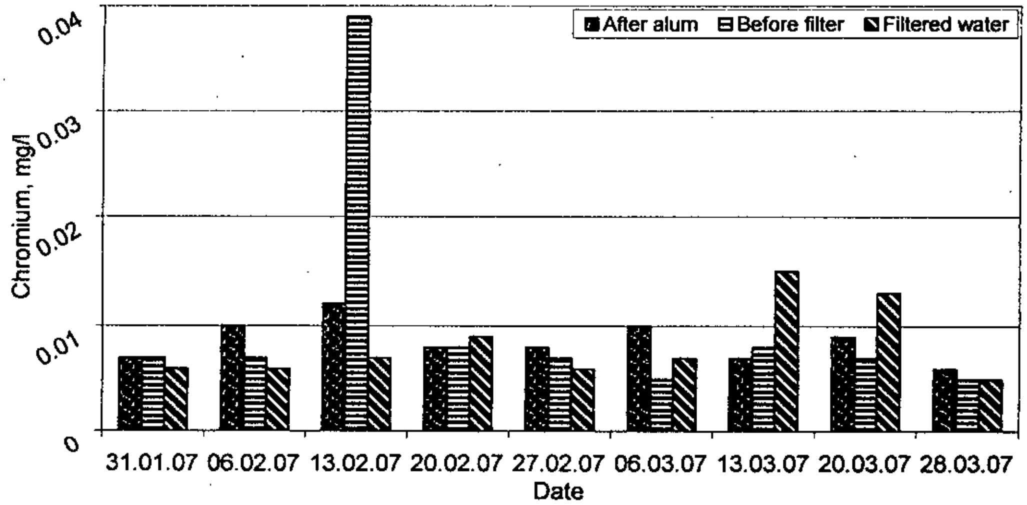


Figure 4.23: Variation of Chromium concentration of water at the SWTP

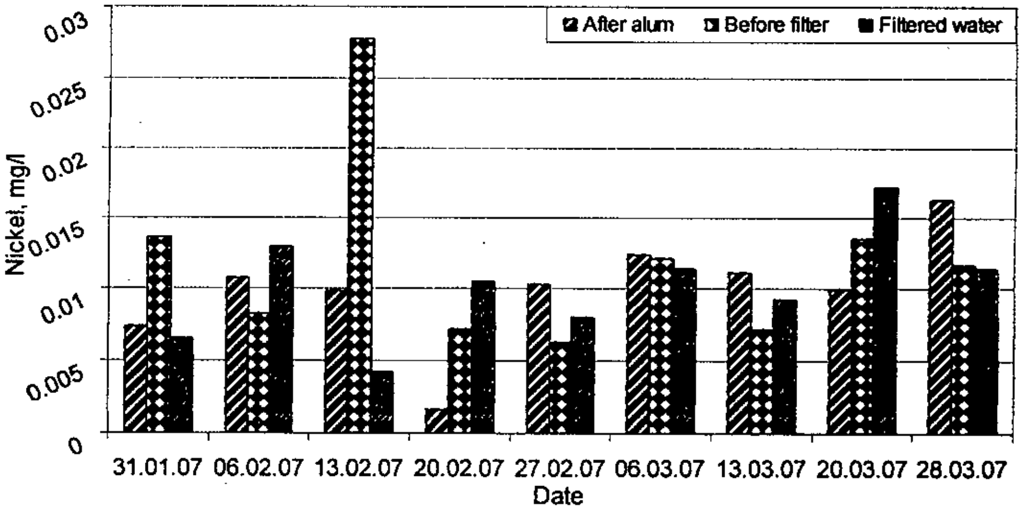


Figure 4.24: Variation of Nickel concentration of water at the SWTP

Nickel (Ni) concentrations of the water samples varied from 0.002 to 0.028 mg/L (Fig. 4.24). For the samples collected after the filtration process, Ni concentration varied from 0.007 to 0.017 mg/L, satisfying the Bangladesh drinking water standard of 0.10 mg/L and WHO guideline value (based on health consideration) of 0.02 mg/L. It should be noted that the SWTP is not designed for removal of heavy metals such as Chromium and Nickel.

4.3.2 Break Point Chlorination (BPC)

Break point chlorination (BPC) is often considered an option for removal of excess ammonia in the raw water at the SWTP. However, no estimates are presently available on the chlorine dose requirement for break point chlorination. In this study, Break Point Chlorination experiments were carried out on raw water samples collected on 6 and 13 March of 2007 from the inlet pit of the SWTP, in order to characterize the nature of chlorine demand of raw water at the SWTP. Total Ammonia concentrations of these two water samples were 8.920 and 9.855 mg/L, respectively. The process involves addition of sufficient chlorine to oxidize all the organic matter, reducing substances and free ammonia in raw water leaving behind free available chlorine, which possesses strong disinfecting action against pathogens. The break point chlorination curves are shown in Figs 4.25 and 4.26.

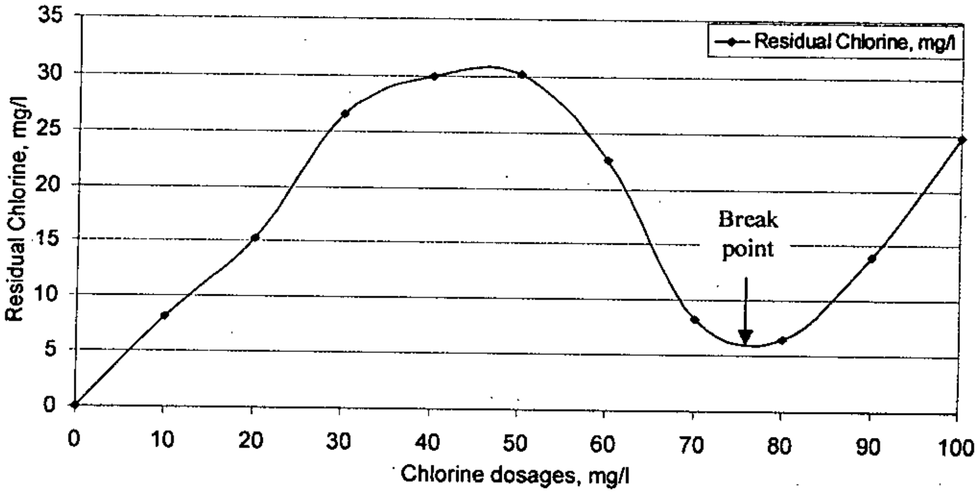


Figure 4.25: Break Point Chlorination curve of water sample collected on 6 March 2007 (Total Ammonia = 8.920 mg/L NH_3-N=10.83 mg/L NH_3)

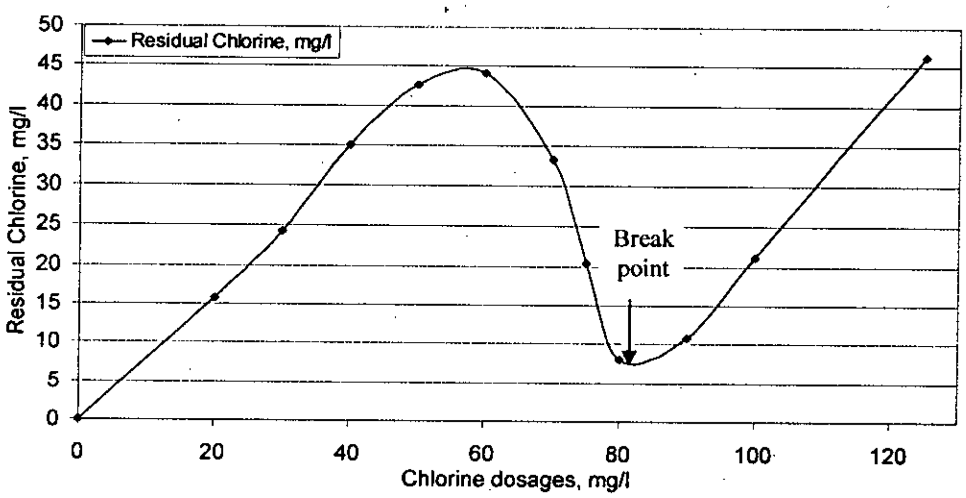


Figure 4.26: Break Point Chlorination curve of water sample collected on 13 March 2007 (Total Ammonia = 9.855 mg/L NH_3-N=11.97 mg/L NH_3)

Theoretically, about 8 mg/L of chlorine is required to oxidize 1 mg/L of ammonia. Ammonia concentrations of the raw water inlet pit were recorded 10.83 mg/L on 6 March and 11.97 mg/L on 13 March 2007. Therefore, theoretically the chlorine requirements to reach break point are about 86.6 mg/L and 95.8 mg/L, respectively. The actual chlorine dose required to achieve break point chlorination was very close to the theoretical requirements, about 80 mg/L in both cases. Such huge chlorine dose is impractical and hence break point chlorination is not likely to be a feasible option for the SWTP. For example, if pre-chlorination is done at the rate of 80 mg/L, then it would require about 19.2 metric tons of chlorine each day at the SWTP, compared to about 1.6 tons needed if chlorine dose is 6.5 mg/L. Application of more Chlorine for ammonia removal would increase the cost of treatment as well as change the odor and taste of drinking water. Higher concentration of Chlorine, if taken for extended period, can cause health hazard. On the other hand, BPC could be considered during the wet season when ammonia concentration in raw water drops significantly and overall raw water quality improves.

4.3.3 THM Formation Potential

The raw water quality data required for estimating THM formation potential include pH, temperature, DOC, UV_{254} and bromide concentrations. As discussed in Chapter 3, the pH and temperature of raw water samples were monitored from six locations of DND canal

(DND-1 to DND-6) during both dry and wet seasons. Nine sets of pH and temperature measurements were carried out during the dry season (January to March). For the wet season, pH of raw water samples were recorded on 29 June and 10 September of 2007 and temperature were recorded on 10 September of 2007. Bromide and UV_{254} concentrations of water samples are presented in Table 4.5.

Table 4.5: Bromide and UV_{254} concentrations of water samples

Parameter	Unit	Sampling Locations		
		DND-1	DND-3	DND-5
Bromide (dry season)[a]	μg/L	65	61	63
Bromide (wet season)[b]	μg/L	5	6	7
UV_{254} (dry season)[a]	cm^{-1}	0.1850	0.1710	0.1685
UV_{254} (wet season)[c]	cm^{-1}	0.2285	0.1480	0.1580

Sampling date: a=26 February 2008; b=29 June 2007; c=10 September 2007

Table 4.5 shows that bromide concentrations did not vary significantly along the canal on a particular sampling date. Average bromide concentration (63 μg/L) in dry season (February 2008) is about 10.5 times higher than the concentration (6 μg/L) in wet season (June 2007). The concentrations of bromide in natural surface and groundwater, except seawater, exhibit a wide range from less than 10 μg/L to more than 1000 μg/L, with an average of about 100 μg/L. Bromide concentrations in the DND canal fall within the usual range reported for surface waters.

Bromide plays a very important role in THM species formation and distribution. Bromide has a negative effect on chloroform formation and a positive influence on the brominated species. Formation of brominated versus chlorinated THM species is affected by the competition between bromine and chlorine. Of the four THM species, three are brominated. The amount of bromide ion present influences the overall THM formation as well as speciation. During chlorination, bromide is oxidized by chlorine to form hypobromous acid (HOBr) and/or hypobromite ion (OBr^-) (Gordon, 1987):

$$HOCl + Br^- = HOBr + Cl^-$$

Hypobromous acid can react with natural organic matter (NOM) to produce brominated DBPs such as bromoform. Collectively, the relative amounts of HOCl and HOBr determine the THM species distribution. Gould et al. (1983) studied the effects of bromide on total trihalomethane and individual THM species formation kinetics. They formulated the order of THM species formation kinetics: $CHCl_3 < CHBrCl_2 < CHBr_2Cl < CHBr_3$ (Gould, 1983). In other words, the THM species having higher bromide concentration form faster than those having less bromide concentration.

The UV_{254} absorbance values on the other hand did not vary significantly; in dry season (February 2008), it varied from 0.1685 to 0.1850 cm^{-1}, while in wet season it varied from 0.1480 to 0.2285 cm^{-1}. Mean UV_{254} concentration during the dry season was 0.1748 cm^{-1} and during the wet season was 0.178 cm^{-1}; i.e. no significant seasonal trend was observed in case of UV_{254} absorbance. UV absorbance at 254 nm is considered an excellent surrogate parameter for estimating the raw water concentrations of organic carbon and THM precursors.

As noted earlier, water samples collected on 10 September of 2007 (wet season) were sent to Plasma Plus Laboratory for DOC measurement. But the results were unrealistic (too high) and could not be used. In the absence of measured DOC data, the DOC concentration for the dry season was set equal to the average value of TOC measured on water samples collected from the DND conveyance canal on 5 February, 19 February and 19 March of 2007. The DOC concentration for the wet season was fixed by assuming that the ratio of DOC concentration in dry season to that in wet season is equal to the ratio of Bromide concentrations in dry and wet season, i.e., equal to 10.5. In other words, it was assumed that the sources of these constituents do not change and variation in concentration is caused by dilution. Accordingly, the calculated DOC concentrations in dry and wet seasons were 29.3 mg/L and 2.8 mg/L, respectively. There are many limitations of these assumptions, but in the absence of actual data, the approach was adopted.

In this study, THM formation potential at the SWTP was estimated for dry and wet seasons using a set of parameters for each season. Table 4.6 shows the set of parameters used for estimation of THMFP.

Table 4.6: Raw water quality of DND canal

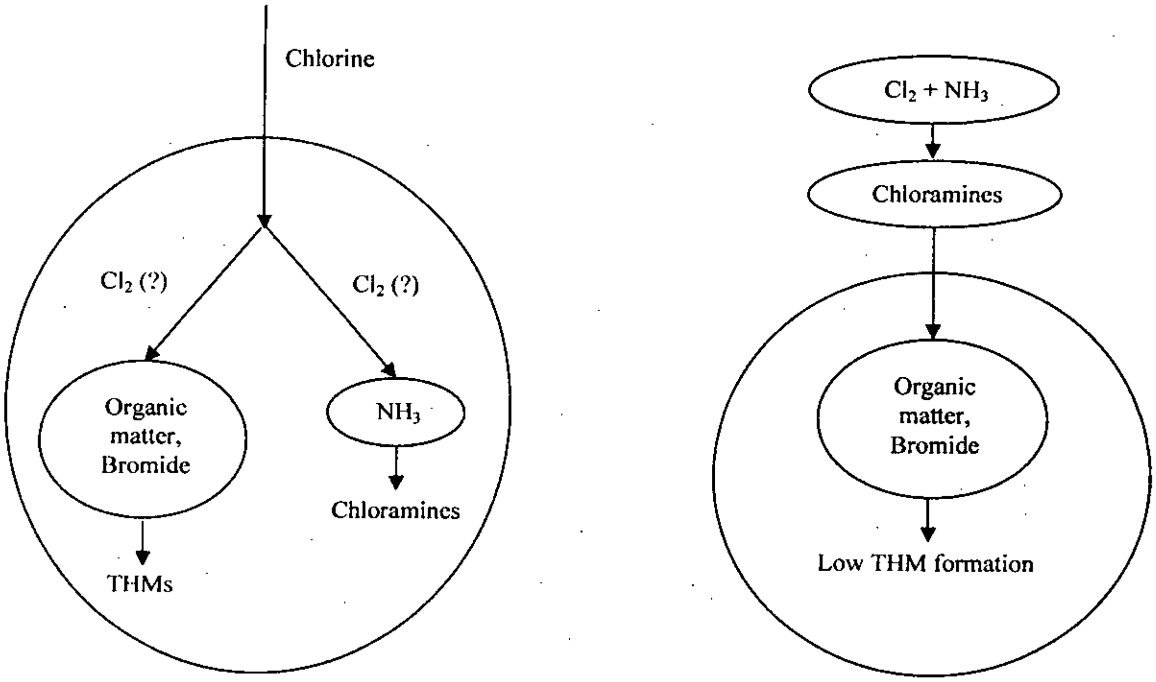
Water Quality Parameters	Unit	Dry Season (January to March)	Wet Season (June to September)
pH	--	6.5 to 8.5^{c}	6.5 to 8.5^{c}
UV_{254}	cm^{-1}	0.1748^{a}	0.1780^{a}
DOC	mg/L	29.3	2.8^{b}
Bromide,	µg/L	63^{a}	6^{a}
Temperature,	°C	20 to 30^{c}	20 to 30^{c}
Chlorine dose	mg/L	6 to 7	3 to 4.5
Reaction Time	hr	24	24

a: avegare of three measued values; b: estimated; c: assumed range based on data

THM Formation Potential based on Amy et al. (1998)

As presented in Section 4.2.2, the method for estimating THMFP developed by Amy et al. (1998) is based on of DOC, Cl_2 and Bromide concentrations, temperature and pH of raw water and contact time. Application of the model is quite straightforward if concentrations of these parameters are known. However, in case of SWTP, the presence of Ammonia in raw water complicates the situation.

In the presence of Ammonia, it becomes uncertain how much free chlorine would be available for reactions leading to formation of THMs. It is well known that disinfection with chloramines, instead of chlorine, significantly reduces the THM formation by liming the availability of free chlorine that would react with organic matter (and also bromide) forming THMs. However, in the case of SWTP, chloramines are not added to water; instead chlorine is being added to water, which contains both ammonia as well as organic matter and bromide. Potential formation of THM would depend on how much free chlorine is available for reaction with organic matter (and bromide) in the presence of high concentration of ammonia. Figure 4.27 schematically describes the situation. Available literatures do not shed light for such a situation, where formation of Chloramines and THMs are competing processes. In this situation, the THM formation was estimated by varying the quantity of free chlorine that could be available for THM formation.



(a) (b)

Figure 4.27: Potential formation of THMs upon addition of: (a) chlorine to water containing ammonia; (b) chloramine to water

THM Formation Potential during Dry Season

Figure 4.28 shows the predicted Total Trihalomethane (TTHM) concentrations (based on Eq. 4.1) as a function of chlorine concentration, which was varied from 0 to 50% of selected chlorine dose of 6.5 mg/L (for dry season). Temperature was fixed at 25.1°C and pH at 7.43 (mean of the measured values of these parameters during the dry season). Concentrations of other parameters are shown in Table 4.6. As shown in Figure 4.28, the THMFP increases sharply at low chlorine concentration (up to about 0.2 mg/L; about 2.5% of applied chlorine), then increases gradually up to about 1086 μg/L at a chlorine concentration of 3.25 mg/L (50% of applied chlorine). It also shows that even a very small concentration of free chlorine, if available for reaction with organic matter and bromide, may result in the formation of significant concentration of THMs (exceeding the USEPA drinking water standard of 80 μg/L).

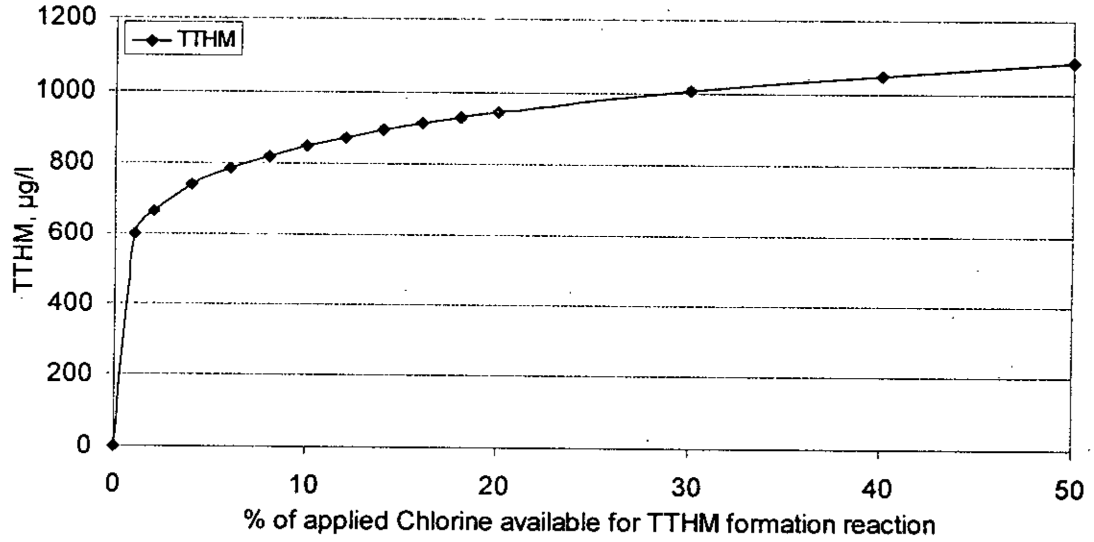


Figure 4.28: Total THM formation as a function of available free chlorine concentration during the dry season

Using equation 4.2 to 4.5, Figure 4.29 shows the predicted distribution of individual THM species for a free chlorine concentration of 1.6 mg/L (25% of 6.5 mg/L), DOC concentration of 29.3 mg/L, bromide concentration of 63 µg/L, Temperature of 25.1°C, pH value of 7.43 and reaction time of 24 hr. As shown in Figure 4.29, chloroform ($CHCl_3$) is the dominant THM species, accounting for about 95% of TTHM, while $CHBrCl_2$ (114 µg/L) accounts for about 5%; concentrations of $CHBr_2Cl$ and $CHBr_3$ are negligible.

Figures 4.30 shows effects of pH on THM formation, respectively, at a DOC concentration of 29.3 mg/L, available free chlorine concentration of 1.6 mg/L (25% of 6.5 mg/L), bromide concentration of 63 µg/l, temperature of 25.1°C and reaction time of 24 hr. As shown in Figure 4.30, the predicted THMFP progressively increases from about 787 µg/L to 1209 µg/L, as the pH value of water increases from 6.5 to 8.5.

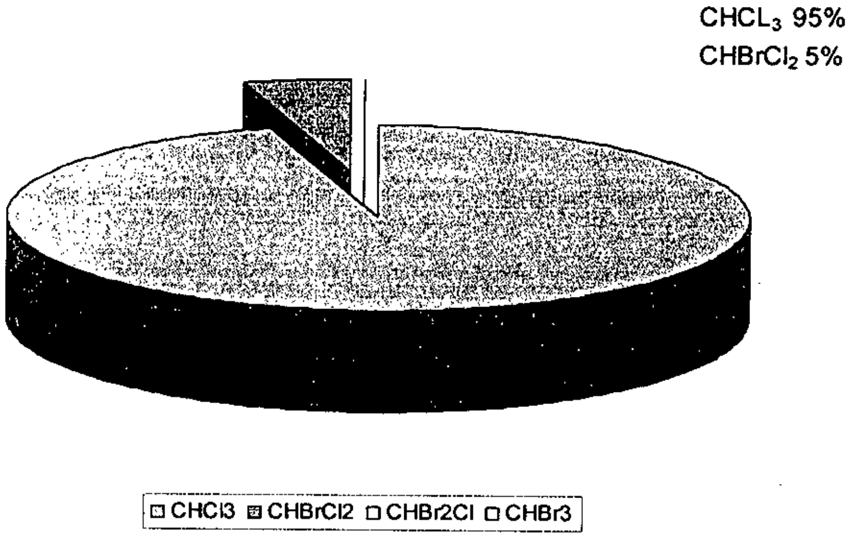


Figure 4.29: Estimated percentages of individual THM species during dry season

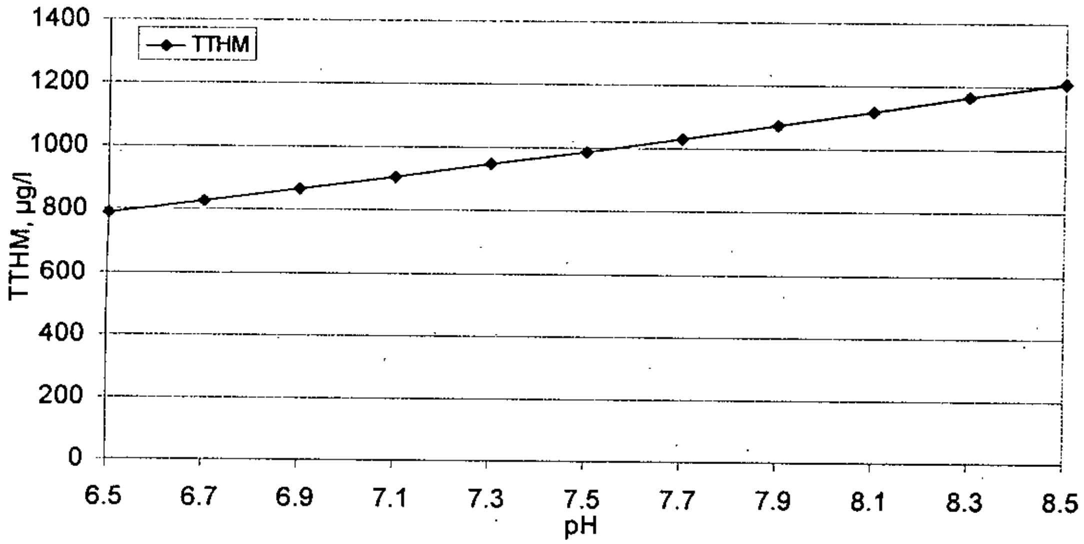


Figure 4.30: Effect of pH on TTHM formation during dry season

Using equation 4.1, Figure 4.31 shows the predicted TTHM concentrations as a function of water temperature at DOC concentration of 29.3 mg/L, available free chlorine concentration of 1.6 mg/L (25% of 6.5 mg/L), bromide concentration of 63 µg/l, pH value of 7.43 and reaction time of 24 hr. As shown in Figure 4.31, the predicted THMFP progressively increases from about 849 µg/L to 1087 µg/L as the temperature of water increases from 20 to 30 °C.

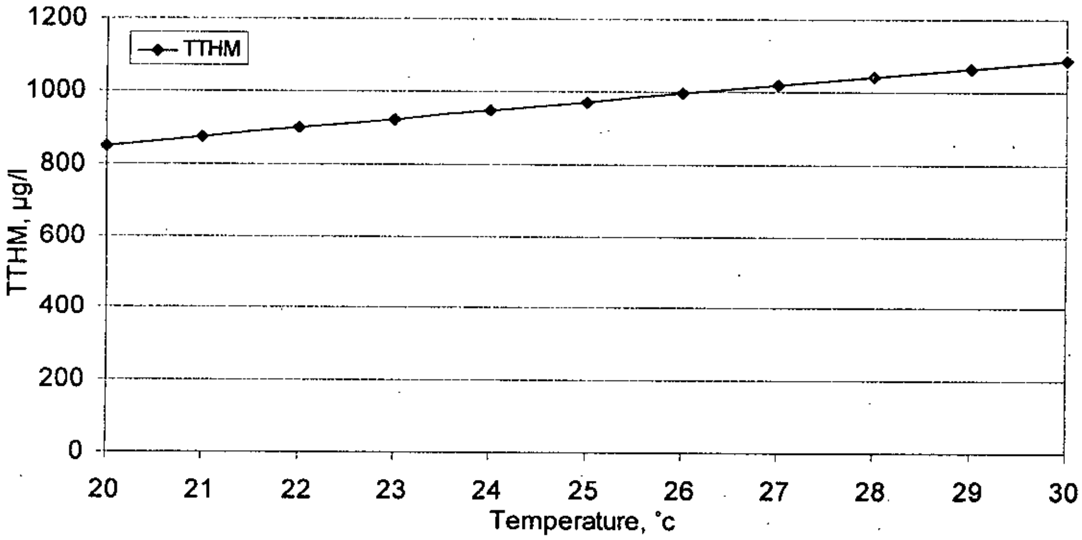


Figure 4.31: Effect of temperature on TTHM formation during dry season

Figures 4.30 and 4.31 and Eq. 4.1 show that pH has a more pronounced effect on TTHM formation than temperature. Since both pH and temperature of raw water increases during dry season at the Saidabad water treatment plant, the dry season appears to be more vulnerable for THMs formation. Controlling pH could be an important option for reducing THMs formation at the SWTP.

THM Formation Potential during Wet Season

Figure 4.32 shows the predicted Total Trihalomethane (TTHM) concentrations (based on Eq. 4.1) as a function of chlorine concentration, which was varied from 0 to 50% of selected chlorine dose of 3.75 mg/L (for wet season). Temperature was fixed at 29.6°C and pH at 7.03 (mean of the measured values of these parameters during the wet season). Concentrations of other parameters are shown in Table 4.6. As shown in Figure 4.32, the THMFP increases sharply at very low chlorine concentration (< 0.1 mg/L), then increases gradually up to about 65 µg/L at a chlorine concentration of 1.88 mg/L (50% of applied chlorine). This figure shows that under the conditions considered, the predicted TTHM concentration remains below the USEPA drinking water standard of 80 µg/L.

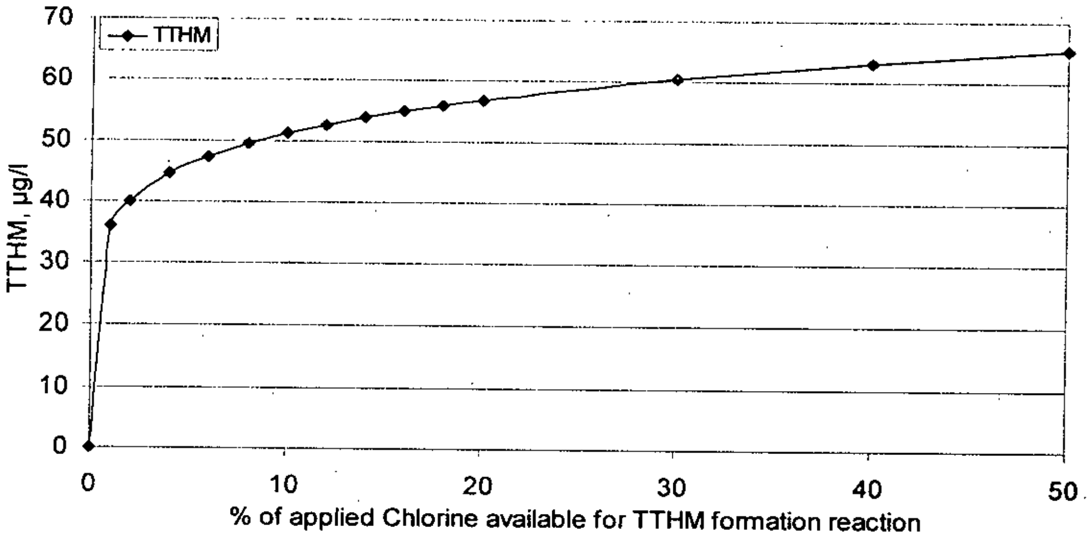


Figure 4.32: Total THM formation as a function of available free chlorine concentration during the wet season

Using equation 4.2 to 4.5, Figure 4.33 shows the predicted distribution of individual THM species at a free chlorine concentration of 0.94 mg/L (25% of applied dose of 3.75 mg/L), DOC concentration of 2.8 mg/L, bromide concentration of 6 µg/l, temperature of 29.6°C, pH value of 7.03 and reaction time of 24 hr. As shown in Figure 4.33, chloroform ($CHCl_3$) is the dominant THM species (97%), while $CHBrCl_2$ accounts for the remaining 3% of THM species. Concentrations of $CHBr_2Cl$ and $CHBr_3$ are negligible.

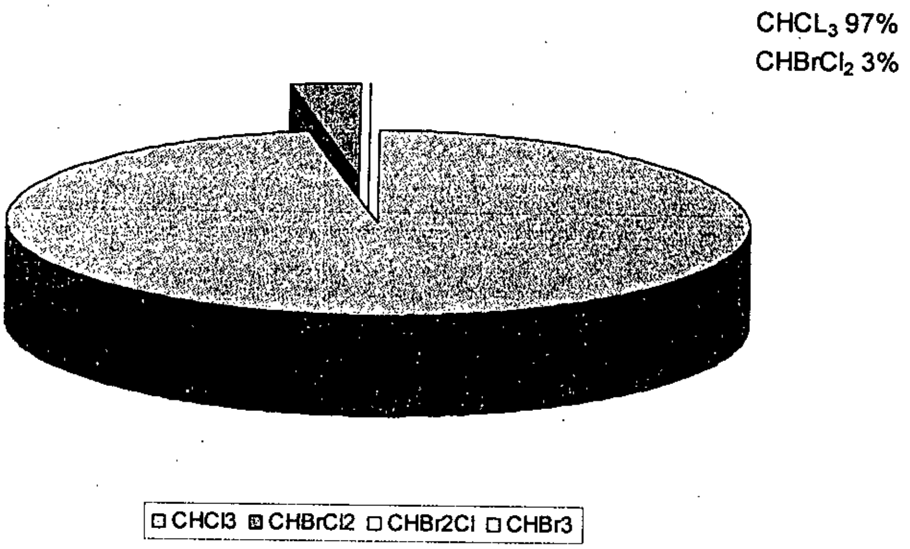


Figure 4.33: Estimated percentages of individual THM species during wet season

Using equation 4.1, Figure 4.34 shows the predicted TTHM concentrations as a function of pH value at DOC concentration of 2.8 mg/L, available free chlorine concentration of 0.94 mg/L (25% of 3.75 mg/L), bromide concentration of 6 μg/l, temperature of 29.6°C and reaction time of 24 hr. As expected, the predicted THMFP progressively increases from about 52 μg/L to about 80 μg/L as the pH value of water increases from 6.5 to 8.5. At pH 8.5, the predicted TTHM concentration is close to the USEPA standard of 80 μg/L. It should be noted however, pH of raw water at the SWTP seldom reaches a level close to 8.5.

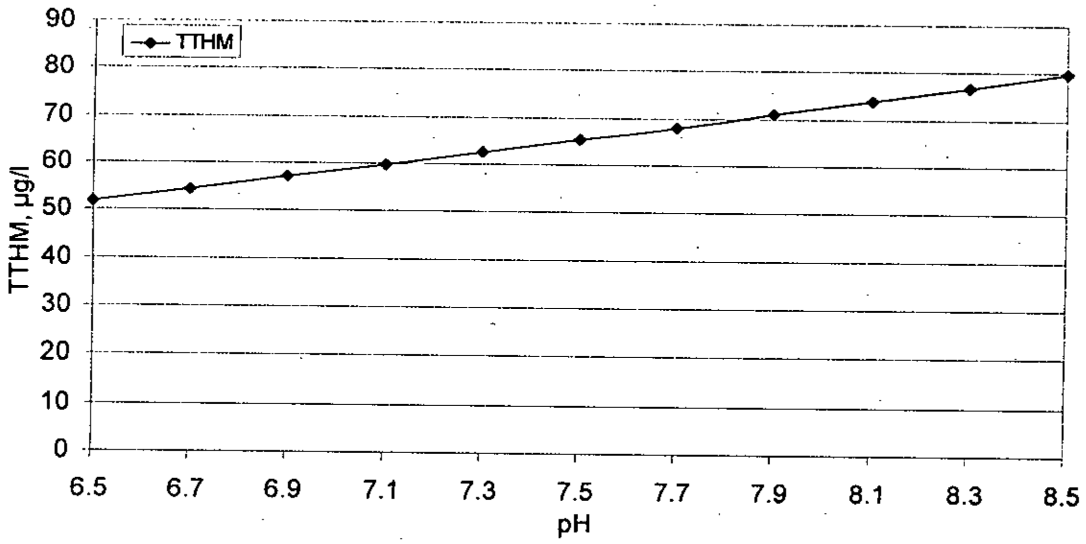


Figure 4.34: Effect of pH on TTHM formation during wet season

Using equation 4.1, Figure 4.35 shows the predicted TTHM concentrations as a function of water temperature at DOC concentration of 2.8 mg/L, available free chlorine concentration of 0.94 mg/L (25% of 3.75 mg/L), bromide concentration of 6 μg/l, pH value of 7.03 and reaction time of 24 hr. As shown in Figure 4.35, the THMFP progressively increases from about 53 μg/L to 65 μg/L as the temperature of water increases from 25 to 35°C; all predicted values are below the USEPA standard of 80 μg/L.

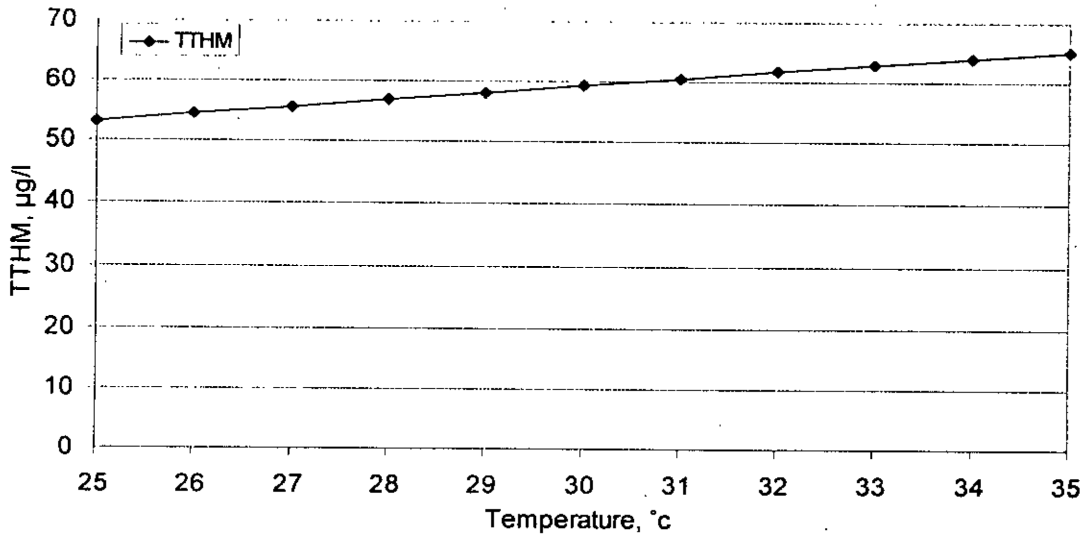


Figure 4.35: Effect of temperature on TTHM formation during wet season

According to the analysis result, the predicted TTHMFP concentration increases with the increase of DOC and bromide concentrations, available free chlorine concentration, pH and temperature of water. TTHM concentrations are much higher during the dry season than those of wet season. In dry season, the predicted TTHM concentrations exceed the European Union recommended value of 100 µg/l as well as the USEPA recommended value of 80 µg/L by a large margin; very high concentrations of DOC, high applied chlorine dose, and relatively higher pH and temperatures contribute to these high predicted values.

During wet season the predicted TTHMFP remains below the European Union and USEPA standards. The lower predicted values are due to low concentration of both DOC and Bromide, relatively low dose of applied chlorine, and relatively low pH and temperature of water during the wet season. Among the estimated individual THMs species, $CHCl_3$ is the dominant THM species in both dry season (95%) and wet season (97%).

It should be noted that the model developed by Amy et al. (1998) for predicting TTHM and individual THM species were calibrated for specific ranges of DOC, bromide, applied chlorine and temperature (see Eq. 4.1 to 4.5). Some of the parameter values used in this study for predicting TTHM and THM species exceeded these ranges. These were DOC concentrations (dry season), temperature (upper limit in both dry and wet seasons) bromide concentrations (wet season).

THM Formation Potential from UV_{254} and DOC

Mean UV_{254} for the raw water of DND canal was 0.1780 cm^{-1} on 10 September of 2007 (wet season) and 0.1748 cm^{-1} on 26 February of 2008 (dry season). Using Eq. 4.6, the estimated Trihalomethane formation potential (THMFP7) is about 333 μg/L for wet season and 328 μg/L for dry season. Thus, the UV_{254} absorbance and hence the estimated THMFP7 for dry and wet seasons, based on UV_{254}, do not vary significantly. The estimated value for the dry season is much lower (by a factor of about 3) while that for the wet season is higher (by a factor of about 3) than the corresponding estimated found using the method of Amy et al. (1998) using a contact time of 24 hours.

As mentioned earlier, estimated DOC concentrations for dry and wet seasons are 29.3 mg/L and 2.8 mg/L, respectively. Using Eq. 4.7, the estimated THMFP7 are 201 μg/L for wet season and 2100 μg/L for dry season. The estimated value for the dry season is higher by a factor of about 2, while that for the wet season is higher by a factor of about 3 compared to the corresponding estimated found using the method of Amy et al. (1998) using a contact time of 24 hours.

4.3.4 Trihalomethane (THM) Concentration in Water

Table 4.7 presents the THM concentrations as well as total ammonia and total chlorine concentrations for four water samples collected on 5 April of 2008. The total THM concentration varied from a low of 8 μg/L for a water sample collected at the SWTP (after post-chlorination) to 33 μg/L for a water sample collected from a residence at Siddeswari, Dhaka. These values are much lower than the WHO 2004 guideline value (health based) of 200 μg/L and Bangladesh standard of 90 μg/L for Chloroform, and the USEPA standard of 80 μg/L for THMs.

Table 4.7: THM concentrations in selected water samples

Sample	Total THM (as $CHCl_3$) μg/L	Total Ammonia (as NH_3-N) mg/L	Total Chlorine (as Cl_2) mg/L
Treated water – 1 (after post Chlorination)	8	7.94	2.9
Treated water – 2 (after post Chlorination)	26	7.68	3.1
Filtered water (before post Chlorination)	<MDL	7.73	2.84
Residence water (Siddeswari)	33	0.075	0.01

MDL: Minimum Detection Limit = 6 μg/L

The THM concentration at the Siddeswari residence water was higher than the treated water of SWTP. This could be due to the long contact times between disinfectant/oxidant and precursors in the distribution system. Generally, DBPs continue to form in drinking water as long as a disinfectant residual and precursors are present. The much lower ammonia concentration in the Siddeswari water suggests that it probably got diluted by mixing with groundwater that is also pumped in the same distribution system. Therefore, it is possible that THM concentration also got reduced by dilution with groundwater in the distribution system. Regular and systematic monitoring of THMs is required before making any concrete conclusions about their presence in drinking water. More sophisticated methods, e.g., using Gas Chromatography (GC) or High Performance Liquid Chromatography (HPLC) should be used to get more reliable results. These facilities are currently not available in the Environmental Engineering Laboratory of BUET.

4.4 SUMMARY

Dry season (January to March) is the critical period for the SWTP, during which raw water quality deteriorates significantly, putting strains on the treatment processes. Monitoring of selected parameters at the SWTP during the dry season (January to March) of 2007 showed that concentrations of both COD (10 to 64 mg/L in treated water) and TOC in raw and treated water remains very high throughout the dry season. Although significant reduction in suspend solids (SS) occurred at the SWTP, on 3 out of 9 sampling dates, the measured SS concentration in the treated water exceeded the Bangladesh drinking water standard of 10 mg/L. Significant reduction in Chlorophyll-A concentrations was found to take place at the SWTP; mean concentrations of Chlorophyll-A in raw and treated water were 46.6 and 6.9 μg/L, respectively during the monitoring period. Relatively high concentrations of Aluminum (Al) in the treated water, exceeding the drinking water standard, most likely comes from high doses of alum (up to 60 mg/L) used during the dry season; suggesting need for optimization of the coagulation process.

Although relatively high concentrations of chlorine (6 to 7 mg/L) is applied, because of high concentrations of ammonia (5.58 to 9.75 mg/L during the monitoring period), the Chlorine to Ammonia ratio remains very low (close to 1 or below 1) at the SWTP. At such low Chlorine to Ammonia ratio, almost the entire applied chlorine is likely to be converted into Monochloramine. The USEPA standard for chloramines in drinking water is 4.0 mg/L (as Cl_2) and the WHO guideline value for Monochloramine is 3 mg/L. Hence, the residual chlorine at SWTP appears to exceed these standards during the dry season. Available information suggest that during wet season, the Chlorine to Ammonia ratio at the SWTP may become very high (> 4) which may promote formation of dichloramine and nitrogen trichloride and give rise to taste and odor problems. While break point chlorination (BPC) does not appear to be a feasible option during the dry season, BPC could be considered as an option to ensure effective chlorination during the wet season.

Total ammonia concentration of treated water at the SWTP has been found to be slightly lower than that in the raw water, possibly due to oxidation of some ammonia to nitrate by the applied chlorine. A significant fraction of total ammonia in the treated water is likely to exist as chloramines. Other observed changes in the treated water quality include: (i) slight reduction in pH and Alkalinity, possibly due to chlorination and coagulation; (ii) slight increase in chloride, possibly due to chlorination applying chlorine gas; and (iii) reduction in phosphate concentration, possibly due to its co-precipitation with aluminum hydroxide flocs.

In the assessment of THM formation potential, the principal uncertainty was the amount of free chlorine that would be available for reaction with organic matters and bromide, leading to THMs formation. It was revealed that at the SWTP raw water quality in the dry season is very susceptible for THM formation. This is primarily because of high DOC concentrations of raw water during the dry season. In addition, higher concentrations of bromide, relatively higher pH and temperature (compared to wet season) are also responsible for high THM formation potential at the SWTP. Even a small concentration of free chlorine may lead to very high concentrations of THMs during the dry season. The predicted Total THMs concentration for the wet season was relatively low, satisfying the Bangladesh standard (chloroform) and USEPA and EU drinking water standards. Limited measurements of THMs during dry season (April 2008) showed that the values are well within the available drinking water standards.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Some of the major conclusions from the present study are summarized below:

Water Quality of DND canal

- The water quality of Sitalakhya river and the DND canal becomes very poor during the dry season (January to March), and is characterized by high concentrations of BOD_5, COD, TOC, Ammonia and Chlorophyll-A (algae); and low concentrations of DO. Possible presence of non-biodegradable organic materials in raw water from industrial discharges may contribute to the high COD and TOC values during dry season.
- Water quality appears to deteriorate progressively from January to March as dry season progresses. Concentrations of a number of water quality parameters, e.g., BOD_5, Ammonia, Phosphate, Chloride and Dissolved Solids increase during this period.
- Water quality within the DND canal does not appear to change significantly during the dry season, except for Chlorophyll-A. The concentration of Chlorophyll-A increases by a factor of 2 to 3 within the 4.6 km stretch of the canal.
- Removal of Ammonia (the major water quality concern at the SWTP during the dry season) or conversion of Ammonia to Nitrate is insignificant along the canal.
- Since residence time of water within the DND canal is relatively short (about 12.9 hrs), BOD reduction by biodegradation is likely to be insignificant (~ 1 mg/L) along the canal. Suspended solids reduction (up to ~ 40%) within the canal during dry season is not accompanied by BOD reduction, which possibly suggests that any reduction in BOD due to settling of particulate BOD (and also biodegradation) is probably accompanied by addition of BOD of similar magnitude from the surrounding areas and from the sediment.

- During the wet season (June to September), water quality of Sitalakhya river and DND canal improves significantly due to rainfall and freshwater inflow from upstream, which results in significant reduction of BOD_5, COD, Ammonia and Chlorophyll-A concentrations and an increase in DO concentration.
- Concentrations of a number of other water quality parameters, e.g., Chloride, Alkalinity, Total Dissolved Solids, Phosphate, are also reduced significantly during this period; pH value of water also drops during the wet season.
- The Suspended Solids concentration in the Sitalakhya river increases significantly during the wet season. However, the DND canal appears to be very effective in reducing the SS concentration, up to 80% reduction of SS concentration was recorded within the DND canal.
- The potential sediment oxygen demand (pSOD) of sediments of DND canal was found to be very high. The sediments of the canal therefore could exert significant oxygen demand on the water, especially during re-suspension events.

Treatment Efficiency at SWTP (Dry Season)

- Significant reduction in Chlorophyll-A concentrations was found to take place at the SWTP; mean concentrations of Chlorophyll-A in treated water was 6.9 μg/L during the monitoring period
- Possible presence of non-biodegradable organic materials in raw water from industrial discharges may contribute to the high COD and TOC values at the SWTP.
- Relatively high concentrations of Aluminum (Al) in the treated water, exceeding the drinking water standard, most likely comes from high doses of alum (up to 60 mg/L) used during the dry season; suggesting need for optimization of the coagulation process.
- Although relatively high concentrations of chlorine (6 to 7 mg/L) is applied, because of high concentrations of ammonia (5.58 to 9.75 mg/L during the monitoring period), almost the entire applied chlorine is likely to be converted into Monochloramine. The residual chlorine at SWTP appears to exceed the available standard (USEPA) and guideline (WHO) of total chlorine and Monochloramine during the dry season.

- The Chlorine to Ammonia ratio at the SWTP may become very high (> 4) which may promote formation of dichloramine and nitrogen trichloride and give rise to taste and odor problems. While break point chlorination (BPC) does not appear to be a feasible option during the dry season, BPC could be considered as an option to ensure effective chlorination during the wet season.
- Total ammonia concentration of treated water at the SWTP is slightly lower than that in the raw water, possibly due to oxidation of some ammonia to nitrate by the applied chlorine. A significant fraction of total ammonia in the treated water is likely to exist as chloramines.
- Other important observed changes include: (i) slight reduction in pH and Alkalinity, possibly due to chlorination and coagulation; (ii) slight increase in chloride, possibly due to chlorination applying chlorine gas; and (iii) reduction in phosphate concentration, possibly due to its co-precipitation with aluminum hydroxide flocs.

THM Formation Potential and THM Concentration in Water

- In the assessment of THM formation potential, the principal uncertainty is the amount of free chlorine that would be available for reaction with organic matters and bromide, leading to THMs formation.
- The raw water at the SWTP is very susceptible for THM formation during dry season because of high concentration of DOC and bromide, and relatively higher pH and temperature. Even a small concentration of free chlorine may lead to very high concentrations of THMs during the dry season.
- The predicted Total THMs concentration for the wet season was relatively low, satisfying the Bangladesh standard (chloroform) and USEPA and EU drinking water standards.
- Limited measurements of THMs during the dry season (April 2008) showed that the values are well within the available drinking water standards.

5.2 RECOMMENDATIONS

The following recommendations are made for future study:

- A systematic study should be carried out to optimize the coagulation process at the SWTP, especially during the dry season.
- Considering the high residual concentrations of chlorine (and monochloramine) during the dry season, and possible formation of dichloramine and nitrogen trichloride during the wet season, systematic study should be carried out to optimize the chlorination process at the SWTP.
- Studies should be carried out to assess possible options of algae control (e.g., applying copper sulphate) and ammonia reduction within the DND canal.
- A study should be carried out for detailed assessment of THM formation at the SWTP, through systematic monitoring of THM precursors, ammonia concentrations and actual concentrations of THMs under different conditions.
- Studies should be carried out to assess alternative disinfection options, e.g., changing the disinfectant, as well as alternative treatment processes, e.g., applying chlorination after coagulation (which would remove humic matters and thereby reduce THM formation potential).

The following recommendations are made for improving raw and treated water quality at the SWTP:

- Maximum efforts should be devoted for improving the raw water quality at the Sitalakhya river, through reduction of discharges of untreated domestic sewage and industrial effluent into the river.
- The feasibility of constructing a second intake point at a suitable location should be considered..
- Studies should be conducted for improving water quality at the SWTP, including studies on: (i) control of algae and ammonia within the DND canal; (ii) optimization of coagulation process; (iii) optimization of disinfection process; (iv) THM formation potential and its control.

- In view of the relatively poor raw water quality at the SWTP during the dry season, the treatment processes to be employed for the planned expansion of the SWTP (Phase-II) should be carefully reviewed.
- THM precursors (e.g., DOC, bromide), THMs, and applied chlorine dose should be included in the regular monitoring program at the SWTP.
- Cleaning of sediment of the DND conveyance canal at suitable intervals should be considered.

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APPENDIX-A
WATER QUALITY OF DND CANAL

Table A-1: pH value of water at the Sarulia intake and along the DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	7.95	7.72	7.57	7.38	7.45	7.63	7.49
05.02.07	7.5	7.6	7.6	7.6	7.6	7.6	7.7
12.02.07	7.09	7.24	7.11	7.23	7.14	7.06	7.15
19.02.07	7.6	7.53	7.7	7.5	7.62	7.65	7.65
26.02.07	7.14	7.05	7.24	7.51	7.4	7.45	7.43
05.03.07	7.14	7.15	7.12	7.05	7.14	7.2	7.12
12.03.07	7.46	7.4	7.5	7.5	7.5	7.5	7.6
19.03.07	7.6	7.47	7.52	7.28	7.22	7.55	7.46
27.03.07	7.48	7.45	7.48	8	7.4	7.42	7.45
29.06.07	--	7.2	6.96	7.05	7.04	7.1	7.05
10.09.07	--	6.83	6.8	7.2	6.96	7.06	7.06

Note: Location of sampling points along DND canal

Sampling Station	GPS Position (Deg Min Sec)		Distance from the starting point of DND canal
	Latitude	Longitude	(km)
Sarulia (SAR)	23° 43′ 02.6″	90° 30′ 0.4″	--
DND-1	23° 43′ 03.8″	90° 29′ 40.9″	0.215
DND-2	23° 43′ 09.7″	90° 29′ 25.5″	0.695
DND-3	23° 43′ 06.2″	90° 29′ 04.1″	1.312
DND-4	23° 43′ 02.4″	90° 28′ 28.1″	2.344
DND-5	23° 42′ 58.8″	90° 27′ 56.8″	3.240
DND-6	23° 42′ 50.8″	90° 27′ 23.1″	4.226

Table A-2: Chloride concentration (mg/L) of water at Sarulia intake and along DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	49	49	45	38	41	42	42
05.02.07	--	--	--	--	--	--	--
12.02.07	56	53	56	56	49	48	49
19.02.07	68	68	68	64	67	64	63
26.02.07	66	65	58	65	71	65	67
05.03.07	73	73	69	70	72	72	65
12.03.07	70	77	77	78	78	78	76
19.03.07	92	90	90	88	92	86	94
27.03.07	94	94	96	92	96	96	96
29.06.07	--	--	8	--	9	--	11
10.09.07	--	4	6	6	5	6	6

Table A-3: Alkalinity (mg/L) of water at the Sarulia intake and along the DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	218	226	214	204	205	215	222
05.02.07	--	--	--	--	--	--	--
12.02.07	230	232	233	226	225	226	232
19.02.07	243	237	244	240	242	234	234
26.02.07	232	221	208	217	227	246	242
05.03.07	257	251	242	255	256	254	262
12.03.07	239	242	271	275	260	260	165
19.03.07	257	253	265	265	264	273	271
27.03.07	199	225	239	245	238	241	232
29.06.07	--	--	39	--	37	--	39
10.09.07	--	56	54	65	56	58	60

Table A-4: TDS (mg/L) of water at Sarulia intake and along the DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	341	325	305	272	300	294	274
05.02.07	400	392	389	395	408	383	392
12.02.07	307	314	306	298	271	301	294
19.02.07	433	442	430	425	417	414	386
26.02.07	375	391	345	349	385	371	379
05.03.07	399	405	390	372	389	375	391
12.03.07	429	454	433	438	423	438	441
19.03.07	480	447	468	451	464	443	474
27.03.07	449	464	472	467	473	445	455
29.06.07	--	--	100	--	99	--	92
10.09.07	--	68	84	93	87	81	79

Table A-5: Electrical Conductivity (µS/cm) and Temperature (°C) of water along the DND

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	587 23.9	584 23.8	565 23.8	515 23.7	529 23.8	533 23.8	524 23.8
05.02.07	679 21.1	661 20.8	653 21	665 21.3	667 21.1	655 20.6	649 21
12.02.07	605 24.1	590 24.1	603 24	587 24	557 23.7	558 24.1	563 24.2
19.02.07	729 23.8	725 23.9	729 23.8	708 23.8	704 23.8	704 23.8	701 23.9
26.02.07	686 25.3	680 25.4	627 25.1	668 25.4	697 25.3	684 25.2	687 25.3
05.03.07	763 25.1	757 25.1	736 25.1	732 25	734 25	731 25	726 25
12.03.07	739 26.9	767 27.4	781 27.2	770 27.6	772 26.4	772 26.8	772 27.3
19.03.07	819 29.2	818 28.9	844 29.1	846 28.9	838 28.1	840 28.5	850 28.7
27.03.07	820 29.4	824 29.3	828 29.9	813 29.9	815 29.1	802 29.2	800 29.1
29.06.07	--	93.7	100.5	106.4	104.4	106.7	113.2
10.09.07	--	115	116.3	137.5	119.9	121	122

Table A-6: TSS (mg/L) of water at the Sarulia intake and along the DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	24	20	21	17	15	12	19
05.02.07	63	54	34	34	31	58	11
12.02.07	19	22	29	31	25	15	28
19.02.07	44	10	25	14	10	17	19
26.02.07	51	35	47	25	37	54	23
05.03.07	43	23	26	33	21	13	19
12.03.07	35	37	41	28	40	19	13
19.03.07	36	29	35	57	6	49	9
27.03.07	50	15	24	30	10	12	4
29.06.07	--	--	85	--	29	--	0
10.09.07	--	110	62	65	7	44	19

Table A-7: Turbidity in NTU of water along the DND canal

Date	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
10.09.07	73	52	50	29	37	20

Table A-8: Color concentration in Pt-Co unit of water along the DND canal

Date	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.06.07		106		100		42
10.09.07	184	202	190	168	164	175

Table A-9: DO concentration (mg/L) of water at the Sarulia intake and along the DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	1.13	0.98	1.02	1.6	1.45	1.7	0.85
05.02.07	1.89	0.56	0.12	0.19	0.1	0.9	0.23
12.02.07	2.95	1.42	1.85	1.1	1.01	2.43	1.95
19.02.07	0.8	0.34	0.41	0.2	0.9	1.01	0.75
26.02.07	0.86	0.43	0.56	0.54	0.6	0.53	0.67
05.03.07	1.97	0.93	0.79	1.37	1.34	1.05	1.09
12.03.07	1.2	1.4	0.6	2.2	0.2	2.6	2.6
19.03.07	3.2	3.2	4.2	3.6	0.4	2.6	2
27.03.07	1.6	2	1.4	3	0.4	2.2	3.2
10.09.07	--	4.53	4.48	4.7	4.33	3.85	3.99

Table A-10: BOD_5 (mg/L) of water at the Sarulia intake and along the DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	12.8	11.2	10	8.4	8.8	6.8	9.2
05.02.07	14.8	15.6	15	14.8	13.8	13.8	14.8
12.02.07	11	15	7	12	14	11	12
19.02.07	26	17	19	22	16	17	17
26.02.07	20	20	15	19	17	19	19
05.03.07	18	17	18	16	15	18	20
12.03.07	22.2	11.2	3.2	22.4	20.8	8	20.8
19.03.07	12.8	9.6	14.4	9.6	19.2	13	12
27.03.07	22.4	22.4	22	22.4	22.4	11.2	12.8
29.06.07	--	4	4	4	4.4	3.6	2.8
27.07.07	--	3	4	2	1	3	7
10.09.07	--	2	2	1.8	1.4	1.8	2.4

Table A-11: BOD_F (filtered water) (mg/L) of water along the DND canal

Date	DND-2	DND-4	DND-6
27.03.07	13	12	11

Table A-12: BOD_3 (mg/L) of water along the DND canal

Date	DND-2	DND-4	DND-6
27.03.07	8	11.2	9.6

Table A-13: COD (mg/L) of water at the Sarulia intake and along the DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
05.03.07	57	59	61	57	59	57	60
29.06.07	--	9	8	9	12	8	6
27.07.07	--	8	5	3	5	12	8
10.09.07	--	6	3	1	5	2	<2

Table A-14: TOC concentration in mg/L of water along the DND canal

Date	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
05.02.07	39.2	27.4	11.6	27.4	28.4	26
19.02.07	24.75	23.75	22.5	21.5	20.5	19.25
05.03.07	76.5	75	75	71.5	67	73.5
19.03.07	41	42	50	36	47	19

Table A-15: Organic-N concentration in mg/L of water along the DND canal

Date	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
27.07.07	0.56	0.672	1.008	0.56	0.56	0.448

Table A-16: Total Ammonia (mg/L as NH_3-N) of water at Sarulia intake and along DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	6.57	6.625	6.035	6.045	6.165	6.015	6.13
05.02.07	7.925	8.07	8.02	7.845	7.645	7.945	7.725
12.02.07	6.48	7.365	7.19	6.725	6.9	7.06	7.3
19.02.07	7.62	7.68	7.325	7.525	7.05	6.915	6.815
26.02.07	9.21	8.77	8.11	8.7	9.47	9.115	8.835
05.03.07	9.155	9.13	9.445	9.4	8.76	8.355	8.53
12.03.07	11.125	10.915	10.785	11.125	11.045	10.615	10.465
19.03.07	8.222	8.355	8.525	8.53	9.73	9.41	9.26
27.03.07	9.4	9.02	8.595	8.185	9.11	8.64	8.5
29.06.07	--	0.476	0.297	0.257	0.344	0.391	0.39
27.07.07	--	0.28	0.52	0.38	0.25	0.51	0.3
10.09.07	--	0.381	0.43	0.387	0.336	0.313	0.334

Table A-17: Nitrate concentration (mg/L) of water at Sarulia intake and along DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	0.2	0.3	0.2	0.3	0.2	0.2	0.2
05.02.07	0.9	1.2	1.1	1	0.9	1.2	1.1
12.02.07	0.5	0.3	0.3	0.3	0.2	0.2	0.2
19.02.07	0.3	0.1	0.1	0.2	0.1	0.1	0.1
26.02.07	0.3	0.3	0.2	0.2	0.3	0.2	0.3
05.03.07	0.1	0.1	0.1	0.1	0.1	0.1	0.1
12.03.07	0.3	0.1	0.2	0.2	0.2	0.2	0.1
19.03.07	0.3	0.3	0.4	0.8	0.2	0.2	0.2
27.03.07	0.7	2.9	2.8	0.4	5.2	3.9	0.5
29.06.07		0.4	0.5	0.5	0.4	0.5	0.5
27.07.07		0.7	0.6	0.6	0.7	0.7	0.7
10.09.07		0.5	0.4	0.6	0.6	0.6	0.7

Table A-18: Nitrite concentration (mg/L) of water at Sarulia intake and along DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	0.007	0.005	0.006	0.055	0.005	0.005	0.007
05.02.07	0.004	0.003	0.005	0.005	0.005	0.005	0.007
12.02.07	0.0095	0.0051	0.02	0.065	0.0038	0.0064	0.0039
19.02.07	0.0661	0.0695	0.158	0.0725	0.0822	0.0581	0.0546
26.02.07	0.0056	0.0051	0.0046	0.0044	0.0047	0.0055	0.0055
05.03.07	0.005	0.0047	0.0045	0.0029	0.004	0.0037	0.0036
12.03.07	0.005	0.0054	0.0058	0.0052	0.0058	0.0051	0.0046
19.03.07	0.1189	0.1241	0.131	0.0766	0.1212	0.0405	0.0745
27.03.07	0.069	0.158	0.225	0.256	0.098	0.093	0.415
29.06.07		0.0279	0.0393	0.039	0.0467	0.0474	0.0355
10.09.07		0.0452	0.0439	0.0531	0.0757	0.0715	0.0816

Table A-19: Phosphate concentration (mg/L) of water at Sarulia intake and along DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	1.103	1.078	1.14	0.946	0.718	0.686	0.839
05.02.07	0.645	1.141	0.38	0.185	0.341	0.201	0.167
12.02.07	0.363	0.496	0.506	0.487	0.499	0.445	0.499
19.02.07	1.218	1.495	1.179	1.716	0.91	1.464	1.168
26.02.07	0.869	1.242	1.361	1.35	1.366	1.596	1.357
05.03.07	0.982	1.544	2.586	1.506	1.836	1.547	1.469
12.03.07	1.335	0.828	1.261	1.431	1.194	1.639	1.566
19.03.07	1.584	1.66	1.724	1.561	1.616	1.484	1.957
27.03.07	2.603	2.952	1.674	2.253	1.848	2.247	2.423
29.06.07		0.218	0.319	0.3	0.235	0.398	0.362
10.09.07		<0.045	0.001	0.001	0.002	0	0.001

Table A-20: Sulfate concentration (mg/L) of water at Sarulia intake and along DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
27.03.07	47.3	46.2	45.2	45.3	45.6	44.4	45

Table A-21: Chlorophyll-A concentration (μg/L) of water along the DND canal

Date	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	12.02	21.36	23.36	24.69	50.73	42.38
05.02.07	27.38	31.37	39.38	40.69	47.3	42.09
12.02.07	19.35	31.37	31.37	52.73	48.06	72.09
19.02.07	31.05	15.18	16.56	29	26.91	31.74
26.02.07	20.73	28.3	44.16	44.06	50.06	60.74
05.03.07	20.7	23.36	18.7	67.42	88.78	52.73
12.03.07	49.4	40.05	57.4	62.08	58.74	116.81
19.03.07	90.4	69.7	77.97	89.7	79.35	60.72
27.03.07	59.4	88.78	92.12	51.4	58.07	73.42
10.09.07	5.34	2.67	4.01	3.67	2.67	4.01

Table A-22: Metals concentrations (sampling on 10.09.07) of water along DND canal

Metals	Acidified water			Filtered water		
	DND-1	DND-3	DND-5	DND-1	DND-3	DND-5
Cu (mg/L)	0.018	0.012	0.008	0.082	0.018	0.015
Cd (mg/L)	0.001	<0.001	0.001	0.004	0.001	0.001
Pb (μg/l)	1.113	0.55	0.181	<1	<1	<1
Cr (μg/l)	3.9	<MDL	<MDL	0.09	<MDL	<MDL

Table A-23: Temperature in °C of water at Sarulia intake and along the DND canal

Date	SAR	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
29.01.07	21.8	21.7	22	22.5	21.6	21.6	21.7
05.02.07	23.9	23.1	23.4	23.6	23.2	23.7	23.4
12.02.07	23.2	21.9	23.3	23	23.1	23.7	23.7
19.02.07	23.3	23.4	23.5	23.1	23.7	23.8	23.7
26.02.07	24.1	24.2	24.2	24	24.1	24.4	24.4
05.03.07	25.7	24.6	24.9	24.9	24.5	24.6	24.9
12.03.07	26.9	27.4	27.2	27.6	26.4	26.8	27.3
19.03.07	29.2	28.9	29.1	28.9	28.1	28.5	28.7
27.03.07	29.4	29.3	29.9	29.9	29.1	29.2	29.1
10.09.07		28.9	29.1	29.3	30.1	30.1	29.9

APPENDIX-B
SEDIMENT QUALITY OF DND CANAL

Table B-1: Sediment quality along DND canal

Parameter	DND-1	DND-3	DND-5
Copper (mg/kg)	57.8	426	39
Cadmium (mg/kg)	0.5	0.4	0.7
Lead (mg/kg)	325	8.8	22.4
Chromium (mg/kg)	13.6	4.55	7.64
Organic Matter (%)	4.35	1.05	2.70
Moisture Content (%)	40.2	25.7	32.2
Specific Gravity	2.71	2.73	2.67

Table B-2: Test results of SOD for DND-1 sample

5 gm sediment		10 gm sediment	
Time, min	DO, mg/L	Time, min	DO, mg/L
1	6.72	1	6.2
2	6.6	2	5.41
3	6.46	3	5.19
4	6.33	4	5.06
5	6.22	5	4.87
6	6.08	6	4.66
7	5.97	7	4.35
8	5.88	8	4.13
9	5.69	9	3.93
10	5.46	10	3.77
11	5.3	11	3.63
12	5.14	12	3.45
13	5	13	3.35
4	4.88	4	3.25
15	4.75	15	3.15
16	4.65	16	3.05
17	4.58	17	2.96
18	4.52	18	2.88
19	4.46	19	2.8
20	4.4	20	2.72
21	4.36	21	2.65
22	4.29	22	2.57
23	4.24	23	2.5
24	4.19	24	2.44
25	4.14	25	2.38
26	4.1	26	2.31
27	4.06	27	2.26
28	4.01	28	2.2
29	3.98	29	2.15
30	3.93	30	2.1
31	3.9	35	1.83
32	3.87	45	1.45
38	3.77	75	0.63
39	3.71	90	0.35
40	3.67	95	0.25
41	3.63	100	0.18
42	3.58	105	0.12
43	3.54	110	0.05
44	3.52	115	0.03
45	3.49	120	0.03

5 gm sediment		10 gm sediment	
Time, min	DO, mg/L	Time, min	DO, mg/L
46	3.46	140	0.02
47	3.42	--	--
48	3.4	--	--
49	3.38	--	--
50	3.34	--	--
55	3.2	--	--
60	3.1	--	--
70	2.87	--	--
80	2.7	--	--
95	2.45	--	--
110	2.24	--	--
130	1.98	--	--
150	1.76	--	--
180	1.49	--	--
210	1.25	--	--
240	1.05	--	--
270	0.88	--	--
300	0.72	--	--
1417	0.03	--	--
1440	0.02	--	--
1467	0.02	--	--

Table B-3: Test results of SOD for DND-3 sample

5 gm sediment		10 gm sediment	
Time, min	DO, mg/L	Time, min	DO, mg/L
1	6.93	1	7.44
2	6.9	2	7.37
3	6.76	3	7.26
4	6.73	4	7.23
5	6.69	5	7.17
6	6.69	6	7.12
7	6.66	7	7.06
8	6.63	8	7.02
9	6.62	9	6.99
10	6.61	10	6.94
11	6.58	11	6.91
12	6.57	12	6.87
13	6.55	13	6.84
4	6.53	4	6.8
15	6.52	15	6.78
16	6.51	16	6.74
17	6.49	17	6.73
18	6.45	18	6.7
19	6.45	19	6.66
20	6.43	20	6.64
21	6.43	21	6.62
22	6.42	22	6.6
23	6.39	23	6.58
24	6.36	24	6.54
25	6.36	25	6.53
26	6.37	26	6.5
27	6.37	27	6.48
28	6.34	28	6.45
29	6.31	29	6.43
30	6.29	30	6.41

5 gm sediment		10 gm sediment	
Time, min	DO, mg/L	Time, min	DO, mg/L
35	6.23	35	6.3
45	6.17	45	6.11
60	6.08	60	5.87
90	5.8	90	5.44
120	5.71	120	5.04
150	5.5	150	4.71
180	5.43	180	4.28
210	5.28	210	3.8
240	5.18	240	3.44
1410	2.9	270	3.08
1440	2.83	300	2.81
--	--	1410	0.04
--	--	1440	0.03
--	--	1455	0.03

Table B-4: Test results of SOD for DND-5 sample

5 gm sediment		10 gm sediment	
Time, min	DO, mg/L	Time, min	DO, mg/L
1	6.7	1	5.67
2	6.4	2	5.28
3	6.24	3	4.97
4	6.1	4	4.7
5	5.97	5	4.49
6	5.85	6	4.27
7	5.76	7	4.08
8	5.65	8	3.91
9	5.57	9	3.75
10	5.49	10	3.6
11	5.39	11	3.45
12	5.3	12	3.3
13	5.21	13	3.14
4	5.12	4	3.03
15	5.05	15	2.9
16	4.97	16	2.79
17	4.87	17	2.69
18	4.83	18	2.59
19	4.75	19	2.49
20	4.69	20	2.39
21	4.63	21	2.32
22	4.58	22	2.22
23	4.52	23	2.14
24	4.46	24	2.06
25	4.4	25	1.98
26	4.35	26	1.9
27	4.31	27	1.83
28	4.24	28	1.75
29	4.2	29	1.69
30	4.15	30	1.62
35	3.92	35	1.3
45	3.6	40	1.02
60	3.24	45	0.74
80	2.68	50	0.54
110	2.04	55	0.34
140	1.49	60	0.12
170	1	65	0.04

5 gm sediment		10 gm sediment	
Time, min	DO, mg/L	Time, min	DO, mg/L
200	0.54	70	0.04
1390	0.02	85	0.03
--	--	95	0.03
--	--	130	0.03

APPENDIX-C
WATER QUALITY AT SWTP

Table C-1: pH value of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	7.81	7.44	7.23	7.65	7.22
06.02.07	7.6	7.6	7.6	7.7	7.7
13.02.07	7.2	6.91	6.89	6.97	6.86
20.02.07	7.38	7.11	7.08	7.13	7.08
27.02.07	7.54	6.97	6.93	6.98	6.94
06.03.07	7.5	6.75	6.74	7.18	6.98
13.03.07	7.5	6.72	6.67	6.96	7.12
20.03.07	7.68	7.19	6.11	7.24	7.34
28.03.07	7.53	6.96	6.78	7.01	7.21

Note: Location of sampling points at the SWTP

SWTPI	Raw water at the plant intake
SWTP-1	Water after alum dose, just before water flows into the blue distribution pipe to the pulsators;
SWTP-2	Water after the pulsators, just before water enters one of the filter beds fed by the same pulsator; and
SWTP-3	Filtrate water of the above filter (it was ensured that the specific filter has been in operation for more than one hour after backwash).
SWTPO	Treated water after post Chlorination

Table C-2: Chloride concentration in mg/L of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	43	52	52	52	50

Table C-3: Alkalinity in mg/L of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	211	195	195	195	180

Table C-4: TDS in mg/L of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	302	304	303	286	284
06.02.07	361	375	394	383	376
13.02.07	358	370	352	359	-
20.02.07	461	453	451	454	448
27.02.07	395	412	406	416	403
06.03.07	276	449	461	468	457
13.03.07	439	457	456	450	427
20.03.07	462	476	462	453	465
28.03.07	483	484	492	497	476

Table C-5: Electrical conductivity in µS/cm (Temperature, °C) of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	560	553	556	553 (24.0)	545
06.02.07	672 (22.9)	680 (23.0)	680 (22.9)	679 (22.9)	673 (22.9)
20.02.07	708 (22.3)	708 (22.2)	707 (22.4)	706 (22.0)	700 (22.1)
27.02.07	649 (22.1)	645 (22.2)	630 (21.0)	628 (20.7)	626 (20.9)
06.03.07	739 (25.1)	750 (24.3)	749 (24.8)	756 (24.2)	745 (25.5)
13.03.07	776 (26.5)	495 (26.9)	483 (26.5)	787 (26.3)	784 (27.1)
20.03.07	845 (28.7)	850 (27.9)	855 (28.2)	862 (27.5)	856 (27.8)
28.03.07	815 (28.1)	813 (28.4)	815 (28.5)	819 (28.2)	815 (28.8)

Table C-6: TSS in mg/L of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	19	21	14	18	6
06.02.07	11	57	7	12	11
13.02.07	28	31	20	11	--
20.02.07	19	14	21	15	14
27.02.07	23	23	24	13	10
06.03.07	19	--	18	10	8
13.03.07	13	37	19	16	12
20.03.07	9	62	11	5	10
28.03.07	4	4	16	6	7

Table C-7: DO in mg/L of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	1.96	3.31	5.2	6.15	6.27
06.02.07	0.77	3.22	4.65	5.68	6.15
13.02.07	2.23	3.81	5.31	6.1	6.15
20.02.07	0.6	3.35	4.9	5.88	5.85
27.02.07	2.3	3.69	5.53	5.91	6.15
06.03.07	2.4	4.6	6.6	8.2	8.2
13.03.07	2.4	5.2	6.6	7.4	7.6
20.03.07	2.4	4.4	7.2	7.6	8
28.03.07	2.4	5.6	7	7.6	8

Table C-8: COD in mg/L of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3
31.01.07	25	33	21	20
06.02.07	43	55	30	29
13.02.07	51	35	21	10
20.02.07	32	25	26	19
27.02.07	45	37	39	37
06.03.07	57.2	64	36	33
13.03.07	54	53	36	32
20.03.07	45	32	31	30
28.03.07	54	47	30	25

Table C-9: TOC in mg/L of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3
06.02.07	20.4	27	22.2	16.4
20.02.07	--	93.5	58.5	62.5
06.03.07	--	78	69	68
20.03.07	--	33	23	23

Table C-10: Total Ammonia (as NH_3-N) concentration (mg/L) of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	6.18	5.65	5.85	5.885	5.58
06.02.07	7.005	6.79	7.095	7.14	6.925
13.02.07	6.73	6.23	6.37	6.31	-
20.02.07	7.21	6.885	6.955	6.535	6.785
27.02.07	8.78	9.035	8.51	8.655	8.4
06.03.07	8.92	8.59	8.26	8.415	8.23
13.03.07	9.745	10.155	10.24	10.01	9.75
20.03.07	7.365	6.905	7.67	7.435	7.34
28.03.07	8.565	8.92	8.595	8.515	8.6

Table C-11: Nitrate (NO_3-N) concentration (mg/L) of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	0.2	1	0.9	0.9	1.1
06.02.07	0.2	08	0.9	0.8	1
13.02.07	--	1	1	1	--
20.02.07	0.2	0.6	0.8	0.7	0.7
27.02.07	0.2	1	0.9	0.9	1.1
06.03.07	0.1	1.1	1	1.2	1.2
13.03.07	--	0.9	0.9	0.9	--
20.03.07	0.4	0.8	0.8	0.8	1
28.03.07	0.2	0.7	0.7	0.9	0.6

Table C-12: Nitrite (NO_2-N) concentration (mg/L) of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	0.015	0.012	0.011	0.011	0.012
06.02.07	0.007	0.02	0.019	0.02	0.026
13.02.07	-	0.006	0.007	0.006	-
20.02.07	0.0101	0.0195	0.0196	0.021	0.0179
27.02.07	0.004	0.007	0.007	0.011	0.014
06.03.07	0.0358	0.0449	0.0202	0.0253	0.0289
13.03.07	0.0254	0.063	0.0465	0.0211	0.0152
20.03.07	0.0275	0.0142	0.0136	0.0197	0.0297
28.03.07	0.0064	0.0065	0.0063	0.0093	0.0151

Table C-13: Phosphate (PO_4) concentration (mg/L) of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	1.176	0.826	0.548	0.512	0.41
06.02.07	0.478	0.398	0.403	0.472	0.707
13.02.07	-	0.186	0.228	0.213	-
20.02.07	1.852	0.34	0.407	0.421	0.434
27.02.07	1.376	0.28	0.27	0.31	-
06.03.07	0.173	0.216	0.226	0.202	0.444
13.03.07	2.248	1.26	1.744	1.562	2.086
20.03.07	2.068	0.512	0.481	0.536	0.827
28.03.07	2.87	1.1	0.804	1.32	0.96

Table C-14: Sulfate concentration (mg/L) of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	4.4	38.3	38.7	39.2	35.3
06.02.07	6.9	53.5	57.4	57.4	52.8
13.02.07	-	49.6	50.9	51.7	-
20.02.07	42.3	63.2	65.2	66.5	63.1
27.02.07	34.9	72.6	76.7	78.2	-
06.03.07	41.7	78.3	93	95	70
13.03.07	65.7	64.7	66.7	66.6	41.6
20.03.07	91	77	88.5	52.5	74
28.03.07	43.6	61.5	58.6	64.4	57.7

Table C-15: Sulfide (S^{2-}) concentration (μg/L) of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	10	8	9	14	10
06.02.07	25	7	10	19	18
13.02.07	-	2	8	5	-
20.02.07	18	9	8	8	12
27.02.07	6	12	10	9	-
06.03.07	14	7	8	15	13
13.03.07	14	10	10	12	18
20.03.07	6	7	8	19	9
28.03.07	11	4	4	7	6

Table C-16: Chlorophyll-A concentration (μg/L) of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3
31.01.07	34.5	23.46	16.56	9.68
06.02.07	44.85	12.01	5.5	<MDL
13.02.07	15.58	34.71	10	3.67
20.02.07	55.17	21.39	9.7	5.86
27.02.07	53.4	29.37	3.67	8.68
06.03.07	30.71	18.7	7.68	2.34
13.03.07	92.78	4.67	5.34	11.35
20.03.07	57.27	11.35	4.14	5.18
28.03.07	35.38	8.01	8.01	14.68

Table C-17: Total Phytoplankton concentration in (Indiv./L)*10^5 of water at the SWTP

Date	SWTP-1	SWTP-2	SWTP-3
31.01.07	4.3	2.1	4.4
06.02.07	2.6	2.7	1.6
13.02.07	2.5	2.2	1.5
20.02.07	4	4.1	2.5
27.02.07	3.5	3.8	3.8
06.03.07	3.3	2	3.4
13.03.07	7.9	10	9.2
20.03.07	16	30	12
28.03.07	19	18	6.8

Table C-18: Aluminum concentration (mg/L) of water at the SWTP

Date	SWTP-1	SWTP-2	SWTP-3
31.01.07	1.418	2.321	0.584
06.02.07	3.532	1.097	0.533
13.02.07	3.742	1.639	0.334
20.02.07	14.466	1.476	0.589
27.02.07	6.242	1.02	0.544
06.03.07	7.254	0.883	0.39
13.03.07	1.253	1.524	0.742
20.03.07	4.994	1.16	0.646
28.03.07	3.215	1.022	0.497

Table C-19: Chromium concentration (mg/L) of water at the SWTP

Date	SWTP-1	SWTP-2	SWTP-3
31.01.07	0.007	0.007	0.006
06.02.07	0.01	0.007	0.006
13.02.07	0.012	0.039	0.007
20.02.07	0.008	0.008	0.009
27.02.07	0.008	0.007	0.006
06.03.07	0.01	0.005	0.007
13.03.07	0.007	0.008	0.015
20.03.07	0.009	0.007	0.013
28.03.07	0.006	0.005	0.005

Table C-20: Nickel concentration (mg/L) of water at the SWTP

Date	SWTP-1	SWTP-2	SWTP-3
31.01.07	0.0073	0.0135	0.0065
06.02.07	0.0107	0.0082	0.0128
13.02.07	0.0098	0.0278	0.0042
20.02.07	0.0016	0.0071	0.0104
27.02.07	0.0102	0.0062	0.0079
06.03.07	0.0123	0.012	0.0113
13.03.07	0.011	0.0071	0.0092
20.03.07	0.0099	0.0134	0.0172
28.03.07	0.0163	0.0116	0.0113

Table C-21: Temperature in °C of water at the SWTP

Date	SWTPI	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	22.7	22.6	23.4	22.4	23.1
06.02.07	23.2	23.2	23.6	23.6	23.7
13.02.07	22.5	22.7	23.3	23	24.5
20.02.07	22.7	23.1	23.4	23.2	24.4
27.02.07	23.6	24	25.1	24	25.1
06.03.07	25.1	24.3	24.8	24.2	25.5
13.03.07	26.5	26.9	26.5	26.3	27.1
20.03.07	28.7	27.9	28.2	27.5	27.8
28.03.07	28.1	28.4	28.5	28.2	28.8

Table C-22: Total Chlorine concentration (mg/L) of water at the SWTP

Date	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	4.4	4.55	4.9	5.95
06.02.07	4.4	3.75	3.9	4.9
20.02.07	3	3.9	3.8	-
06.03.07	4	4.2	4.3	4.2
13.03.07	4.3	4.1	4.15	-

Table C-23: Free Chlorine concentration (mg/L) of water at the SWTP

Date	SWTP-1	SWTP-2	SWTP-3	SWTPO
31.01.07	0.26	0.3	0.3	0.35
06.02.07	0.33	0.3	0.38	0.41
20.02.07	0.86	0.96	1.2	-
13.03.07	2.24	0.9	1.46	-

Table C-24: Break Point Chlorination experiment of inlet pit water at the SWTP

6 March 2007		13 March 2007	
Chlorine dose, mg/L	Residual Chlorine, mg/L	Chlorine dose, mg/L	Residual Chlorine, mg/L
0	0	0	0
10	8.15	20	15.74
20	15.3	30	24.38
30	26.6	40	35.02
40	29.92	50	42.55
50	30.14	60	44.1
60	22.61	70	33.24
70	8.2	75	20.39
80	6.43	80	7.98
90	13.96	90	10.86
100	24.82	100	21.28
--	--	125	46.32

Table C-25: Raw water quality of inlet pit water at the SWTP

Date	Alkalinity, mg/L	Chloride, mg/L	Hardness, mg/L	BOD_5, mg/L	NH_3-N, mg/L
06.03.07	184	69	154	-	8.92
13.03.07	244	75	160	12.8	9.855

Table C-26: Detention time within SWTP

Intake to SWTP		
Sarulia Intake P/S. to DND Canal	6 min. to 7 min.	0.11 hour
DND Canal	12 hour to 12.5 hour	12.25 hour
Mirdhabari to SWTP	30 min. 35 min.	0.54 hour
	Total (intake to SWTP)	*12.90 hour*
Treatment Plant *(RWPS to TW Reservoir)*		
R/W Pump station to Dividing chamber	2 to 3 min.	0.04 hour
Dividing Chamber	0.5 min. to 1 min.	0.01 hour
Clarifier	1 hr to 42 min.	1.70 hour
Filter	10 min. to 12 min.	0.18 hour
	Total (RWPS to TW reservoir)	*1.94 hour*

RWPS: Raw Water Pump Station; TW: Treated Water
Source: DWASA document

APPENDIX-D
THM FORMATION POTENTIAL

Table D-1: Raw water quality of DND canal

Water Quality Parameters	Dry season (January to March)	Wet season (June to September)
pH	7.05 to 8.0	6.4 to 7.4
UV_{254}, cm^{-1}	**0.1748	**0.178
DOC, mg/L	*29.3	*2.8
Bromide, µg/l	**63	**6
Temperature, °c	21.6 to 29.9	28.9 to 30.1
Chlorine dosage, mg/L	6 to 7	3 to 4.5

*Estimated; **Average concentration

Table D-2: Bromide concentration in µg/l of water along the DND canal

Date	DND-1	DND-3	DND-5
29.06.07	5	6	7
26.02.08	65	61	63

Table D-3: UV_{254} concentration in cm^{-1} of water along the DND canal

Date	DND-1	DND-3	DND-5
10.09.07	0.2285	0.148	0.158
26.02.08	0.185	0.171	0.1685

Table D-4: DOC concentration in mg/L of water along the DND canal
(measured from Plasma Plus Laboratory)

Date	DND-1	DND-3	DND-5
10.09.07	3568	3542	3546

Note: DOC values appear to be too high; not used in estimation of THMFP

Table D-5: Total Chlorine concentration (mg/L) of water along the DND canal

Date	DND-1	DND-2	DND-3	DND-4	DND-5	DND-6
10.09.07	0.01	0.01	0.01	0.02	0.02	0.01

Table D-6: THM concentration in water

Sample	THM as $CHCl_3$, ppb	Ammonia as NH_3-N, mg/L	Total Chlorine, mg/L
Treated water – 1 (after post Chlorination)	8	7.94	2.9
Treated water – 2 (after post Chlorination)	26	7.68	3.1
Filtered water (before post Chlorination)	<MDL	7.73	2.84
Residence water (Siddeswari)	33	0.075	0.01