ANALYSIS OF ROOT CAUSES OF THE EXCESSIVE CHLORINE DEMAND IN WATER TREATMENT

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Analysis of root causes of the excessive chlorine demand in water treatment

ABSTRACT

To make water suitable for human consumption, water from most sources must first be treated, and the source water that can be used as raw water for public water supplies should conform to quality standards stipulated in the Sri Lanka Standard SLS722. However, sometimes, National Water Supply and Drainage Board (NWSDB) water treatment plants do not receive raw water according to SLS722 due to contamination. In some cases, existing treatment facilities is not enough to face emergency situations, even though the average quality conforms to the SLS 722. In such situations, the operation of treatment plants becomes a challenge, as it is the responsibility of the NWSDB to provide safe drinking water to the consumers, which means that disinfection, has to be carried out even though the chlorine demand may become very high due to excessive amounts of contaminants during such events. The purpose of this research was to analyze the root causes of the excessive chlorine demand in water treatment and recommend an appropriate system capable of removing dissolved iron, ammonia and manganese from the raw water, avoiding the use of chemical treatment if possible, and prepare an emergency plan to face the situation at the Biyagama Water treatment Plant.

According to the past water quality data at BWTP colour, turbidity, BOD, faecal coliform, free ammonia content, nitrate, sulfate etc. of raw water were rapidly varying with the occurrence of extreme events such as sudden rainfall followed by prolonged dry season, a few days after flood events etc. In addition, it was found that foul odour is present in the raw water which has been abstracted from the river during the drought season and right after flooding events, etc. In spite of these variations in raw water quality, the treated water quality is achieved through the treatment process without any failure. However, during the drought season and right after flooding event, Chlorine demand at Biyagama Water Treatment Plant was increased and intermediate chlorination was implemented to maintain the optimum Rcl level recently. Hence, aim of this study is to analyze the root causes for the excessive chlorine demand in raw water, investigate adverse effects of treated water due to high chlorine dosages, and prepare an emergency plan to face the situation and suggest the appropriate long term solution to avoid high chlorine demand on treating water without chemicals at the Biyagama Water treatment Plant.

Presence of Fe, Mn and TOC in the raw water is known to cause for high chlorine demand at the Biyagama water Treatment Plant. These high chlorine demands have been attributed to the presence and oxidation of Fe, Mn, and TOC by chlorination.

In order to find the root causes for the high chlorine demand in the BWTP, it is necessary to first investigate the mechanisms that cause the problem in this particular situation. As such, a comprehensive water quality study was carried out in 19/10/2016 to 21/10/2016, 7/10/2016 to 11/10/2016 and 4/6/2016 to 9/6/2017 by the Biyagama Water Treatment Plant laboratory, Central Laboratory and Bureau Veritase laboratory samples from the intake (raw water), Treated water tank (treated Water), Pattiwila canal and suspected points of connected Marshy

area, along the Kelani River up to 5km upstream of Kelani River and along the Ragahawatta Ela up to BOI waste water treatment plant out let.

This study revealed, that the chlorine demand was increased when Fe, Mn or TOC were present alone or together and DO level was less than 5mg/l in raw water at BWTP due to oxidation of Fe, TOC and Mn by chlorination. BWTP is used pre chlorine to alter taste and odor producing compounds, to suppress growth of organisms in the treatment plant, to remove Fe2+, manganese, and to reduce the interference of organic compounds in the coagulation process. However, according to literature, pre chlorination can affect the undesirable THM content of the finished water.

According to the WSP at BWTP, there should be an emergency response plan to risk mitigation due to emergency cases. Hence, it is proposed to use the emergency response plan for any similar incident happened in future.

However, in the long-term, it is recommended to install tailor made bubble aerator to Biyagama Water treatment Plant to use when the DO content is less than 5.0mg/l in raw water, after pilot scale studies, to include aeration and activated carbon dossing facility to upcoming Kelani Right Bank Project Stage II, to implement the proper catchment management plan to Pattiwila and Mabima Catchment areas to avoid the Mn and Fe contamination, to implement continuous monitoring system to monitor the Fe and Manganese in the raw water at BWTP and to maintain a residual chlorine level of 0.1 to 0.2 mg/l throughout the distribution system in all the time. This may require installing booster chlorination equipment at appropriate locations.

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
TTHM	- Total Trihalomethane
RCl	- Residual Chlorine
TOC	- Total Organic Carbon
DBP	- Disinfection by Products
NWSDB	- National Water Supply and Drainage Board
SLS	- Sri Lanka Standards
WHO	- World Health Organization
WSP	- Water Safety Plan
WTP	- Water Treatment Plant
SACDA	- Supervisory Control And Data Acquisition
O&M	- Operation and Maintenance
USEPA	- United States Environmental Protection Agency
DOC	- Dissolved Organic Carbon
Mn	-Manganese
Fe	- Ferrous
CDC	-Centre for Disease Control and Prevention
UN	-United Nation
WHO	-World Health Organization
BOD	–Biochemical Oxygen Demand
POU	-Point of Use
E- Coli	-Escherichia Coli
MAC	- Minimum Acceptable Concentration
NTU	-Nephelometric Turbidity Unit

LIST OF APPENDICES

1. INTRODUCTION

1.1 The Value of Water

Water fit for human consumption was at one time considered to be a freely available commodity, which would never be in short supply. The result of this way of thinking led to overuse, waste, and abuse of water supplies. This is clearly demonstrated by our standards of living in the modern world. According to the World Health Organization (Hehir, 2009) more than three million people die each year as a result of water related diseases, making it the leading cause of sickness and death in the world, greater than war, terrorism and weapons of mass destruction combined. Most of the victims are children. Water sources are contaminated by raw sewage account for the majority of the fatalities. Every year, nearly 1.8 million people die from diarrheal diseases, including cholera, according to the WHO of that number, almost 90 percent are children under five years old. Up to 88 percent of waterborne diseases arise from unsafe water supplies and inadequate sanitation and hygiene. The contamination of water can take many forms. These include microorganisms, metals, and pesticides. Turbid or cloudy water may also be classified as contaminated since the solid particles responsible for the turbidity form sites to which viruses may become absorbed. Naturally occurring and synthetic chemical compounds may occasionally be present in drinking water. Such water has the greatest effect on vulnerable populations, such as children, older people, pregnant women, and people whose immune systems have been compromised. The use of any contaminated drinking water can result in infection or other ill health. An example of illness caused by dissolved metals in water is aggravation of a medical condition known as hemochromatosis, (iron overload disease caused by excessive iron in the body). Hemochromatosis is a hereditary condition, which is exacerbated in susceptible people with excess dissolved iron in drinking water.

The presence of Manganese (Mn) in groundwater is always associated with ferruginous water. The effect of Mn in water is primarily staining of washing. Many sanitary authorities and Government agencies have highlighted illegal dumping and quarrying in Sri Lanka as causes of water contamination.

Water is contaminated in three primary ways:

(i) Natural pollutants

(ii) Waste run off.

(iii) Pathogenic contamination.

Natural pollutants are added to water as it passes through the ground where it dissolves and leaches elements and metals out of the soil. These pollutants include iron, manganese, arsenic, aluminum salts and fluoride. Pollution from waste run- off can be as a result of by-products of human activities, i.e. industry, farming and dumping. Pathogenic contamination can take many forms such as pathogens can be protozoan, parasitic, bacterial and viral.

Climate change can also be a contributory factor in water pollution. Dr Jeremy Hess from the centre for disease control and prevention (CDC) explored the possibilities of storm intensity and the quality of water. He points out the high correlation between outbreaks of diseases and storm intensities. This is the result of studies carried out in the US for the period 1948 to 1994, and 1975 - 2001 in Canada. He also made the point that there could be increases in water borne pathogens depending on their sensitivity to warmer temperatures **(**Roy, and Hess, 2008)**,** Approximately 0.8% of the earth's water is available as drinking water. This water is ground water or surface water. The amount of fresh drinking water available is on the decline as industrialized and developing countries are polluting more of this water. In their efforts to provide wholesome drinking water for the ever-increasing populations, many solutions have been proposed and include the following ('Hehir, 2009).

(i) Greater numbers and capacities of their water treatment systems.

(ii) Increased chemical treatment.

(iii) Alternative methods of sourcing water (sea water desalination)

1.2 Water Supply in Sri Lanka

According to the data given by the department of Census & Statistics (Department of Census & Statistics Sri Lanka, 2012) 40% of the Sri Lankan population has organized water supply facilities and 59.4% is depending on other sources such as wells, tube wells, streams and rivers etc., including 10% of unprotected sources. The Sri Lankan Government targets to provide safe drinking water supply for all by 2025 with 60% pipe borne water supply coverage by 2020, through the national authority to provide drinking water, National Water Supply & Drainage Board (NWSDB).

1.2.1 Water safety Plans

The WHO guidelines (World Health Organization) are intended to support the development and implementation of risk management strategies that will ensure the safety of drinking water supplies through the control of hazardous constituents of water. "The framework for safe drinking water," is a preventive management approach comprising three key components.

- Health based targets
- Water safety plans &
- System of independent surveillance

These three are the most effective means of consistently ensuring the safety of a drinking water supply through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer. A Water Safety Plan provides for an organized and structured system to minimize the chance of failure through oversight and lapses of management and for contingency plans to respond to system failures or unforeseen events that may have an impact on water quality, increasing severe droughts and heavy rainfall or flood events. (Souce; 4th Edition -WHO Guide lines for drinking water quality)

Sri Lanka is a one of the countries committed to the Sustainable Development Goals articulated by the UN in the year 2016. It includes a commitment to ensure access to water and sanitation for all by 2050.

Therefore, all water suppliers have a duty of care to persons utilizing the water or service that they supply and therefore need to be aware of the regulatory and policy framework within which they must operate, including common law statute, policy guidelines and best management practice.

1.2.2 Policy and commitment

Safe water is an essential prerequisite for better health and socioeconomic development. The National Drinking Water Policy of Sri Lanka provides a framework for addressing the key issues and challenges facing the country's water supply sector in the provision of safe water supply to the people of Sri Lanka. That Policy provides a broad framework and policy guidelines for improving national service coverage in safe water through mobilization of efforts and resources of all stakeholders of the sector.

1.2.3 Scope of the National Policy

The policy applies to potable water supplied for human consumption, including qualitative and quantitative aspects. Safety of drinking water supplied to the people needs to be ensured at all times by all water service agencies through adoption of appropriate instruments or tools. The National Water Supply & Drainage Board (NWSDB) is the principal agency responsible for the development, operation and maintenance of drinking water supplies.

1.2.4 Policy of NWSDB

- Water Resource Management and Water Conservation through a holistic approach for water source, watershed and catchment protection will be adopted, to prevent pollution and depletion of the resource, to ensure adequate supply of water through proper environmental conservation.

- Enhance the quality of service provision by continuous assessments and improving operational and system efficiency.
- Enhance the quality of products and services by improving compliance with standards and guidelines. (Water Safety Plans (WSP) required to be operationalized by all service providers in order to ensure that the water supplied to the public is safe at all times)
- Disaster risk reduction and preparedness in terms of provision of basic water needs of the affected population due to floods, droughts, landslides and man-made disasters like unauthorized sand mining need special attention. The Policy will promote a government led approach to mobilize resources and coordinate efforts of humanitarian agencies to be established. Ensure maintenance of basic water for drinking and hygienic purposes during emergencies caused by disasters. (Water Safety Plan, BWTP, 2016)

According to the National and NWSDB policies, all urban and rural water supply schemes are bound to prepare and implement the **Water Safety Plans** for each and every water supply scheme to achieve the above policy requirements.

The utilization, management and distribution of water supplies for municipal, urban and domestic purposes are generally being administered under the above legal enactments, under which the Local Government Bodies are empowered to make their bylaws in respect of any waters that may be vested in them. Most schemes of water supply for domestic purposes are generally constructed and supervised by the National Water Supply and Drainage Board. In the areas defined and vested with the Mahaweli Authority of Sri Lanka, the right to control and regulate water lie with them.

1.2.5 Water Waste, Quality and Pollution Control

The Water Resources Board Act of 1964 has empowered the Board to draft legislation for the prevention of pollution and to take adequate steps to enforce such laws. The Central Environmental Authority can exercise much power in preventing pollution under the provisions of the National Environmental Act. 97. (Water Safety Plan, BWTP, 2016)

1.2.6 Contaminants Resulting from Water Treatment

At present, the normal treatment for potable water carried out by Water Treatment Plants in NWSDB is to add a coagulation agent (either aluminum sulphate (alum) or polyaluminium chloride) to assist sedimentation (clarification), followed by filtration, and post-chlorination for disinfection. Finally, before distribution lime is added to correct the pH for stabilization. These chemicals can have an adverse effect on consumers. Literature shows (Environmental Protection Agency, Washington, 1973) that chlorine is associated with the formation of trihalomethanes (THMs). These disinfection by-products are known to be carcinogenic.

NWSDB has 304 Water Treatment Plants. Out of them, Biyagama Water Treatment Plant (BWTP) is the 2nd largest water treatment plant in Sri Lanka. According to the past water quality data, colour, turbidity, BOD, faecal coliform, free ammonia, DO, total iron, nitrate, sulphate content, etc. of raw water were rapidly varying with the occurrence of extreme events such as sudden rainfall following prolonged dry season, a few days after flooding events etc. In addition, it was found that foul odour is present in the raw water which has been abstracted from the Kelani River during the drought season and right after flooding events etc. In spite of these variations in raw water quality, the treated water quality is achieved through the treatment process without any failure. However, during the drought season and right after flooding events, Chlorine demand at Biyagama Water Treatment Plant is increased and intermediate chlorination has been implemented to maintain the optimum RCl level recently. Hence, there is a concern about system capacity at the Treatment Plant as well as adverse effect on treating water due to high chlorine dosages.

1.3 Aims and objectives of the research

1.3.1 Aim

The main aim of this research is to analyze the root causes of the excessive chlorine demand in water treatment and recommend an appropriate system capable of removing chlorine demanding chemicals such as dissolved iron, free ammonia and manganese from the raw water without the use of chemical treatment.

1.3.2 Objectives

The objective of this study is to,

1. identify the root causes for the excessive chlorine demand in raw water,
2. investigate adverse effects of treated water due to high chlorine dosages,
3. prepare an emergency plan to face the situation and suggest the appropriate long term solution to avoid high chlorine demand in treatment of water during such emergency situations without using chemicals, at the Biyagama Water treatment Plant

1.3.3 Scope of the research

NWSDB has 304 Water Treatment Plants. Out of them, the Biyagama Water Treatment Plant was selected for this research study. However, it is attempted to generalize the results to other treatment plants too.

Due to the time and resource limitations, the scope of this study was limited to analysis of free ammonia, iron, manganese, colour, turbidity, TOC, DO, sulfate, total phosphate, nitrite, nitrate, alkalinity and conductivity as water quality parameters in raw water, during its treatment and treated water. Testing of samples for THM was not possible due to lack of testing facilities.

There were several barriers that were encountered when collecting water quality data on raw water as well as treated water. Close coordination with chemists, engineering assistants, plant technicians and reference to the available data in the Supervisory Control and Data Acquisition (SCADA) system and design reports was necessary to obtain the required information.

2. LITERATURE REVIEW

This literature review gives an overview of water sources, hydrological circle and the main non-biological contaminants examined in this study. It also discusses their effect on the water supply system, prevailing theories and hypotheses, what methodologies are appropriate and useful for treatment without chemicals.

2.1.1 Water Sources

Water for human use is obtained from two main sources, classified as surface water and groundwater. Rivers, lakes, and reservoirs contribute to surface water supplies. The other main source of water, groundwater is sourced from beneath the ground.

2.1.2 Surface and Ground Water

When rain falls to the ground, some of the water flows down hills to form lakes and rivers. This type of water is used by municipal bodies to supply for public consumption. Water that does not form rivers or lakes as surface water, percolates (soaks) through the ground and is soaked up by porous subsoil to form aquifers. (Wilson, 1974) These are accessed by boreholes to yield ground water, mainly to private dwellings, these boreholes are referred to as wells.

2.1.3 The Hydrological Cycle

The supply of ground or surface water is totally dependent on the hydrological cycle. The hydrological cycle, (Wilson, 1974 and EPA, 2002) occurs when water from the earth's surface evaporates and returns to earth in the form of rain, snow and hail. Water is located in all regions of the Earth, but water resources vary widely. The supply is dependent on topography and meteorological conditions since these influence precipitation and evapotranspiration. In Sri Lanka, the greatest amount of annual rainfall is experienced along the west coast, while the greatest population density is along the east coast. A better understanding of the cycle of water can be obtained from the diagram of the hydrological cycle shown in Figure 2.1.

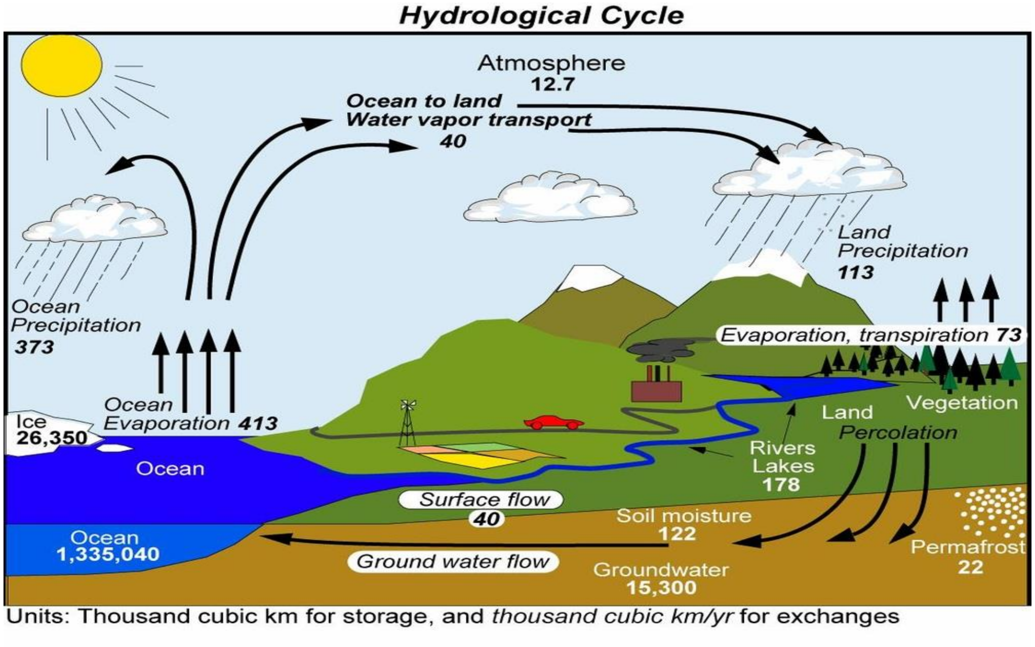


Figure2.1 The Hydrological Cycle

(Souce:https://www2.ucar.edu/sites/default/files/news/images/profile/2010/hydrocycle.jpg)

As seen in Figure 2.1, all fresh water on the earth's surface falls as snow, hail, rain, or mists that has been previously evaporated from the oceans and carried over the land by winds and air currents. It drains into streams, rivers, and underground streams and eventually back into the oceans from where it came.

2.1.4 State of Water Quality in Sri Lanka

It is difficult to comprehend the trend of water quality in public water bodies due to lack of monitoring data. However, the Sri Lanka National Water Development Report (2006) pointed out a variety of quality concerns in Sri Lanka, including contamination by nitrate and bacteria in underground and surface waters mainly due to poor sanitation and untreated wastewater or insufficient wastewater treatment, toxic chemicals from industrial and agricultural activities, and eutrophication in lakes/reservoirs (UNESCO and MoAIMD, 2006).

2.1.4.1 Rivers

Deterioration of water quality has been reported in some rivers. The main cause of water pollution in urban area is dumping of domestic and industrial wastes and untreated wastewater into waterways. In agricultural areas, agrochemicals are the main pollutants (UNESCO and MoAIMD, 2006). Water quality in the Kelani River, which is one of the major water sources in Colombo, is considered to be threatened by untreated or insufficiently treated wastewater (Ratnayake, 2010) and solid waste.

2.2 Contamination of Drinking Water

The pollution of drinking water is a mixture of hazardous commercial chemicals, and bacteria, viruses and inorganic minerals. Such water is unsuitable for human consumption. It has been estimated approximately major industrial parks of Sri Lanka generate 30 million cubic meters of wastewater per year (Source: Central Environmental Authority). Estimates for other sectors are not readily available as data not compiled by a single agency. Approximately ten percent (Source: Central Environmental Authority) of wastewater produced by industries is discharged to the environment without any treatment. This is mainly by small scale manufactures operating without formal licenses. Livestock farmers also use their wastewater in their own agricultural farming with minimal or no treatment.

2.2.1 Natural Contaminant

As shown in Figure 2.1, water; which starts as rain, with becoming contaminated as it falls through the atmosphere, gathering minute pollutants from the contaminated air, especially in industrialized regions (acid rain). When it makes contact with the ground and percolates through the ground to replenish the aquifers, (water bearing rocks) it leaches out contaminants from the ground. At the surface run –off Forms, Rivers and lakes, these bodies of water are open to pollution, slurry pits and silage making activities

(Commission of The European Communities, 2001, Campbell, 1983) the more common water contaminants are Coliform, Colour, Iron, Manganese, Aluminium, odour, Flouride, PH, Taste, Turbidity, Ammonium, Nitrates, and Nitrites.

2.2.2.1 Coliforms

These are regarded as indicator organisms. The presence of coliforms does not mean that pathogens are present, however large numbers would indicate that the water has been polluted by waste from warm blooded animals, therefore the water should be tested prior to consumption (Elsevier Science and Technology, 1997). Tests are carried out by filtering a quantity of water through a glass filter with openings of 0.5pm. The retained material is cultured and the results can reveal coliforms, faecal coliforms and faecal streptococci (Barnes, GauId, Vallentine, 1981and EPA, 2000).

2.2.2.2 Colour, Odour, Taste and Turbidity

These are referred to as the physical properties of water. They all contribute to the aesthetics of the water. If it is coloured and has an unpleasant odour, people would be reluctant to drink it (Elsevier Science and Technology, 1997). Taste is a result of the reaction of the water to dissolve minerals and metals. Taste in water is generally accepted, provided it is not objectionable. Excess concentrations of chlorine with a taste threshold of 0.16mg I 1 at pH 7 are reported to be quite objectionable (Gray, 1996). Turbidity not only contributes to the aesthetics, but turbid or cloudy water may also be infected with bacteria, since the particles causing the turbidity can hinder the disinfection process.

2.2.2.3 Ammonium

This is a derivative of ammonia. It is formed when ammonia reacts with water as shown in equation 2.1 where ammonia combined with water results in an ammonium ion and a hydroxyl ion. This reaction is reversible.

$NH_3 + H_2O \longrightarrow NH^{+4} + OH^-$ Equation 2.1 (Wilkes University Center for Environmental Quality, 1996).

The principal cause of this contaminant is farming activities (Wilkes University Center for Environmental Quality, 1996). The use of ammonia-rich fertilizer, ammonia based cleaning products, septic systems, and improper disposal of ammonia products all contribute. Ammonia in the atmosphere is a by-product of combustion processes such as domestic heating and internal-combustion engines. This area is further dealt with in section 2.6 (Wilkes University Center for Environmental Quality, 1996).

2.2.2.4 Aluminum

This metal is associated with neurodegenerative diseases, e.g., Alzheimer's disease (Ghee, Terrance1991). It can also have adverse effects on dialysis patients, since they receive approximately 400 L of dialysis fluid weekly, the makeup water must be of a very high quality (Gray, 1996).

2.2.2.5 pH

The pH of a substance is a measure of its acidity or alkalinity. If the pH of water is incorrect, it can lead to corrosion of pipes (acidic) or deposition of salt (alkaline) (Gray,1996).

2.2.2.6 Fluoride

This is one of the most toxic inorganic poisons known, yet it is added to drinking water for dental health. However the maximum allowable concentration (MAC) must not exceed 1mg/l excess fluoride can lead to dental fluorosis. This is a condition where the teeth become mottled in appearance. It also causes brittleness in the bones. (Environmental pollution and control, 1997 and Gray, 1996).

2.2.2.7 Nitrates

This form of pollutant in drinking water is as a direct result of farming. The nitrates leach into the aquifers affecting groundwater or as farm run-off running into rivers, streams and lakes, affecting surface water supplies. The main health concern of nitrate pollution is "blue baby" syndrome or methaemoglobinaemina (Environmental pollution and control).

2.3 Pollution through Human Activity

Human induced pollution can take on many forms such as **(**Wilkes University Center for Environmental Quality).

(i) Industrial pollution; this can give rise to the atmosphere being polluted with toxic dust e.g. asbestos, pesticides, nuclear fallout, etc. Toxic gases are the by-products of burning lead-based fuels, spray residues, hydrocarbons from factory chimneys.

(ii) Agricultural pollution. This type of pollution is a result of silage by- products. Fertilizers and animal waste can leach through the ground or run-off into streams and rivers, thus polluting the ground and surface water.

(iii) Human waste disposal. This type of pollution would originate from septic tanks and waste disposal sites. Each of these leaches polluted matter into the ground water (Ghee, 1991).

2.4 Industrial Activities

Industrial activities such as mining, smelting and oil refinery activities can give rise to mineral contamination. The by-products of these industries introduce metals such as lead, tin, arsenic, zinc, copper, and iron, amongst others. While all of these metals can occur naturally in water, the aforementioned operations concentrate the amounts leached into surface and ground water (Commission of The European Communities 2001).

2.4.1 Flood drinking Water Contamination

Depending on location and sanitation conditions, flood water can contaminate drinking water (surface water, groundwater, and distribution systems). Groundwater wells can be rendered useless from inundation of water laced with toxins, chemicals, animal carcasses, septic seepage, and municipal sewage. Surface water sources are impacted in similar manners. Infectious diseases can also be spread through contaminated drinking water (https://waterfortheages.org/2008/01/05/flood-drinking-water-contamination-risk-factors/, 2017).

At the beginning of the rainy season, runoff with pollutants are getting collected to the canals and drain to the nearest river. At the same time if the river water flow rate is less and dilution of pollutants coming through the canals after the first or second rain is relatively less. As a result of this fact, pollution level in the river would be increased.

2.5 Monitoring of Drinking Water Quality

The Central Environment Authority (CEA) and National Water Supply and Drainage Board (NWSDB) have the responsibility of monitoring the quality of the raw and drinking water. The NWSDB covers bacteriological, chemical and physical parameters and they have set MAC for contaminants and MRC (Minimum Required Concentrations) for treatment additives. These limits apply to water that is treated prior to distribution The sampling survey conducted by the CEA and NWSDB for the period 2015 to 2016 shown in "Appendix A" outlines some of the impurities, their levels and their **exceedances** in relation to the MAC (Minimum Acceptable Concentrations) standards.

2.6 Water Treatment Steps

Public drinking water systems use various methods of water treatment to provide safe drinking water for their communities. Today, the most common steps in water treatment used by public water treatment (mainly surface water treatment) include:

- **Coagulation and Flocculation**

Coagulation and flocculation are often the first steps in water treatment. Chemicals with a positive charge are added to the water. The positive charge of these chemicals neutralizes the negative charge of dirt and other dissolved particles in the water. When this occurs, the particles bind with the chemicals and form larger particles, called floc.

- **Sedimentation**

During sedimentation, floc settles to the bottom of the water supply, due to its weight. This settling process is called sedimentation.

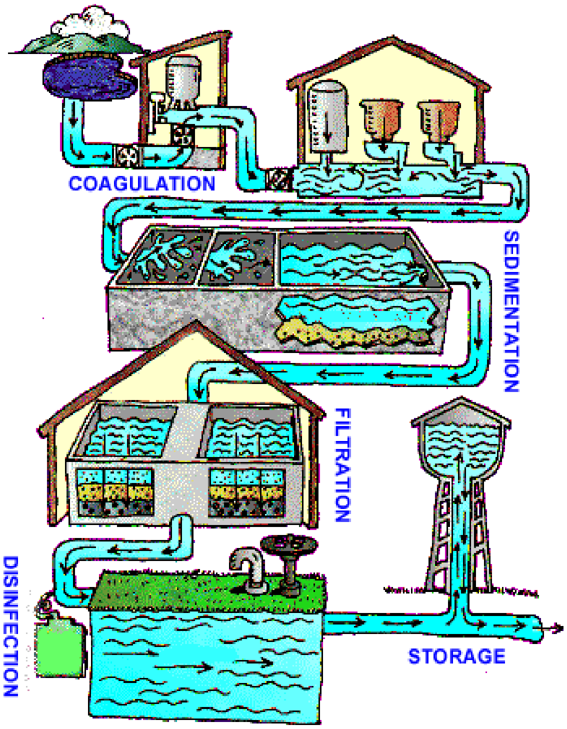


Figure2.1 The most common steps in water treatment (Source; EPA)

- **Filtration**

Once the floc has settled to the bottom of the water supply, the clear water on top will pass through filters of varying compositions (sand, gravel, and charcoal) and pore sizes, in order to remove dissolved particles, such as dust, parasites, bacteria, viruses, and chemicals.

- **Disinfection**

After the water has been filtered, a disinfectant (for example, chlorine, and chloramine) may be added in order to kill any remaining parasites, bacteria, and viruses, and to protect the water from germs when it is piped to homes and businesses.

2.7 Methods of Disinfection

There are three preferred methods of disinfection.

(i) Chlorination.

(ii) Ozonation.

{iii) Ultraviolet radiation.

2.7.1 Chlorine Demand

This is the amount of chlorine that must be added to water to produce an excess of chlorine or chlorine residue after reacting with the contaminants in the water (Gray, 2002 and Environmental pollution and control, 1997).

2.8 Water quality problems related to Ammonia, Iron and Manganese

When ammonia, Iron and Manganese are present in both surface and ground water, even at low concentrations, they can be linked to various water quality problems and their removal is essential. Ammonia needs to be removed before water is disinfected with chlorine, as it reacts with chlorine and produce chloroamines, which have recently been found to be carcinogenic. Also, the presence of ammonia in water systems leads to oxygen depletion, eutrophication of surface water and toxicity to fish. The upper permitted limit of ammonia in potable water is 0.5mg/l NH_3-N. Iron and manganese in water supplies cause aesthetic and deposition problems, such as bad taste and colour, staining and deposited in the water distribution system leading to high turbidity . The highest permitted limit of iron concentration in drinking water is 0.2mg/l. Although ingestion of manganese, through drinking water, at concentrations of up to 500 µg/l has no harmful effects on human health its presence in drinking water at concentrations above 100 µg/l is undesirable to customers due to the subsequent staining of laundry and plumbing fixtures. The European Commission (98/83/1998) recommends an upper limit of 0.05mg/l for manganese in drinking water (Tekerleopoulou & Vayenas, 2007).

2.8.1 Ammonia removal by chlorination

Breakpoint chlorination, as practiced for many years in the water treatment industry provides a physical-chemical means for removing ammonia from waste waters. In water, at NH3-N concentration usually below 1mg/l, chlorine reacts with the ammonia to form various chloramines:

$$Cl_2+H_2O \longrightarrow HOCl + HCl \quad (1)$$

$$NH_4+HOCl \longrightarrow NH_2Cl+H_2O \quad (2)$$

$$NH_2Cl + HOCl \longrightarrow NHCl_2 + H_2O \quad (3)$$

$$NHCl_2 + HOCl \longrightarrow NCl_3 + H_2O \quad (4)$$

Chlorine is added to processed waters until a point is reached a minimum (the breakpoint) and the NH_3-N has disappeared.

In water at NH_3-N concentrations of less than 1mg/l, and before the break point, the type of chloroamine formed depend upon the pH decreases below 7, increasing amount of chloramine appear. In the PH range of 4.5-5.0, dichloramine is the chief product: below PH 4, nitrogen trichloride is the chief product.

Breakpoint chlorination studies on buffered synthetic ammonia samples at PH 7.0 reveal that the monochloramine concentration reaches a maximum at the 5:1, the monochloroamine breaks down to form dichloramine and ammonia according to equation 5.

$$2NH_2Cl \longrightarrow NHCl_2 + NH_3 \quad (5)$$

The dichloramine reaches a maximum concentration at the Cl: NH_3-N weight ratio of about 7.5:1.

The literature indicates that in water with less than 1mg/l of NH_3^-‘the reaction proceeds in competition with the monochloraminen formation (equation 2) until the chlorine dosage reaches the break point at approximately a 10;1 weight ratio of Cl:NH3-N. Other studies, (Cole, and 1956 and Palin, 1952) however, indicate that monochloramine is oxidized by excess chlorine under slightly alkaline conditions of nitrogen gas as shown in equation 6.

$2NH_2Cl + HOCL \longrightarrow N_2 + 3Hcl + H_2O$ (6) Nitrogen trichloride.

In fact, the nitrogen trichloride produced (equation) in water treatment plant (10) during break point chlorination has been a serious problem. Stochiometrically, the ammonia oxidation through monochloramine to N2 corresponds to a 7.6.1:1 weight ratio of Cl:NH3-N.The literature (Ratrnanghelidj,2007, Hurnphreys, 2005 and EPA, 2007) also suggests the occurrence of other end products , including nitrate as shown in equation 6 and nitrogen trichloride. In fact the nitrogen trichoride produced, (equation 4) in water treatment plants (Kirk and Othmer,1964) during break point chlorination has been a serious problem

2.8.2 Reaction Products

In laboratory studies on buffered aqueous systems, monochloramine concentration increased with cl doses of up to about a 5:1 weight ratio of Cl: NH_3-N. Qualitatively, the formation of monochloramine and the reaction between intermediate monochloramine and free chlorine at PH 7.0 was completed in less than 1 minute.

In the aqueous systems, traces of dichloramine were produced in the 5-8 PH range. Nitrate and nitrogen trichloride were also produced. Potential products of N_2O, NO, and NO_2 were not detected.

In buffered aqueous system at the breakpoint, NO_3^- formation increased from 1.5% of the influent NH_3-N at PH 5 to about 10% at PH 8.Simultaneously, the NCl_3 formation decreased from 1.5% of the influent NH_3-N at PH 5 to 0.25% at PH 8.

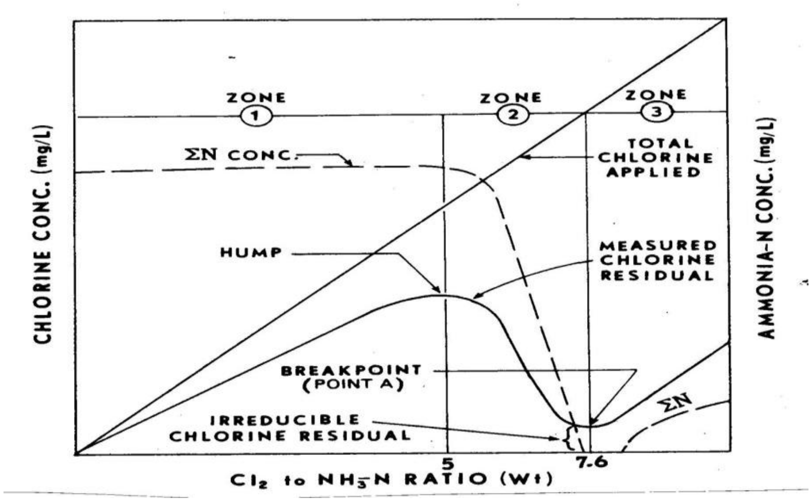


Figure2.2 Theoretical breakpoint curve

(Zone 1 is associated with the reactions of chlorine and ammonia to form Monochloramine; Zone 2 is associated with an increase in dichloramine and the disappearance of NH3; Zone 3 is associated with the appearance of free chlorine after the breakpoint) (Mathew, 1999).

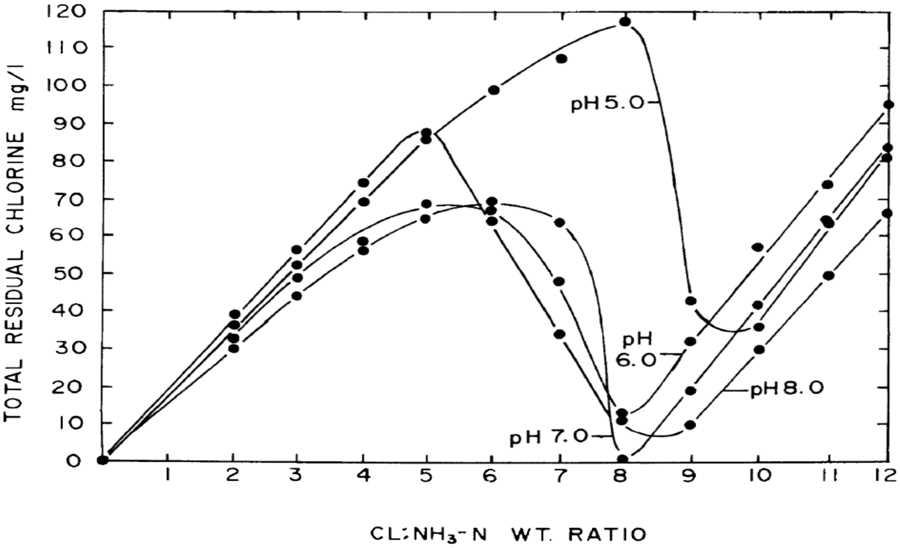


Figure2.3 Break point in Buffered aqueous system

The Cl: NH_3-N weight ratio at breakpoint varied from approximately 8:1 to 10:1 in the waste waters tested. Increased pretreatment reduced the amount of chlorine with lime clarified and filtered secondary effluents recurring an 8:1 Cl: NH_3 dosage. (Figure 2.2) (Environmental Protection Agency Washington DC, 1973)

2.8.3 Removal of Ammonia from Water by Ozone Microbubbles

Ammonia is a major source of water pollution. One of the most common methods for removal of ammonia from water is oxidation. In this work, ozonation of ammonia using microbubbles was studied in a pilot plant. The experimental results indicate that ozone microbubbles were quite effective in oxidizing ammonia. The oxidation of ammonia was effective at high pH and high ozone generation rates. Ozonation was found to occur by direct reaction of ozone with ammonia at the higher pH. However, the hydroxyl radicals were also involved at the lower pH. Bromide ions acted as a catalyst in the ozonation process, and a faster rate of oxidation of ammonia and lower yield of nitrate was observed. The volumetric mass transfer coefficient of ozone in water was determined. It increased with the increasing rate of ozone generation and the pH of the medium (Snigdha, Subrata, Majumder, and Pallab, 2013).

2.8.4 By Products of Chlorination

One of the major drawbacks of chlorination is the formation of by-products and reactions that take place within the water. Chlorine reacts with ammonia and humic acids (peaty water). This reaction interferes with the disinfection process. Where phenol is present, the reaction affects the odour and taste. Another problem was discovered with the development of gas chromatography and mass spectrometry. This new technology can "expose" natural and man-made organic compounds with concentrations of less than 1 pg/l which were otherwise undetectable. Some of these compounds, e.g. humicacid could react with chlorine to form complex and sometimes dangerous chemicals known as TrihalomethanesTHMS (Ghee, Terrance 1991**)**. (First discovered in drinking water from the Rhine (Rook, 1974). They are all considered to be carcinogens (Gray 1996). According to a study carried out by Krishna Gopal et a1 the development of disinfection by-products (DBPs), of which there are in excess of 300 types, in water is dependent on the: (Gopal, Krishna, Tripthy, Bersillon, Shashi, 2007).

(i) Temperature.

(ii) Contact time.

(iii) Dose.

(iv) pH.

(v) Inorganic and organic natural compounds in the water.

Huseyin Salcuk et al. measured (DBPs) and toxicity levels on treated water. They mention many species of THM which include chloroform which is the major and most dominant THM. Other THMs mentioned in his work are dibromochloromethane and bromoform. They have been linked epidemiologically to the intestinal tract and bladder cancer, as well as adverse birth outcomes (Huseyin, 2006). One of the many by-products of chlorine is chlorine dioxide. This compound, according to Gopal is effective in the destruction of oocysts such as Giardia and Cryptosporidium, which are resistant to chlorine. They (Gopal, Tripthy, Bersillon,., Shashi, 2007) also discuss that it has been used for the removal of,

(i) Iron and manganese.

(ii) Taste and odour.

(iii) Hydrogen sulphide.

However, Chlorine dioxide has some disadvantages, these are,

(i) The disinfection by-products, which are chlorite and chlorate can create problems for dialysis patients.

(ii) Chlorine dioxide is about 5 to 10 times more expensive than chlorine. Chlorine dioxide is usually made on site. This makes it unsuitable for use on a small scale installation.

(iii) Chlorine dioxide is effective for the deactivation of pathogenic microorganisms. It is less effective for the deactivation of rotaviruses and E. coli bacteria (Lenntech, 2002). It is a very hazardous compound rated according to the national pollutant inventory (NPI). They give it a hazard rating of 3.3 and rank it 41(Austrailian government department of environment).

2.8.5 How TOC Relates to DBPs

TOC in drinking water is formed from the decay of naturally occurring vegetation, including algae, sediment, and particles in water. TOC content in water sources varies from region to region, by type of water body, and even seasonally within a water source. Algae blooms, for example, are usually more prominent in summer and early fall, and can increase the organics of source water. TOC can also be increased in a raw water source through the transfer of other water sources, nearby wetlands, terrestrial runoff, or river channels. There are also quite a few man-made organic chemicals such as industrial solvents, hydrocarbons, pesticides, and herbicides derived from industrial sources and contributing to TOC.

Several DBPs have been linked to cancer in laboratory animals and are therefore regulated. Naturally occurring carbon compounds are not hazardous by themselves, but combined with a disinfectant they produce by-products, which pose a health concern. THMs, one class of DBPs, are formed from the interaction of TOC, naturally occurring bromide, and chlorine (see Figure 2.4) (www.geinstruments.com,2017).

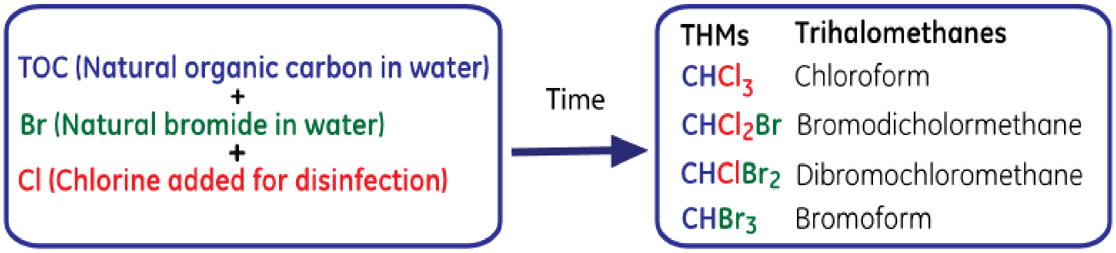
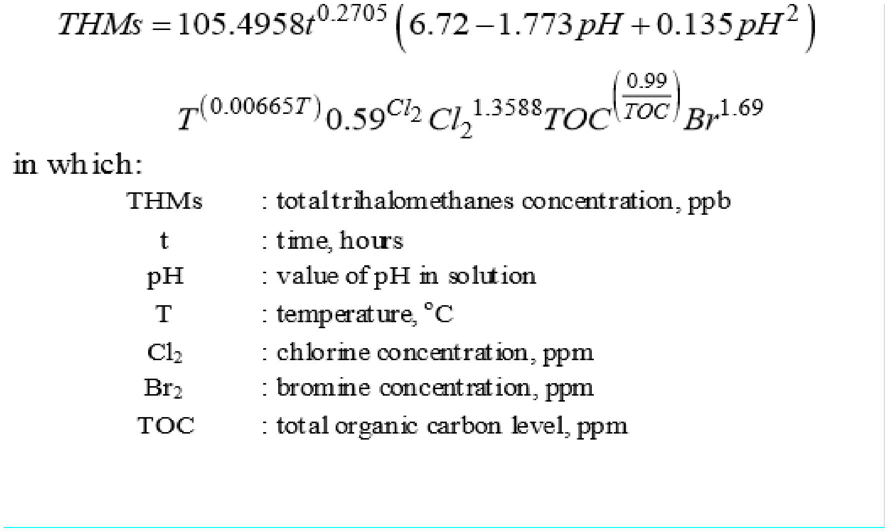


Figure2.4 THMs formed from TOC, Bromide and Chlorine

2.8.6 Effect of Total Organic Carbon

Trihalomethanes are formed according to the above generalized equation. (Figure 2.4) The formation of THM is strongly dependent on the amount of naturally present humic substances (Humic and Fulvic acid); generally referred to as Total Organic Carbon (TOC), i.e. it increases with increasing TOC in presence of free chlorine residuals. As shown in Figure 2.6, it is seen that THMs concentration increases almost linearly with TOC concentration. This trend is very well followed by the predictive equation as shown in the figure 2.5 (Motasem, Khaled, Manar, 2013).



$$THMs = 105.4958t^{0.2705}\left(6.72 - 1.773pH + 0.135pH^2\right)$$

$$T^{\left(0.00665T\right)}0.59^{Cl_2}Cl_2^{1.3588}TOC^{\left(\frac{0.99}{TOC}\right)}Br^{1.69}$$

in which:

THMs : total trihalomethanes concentration, ppb
t : time, hours
pH : value of pH in solution
T : temperature, °C
Cl_2 : chlorine concentration, ppm
Br_2 : bromine concentration, ppm
TOC : total organic carbon level, ppm

Figure2.5 The predictive equation

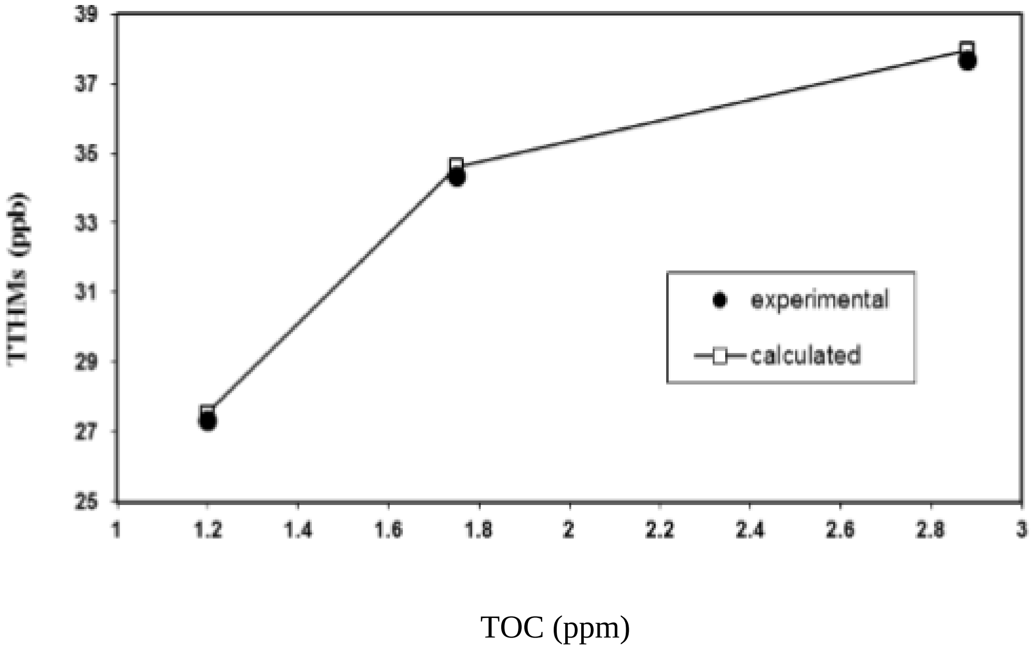


Figure2.6 Effect of TOC level on TTHMs formation (Source: American Journal of Environmental Engineering, 2013)

2.9 Bacteria, iron and Manganese

Iron and manganese in water also promote the growth of bacteria (including iron bacteria). These organisms obtain energy for growth from the chemical reaction that occurs when iron and manganese mix with dissolved oxygen. These bacteria form thick slime growths on the walls of the piping system and on well screens. These shines tend to be are rust-colored from iron and black-colored from manganese. Variations in flow can cause these slime growths to separate from pipe walls, resulting in dirty water in the system.

The growth of iron bacteria can be controlled by chlorination. However, when water containing iron is chlorinated, the iron is converted from the ferrous state to the ferric state, in other words, rust and manganese is converted into black manganese dioxide. These materials form a coating on the inside of the water main and, when they break loose, a customer will sometimes complain of “dirty” water.

Iron bacteria will use even small amounts of iron present in the ferrous state, oxidize it, and then use the energy. Manganese is also used by other bacteria to form organics, which contribute to the iron bacteria slime in the well and/or water system. Iron bacteria are found anywhere a food source of iron is available. The presence of one bacterium is all that is needed to start an infestation in a well or a distribution system

2.9.1 Iron and Manganese Control

Methods to control iron and manganese in distribution systems include arranging for alternate water sources, adding phosphate to the water to keep iron and manganese in solution, and oxidizing and removing both by filtration.

2.9.2 Phosphate Treatment

Phosphate can be added at the source to mask the effects of elevated iron concentrations in the distribution system. This is effective when the water contains less than 0.3 ppm of iron or 0.1 ppm of manganese. Phosphate delays the precipitation of oxidized manganese and iron, thereby greatly reducing the layer of scale that forms on the pipe. The effect is called sequestration. The iron or manganese, iron is surrounded by a chain of phosphate molecules and is not allowed to precipitate in the water.

Pyrophosphate, tripolyphosphate, and metaphosphate may be effective as iron and manganese sequestering agents. However, the most effective seems to be sodium phosphate in low concentrations. The proper dose and type of phosphate should be selected only after bench-scale testing is performed by a qualified technician or consultant.

Phosphate feed points should be separated from the chlorine injection point by as much distance as possible and ahead of the chlorine injection point. If phosphate is fed after chlorine, there is a possibility the iron and manganese will be oxidized by the chlorine before sequestering can take place, causing iron and manganese precipitates to be pumped out into the distribution system.

Feed equipment used for phosphate consists of a storage tank, solution tank, feed pump, and controller to pace the feed rate. The storage tank and solution tank must contain at least 10 ppm of free chlorine residual to prevent bacterial growth in the phosphate solution (phosphate is an excellent food source for bacteria).

Phosphate solutions can be made up from powder in a saturator similar to the one used to make dry-fluoride solutions. Phosphate solutions containing more than one-half pound of phosphate per gallon (60 ppm) may be very viscous. It is important that any solution be fed within 48 hours of its production. Polyphosphates tend to break down into orthophosphate, which is much less effective in preventing manganese deposits.

The amount of phosphates required sequestering iron and manganese generally has to be approximately two parts actual phosphate (as product) for one part of iron and manganese. It is also important to remember that chlorine residual must be maintained throughout the distribution system to control bacterial growth. The chlorine residual should be greater than 0.2 ppm in the most distant part of the system.

If the total detention time in the distribution system exceeds 72 hours, the phosphates may break down and release the iron and manganese in the outer portions of the system. If the detention is exceeded, the iron or manganese problem may not be resolved with phosphate.

2.9.3 Removal by Ion Exchange

Ion exchange may also remove iron and manganese (typically used in home softening). If the water has not been exposed to oxygen, the resins in the softener will remove the iron and manganese ions from the water. If the water contains any dissolved oxygen, the resin can be fouled with iron and manganese deposits. The resin can be cleaned, but the process is expensive and the capacity of this resin is reduced with each cleaning. This method is not recommended for municipal treatment.

2.9.4 Removal of Iron and Manganese by Filtration

Removing iron and manganese from drinking water instead of sequestration it is recommended if the water contains over 0.3 ppm of iron or 0.05 ppm of manganese. These elements can be removed during softening with lime, but most commonly iron and manganese are removed by filtration after oxidation (with air, potassium permanganate, or chlorine). Gravity and pressure filters are both used, with pressure filters being the more popular.

The operator should frequently check to see that all the iron in the water entering the filter has been converted to the ferric (or insoluble particulate) state. The operator collects a water sample, passes it through a filter paper, and runs an iron test on the clean, filtered water (filtrate). If no iron is present, it has all been oxidized and is being removed in the filtration process. If iron is found in the filtrate, oxidation has not been complete and some of the iron will pass through the filter and end up in the treated water. In this case, the operator should consider adjustments to the oxidation process.

Most iron removal filters are designed so that the filters are backwashed based on head-loss of the filter. If iron breakthrough is a problem, the filters will have to be backwashed more frequently. Accurate records will reveal when breakthrough is expected, so that the operator can backwash before it is likely to occur.

2.9.5 Oxidation with aeration

Iron is easily oxidized by atmospheric oxygen. Aeration provides the dissolved oxygen needed to convert the iron and manganese from ferrous and manganous (soluble) forms to insoluble Iron and Manganese oxidized ferric and manganic forms. It takes 0.14 ppm of dissolved oxygen to oxidize 1 ppm of iron, and 0.27 ppm of dissolved oxygen to oxidize 1 ppm of manganese.

Aeration requires careful control of the water flow through the process. If water flow is too great, not enough air is applied to oxidize the iron and manganese. If water flow is too small, the water can become saturated with dissolved oxygen and, consequently, become corrosive to the distribution system. Corrosive water may lead to increased lead and copper levels at customers' taps.

During aeration, slime growths may develop on the aeration equipment, and if these growths are not controlled, they can produce taste and odor problems in the water. The growth of slime can be controlled by adding chlorine at the head of the treatment plant. The process should be inspected regularly to catch problems early.

A detention basin can be provided after aeration to allow complete oxidation. These basins should be cleaned regularly to avoid sludge accumulation. Detention time can also be provided with a head on the filters rather than requiring a separate tank. Detention time before filtration should be at least 20 minutes, more if possible. The pH of the water influences how much time is needed for the reaction to be completed. After oxidation of the iron and manganese, the water must be filtered to remove the precipitated iron and manganese.

Oxidation of iron and manganese with air is by far the most cost-effective method since there is no chemical cost; however, there are disadvantages. The oxidation process can be slowed and the reaction tank has to be quite large (if there are high levels of manganese). In addition, small changes in water quality may affect the pH of the water and the oxidation rate may slow to a point where the plant capacity for iron and manganese removal is reduced.

2.9.6 Oxidation with Chlorine

Iron and manganese in water can also be oxidized by chlorine, converting to ferric hydroxide and manganese dioxide. The precipitated material can then be removed by filtration. The higher the amount of chlorine fed, the more rapid the reaction. Most treatment plants use 1 – 2 parts of chlorine to 1 part of iron to achieve oxidation (John, 1963).

When using this process in water containing organics such as Total organic carbon (TOC) or natural organic material (NOM), the likelihood of creating disinfection by-products (DBPs) increases.

2.9.7 Potassium permanganate

Potassium permanganate oxidizes iron and manganese into their insoluble states. The dose must be great enough to oxidize all of the manganese, but not too great as this will produce a pink color in the water in the distribution system. Observing water being treated will indicate if adjustments to the chemical feeders are needed. Potassium permanganate is typically more effective at oxidizing manganese than aeration or chlorination.

When oxidizing with potassium permanganate, the operation of the filters becomes important since the reaction also continues to take place in the filter media. The normally-used filter media (sand) will remove iron and manganese if the combined concentration is below 1 ppm. Higher concentrations require different type of filter materials (greens and others) and different methods of operation.

Potassium permanganate is often used with manganese greensand, a granular material that is charged with potassium permanganate after the backwashing process. This method allows the oxidation process to be completed in the filter itself and is a buffer to help avoid pink water in the distribution. After the filter is backwashed, it regenerates for a period of time with a high level of permanganate before it is put back into operation.

2.10 Possible Existence of Fe(OH)3 Aqueous and $Fe(OH)_2$ Aqueous

Detectable amounts of iron occur in many natural waters whose pH and Eh plot in the $Fe(OH)_3$ (c) field in figure 2.7, although theoretical considerations indicate that the amount in solution should be far below the limits of detection by standard procedures. Some of the iron in these waters could be present as dissolved un dissociated hydroxide. Fe(OH)3 (aq) and Fe(OH)2 (aq) are not specifically mentioned in most of the published literature, but some experimental data do exist from which computations can be made to indicate the possible importance of these two forms of iron. The work of Lamb and Jacques (1938) on the hydrolysis of ferric chloride in dilute solutions indicates that solutions containing ferric hydroxide generally are supersaturated. They showed that the rate at which $Fe(OH)_3$ was precipitated from such solutions decreased as the concentration decreased, reaching zero at a concentration of $2X10^9$ molar(John.1962). They give this value as the solubility of ferric hydroxide in undissociated form $Fe\ (OH)_3$ (aq).

$$Fe(OH)_3(aq) \rightleftarrows \pm Fe(OH)_2^+ + OH$$

A value for K for the equilibrium can be computed from this value for total solubility, assuming a neutral pH and amounts to $2.5X10^8$. (Oka, 1940) gives $1.3X10^5$ molar as the total solubility of ferrous hydroxide in pure water, and (Schrager,1929) gives $3.5X10^5$ molar as the solubility in a solution 1.375 N in OH+. The amounts of Fe^{++} and $Fe\ OH^+$ present at high pH, computed from equilibrium constants in table 2.7, are substantially less than these solubilities, which suggests the possible presence of $Fe(OH)_2$ (aq). A value for K for the equilibrium estimated from these

$$Fe\ (OH)_2\ (aq). \rightleftarrows FeOH^+ + OH$$

data, is about $2X10^5$. The thermodynamic properties of the dissolved molecular species differ from those of the solid-phase material, and if the existence of $Fe(OH)_3$ (aq) and $Fe(OH)_2$ (aq) had been assumed in the preparation of figure 1, the position of some of the lines would have been somewhat different. The most marked differences would occur at high pH. Data used in preparing figure 1 were taken from Latimer (1952). The existence of dissolved, undissociated species was not assumed. More experimental work would be required to establish the prevalence of undissociated dissolved species in natural water. Their practical significance, in any event, is not great because the dissolved $Fe(OH)_3$ (aq) would be below the limits of detection by ordinary means, and the ferrous species could exist only at pH levels far above those of natural water. An explanation of the phenomena reported by Lamb and Jacques (1938) might be that stable colloidal or sub colloidal system of Fe $(OH)_3$ are found (John,1962).

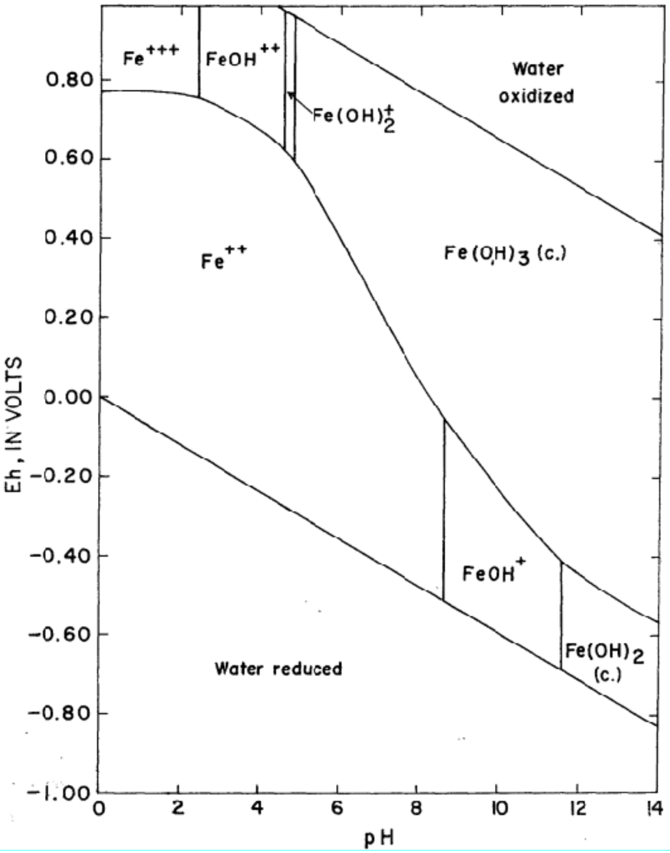


Figure2. 7 Ferrous- Ferric Chemical Equilibrium and Redox Potential (Source: Chemistry of iron in natural water,1962)

2.10.1 Occurrence of Ferrous Iron in Natural Waters

The area bounded by pH 5.0 and 8.0 and by Eh 0.3 and 0.5 on figure 2.7 includes most of the range that has been observed in natural waters exposed to the atmosphere. About two thirds of this area lie in the ferric part of the field, and only in waters that plot in the remaining one third of the area should there be detectable amounts of iron in solution. If waters plotted in this area are high in iron, most of it should be in the ferrous state. By extrapolation of figure 2.8, a maximum of somewhat more than 100 ppm of ferrous iron could be present at Eh 0.3 and pH 5.0 (John, 1962).

Waters that is high in iron generally contain it in the ferrous form. However, dissolved ferrous iron would be oxidized to the ferric state by atmospheric oxygen under the pH-Eh conditions that are ordinary in natural surface waters.

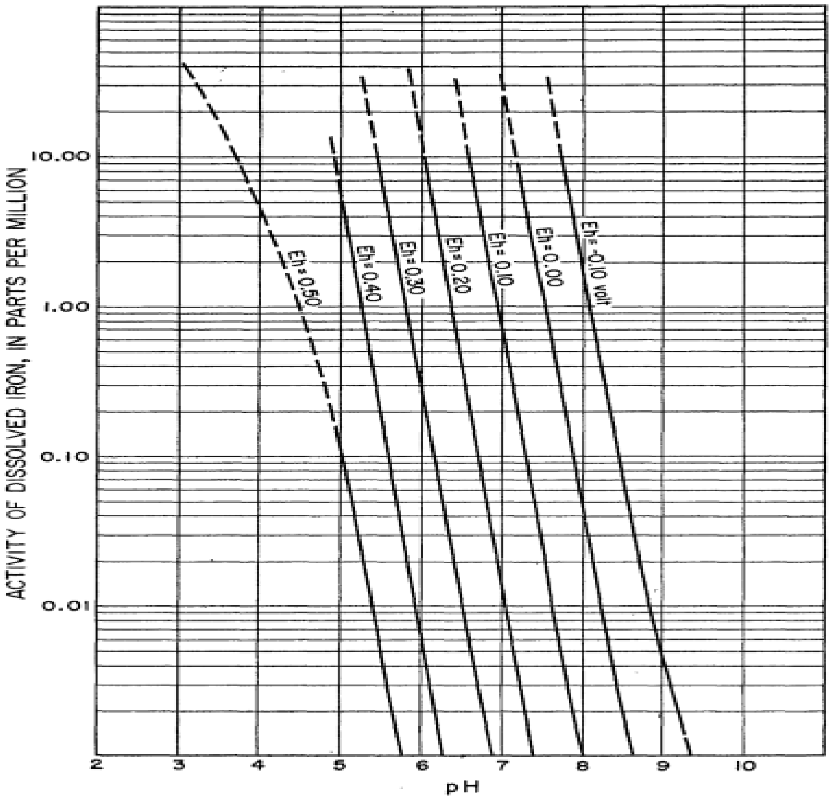


Figure 2. 1 Relation of total activity of iron in water to pH and Eh; (Source: Chemistry of iron in natural water,1962)

2.10.2 Chemistry of Manganese in Natural Water

Although manganese is a minor constituent of natural water, even small concentrations of the element constitute an undesirable impurity in water to be used for domestic and for many industrial purposes. The U.S. Geological Survey is conducting research in the chemical behavior of manganese and other hydrosolic metals. These elements are readily soluble under some of the chemical conditions common to natural water, but under some others, also common in natural water, they form oxides and hydroxides of very low solubility.

Manganese is located adjacent to iron in the periodic table, and the two elements have some chemical resemblances. The two elements are often considered together, particularly in the technology of water supply and treatment, because they cause similar problems and both may need to be removed. Because the chemistry of manganese is different from that of iron in several important respects, manganese is much more difficult to remove from water than iron.

The stability-field, or Eh-pH, diagram is a graphical means of showing the conditions of redox potential and hydrogen-ion concentration that are compatible with specified dissolved ions and solid species of an element at chemical equilibrium in the presence of water.

The distribution of manganese species in stability-field diagrams in chemical equilibrium and rates of Manganese Oxidation report is given only for conditions under which water is stable (John,1963). The redox potential at which water is oxidized with the liberation of gaseous oxygen is 1.23 v (volts) at a pH of 0. At a pH of 14, the Eh for this reaction is just over 0.4 v. Water may be reduced to liberate gaseous hydrogen at Eh values of less than 0 v at a pH of 0 and at Eh values of less than 0.82 v at a pH of 14 (Thomas,1962). Although it is usually assumed that pH-Eh conditions beyond the water.

Figure 2.9 shows the fields of stability for 4 solid phases of manganese and the fields of dominance of 3 dissolved species of manganese. Interfering anions and cations are absent. This is about the simplest representation that can be made for a manganese system that includes enough variables to approach actual conditions in laboratory solutions. The four solids having fields of stability in the figure are MnO_2, Mn_2O_3, $Mn3O_4$, and $Mn(OH)_2$. The symbol (c) on the diagram indicates crystalline (solid) material.

The solid lines represent the positions of the boundaries of the stability fields of solids, when the effective concentration of dissolved manganese is 0.01 ppm ($1.8X10^7$ molal). The dissolved species considered are Mn^{+2}, $MnOH^+$, and the anionic form $HMnO_2^-$. All these are varieties of divalent manganese. Within the stability limits of water, Mn^{+3} (aq) is less abundant than Mn^{+2} , is not considered. The line along which Mn^{+3}=Mn^{+2} is above 1.23 v at a pH of 0. Also, with one minor exception, the highly oxidized anionic species are stable only outside this area. Therefore Mn (as in permanganate) is not considered. Near a pH of 14 and an Eh of +0.40, the stability boundary between the manganate ion, in which the manganese is hexavalent, and MnO_2 (c) intersects the water- stability boundary. However, the area of stability of manganate is very small and lies in a region that never exists in nature. Hence, the manganate species have been omitted from the diagrams. The area in which the aqueous hydroxide complex is the dominant dis- solved species is separated from the Mn^{+2} (aq) region by a dotted line. Dashed lines represent the positions of the stability-field boundaries of the solids when dissolved Mn+2 activity is 0.10, 1.0, 10, and 100 ppm. These dashed lines are, in effect, solubility "contours" for manganese in the system described as functions of pH and Eh. Activities of dissolved manganese and of anions are given in parts per million, because this unit is the most widely used in water chemistry. However, the calculations require that reactant activities be expressed in moles. Molar concentrations (moles per liter) are related to molal concentrations (moles per kilogram of solution) in the same way as milligrams per liter are related to parts per million. In dilute solutions, such as the ones considered here, the difference between molal and molar quantities is insignificant.

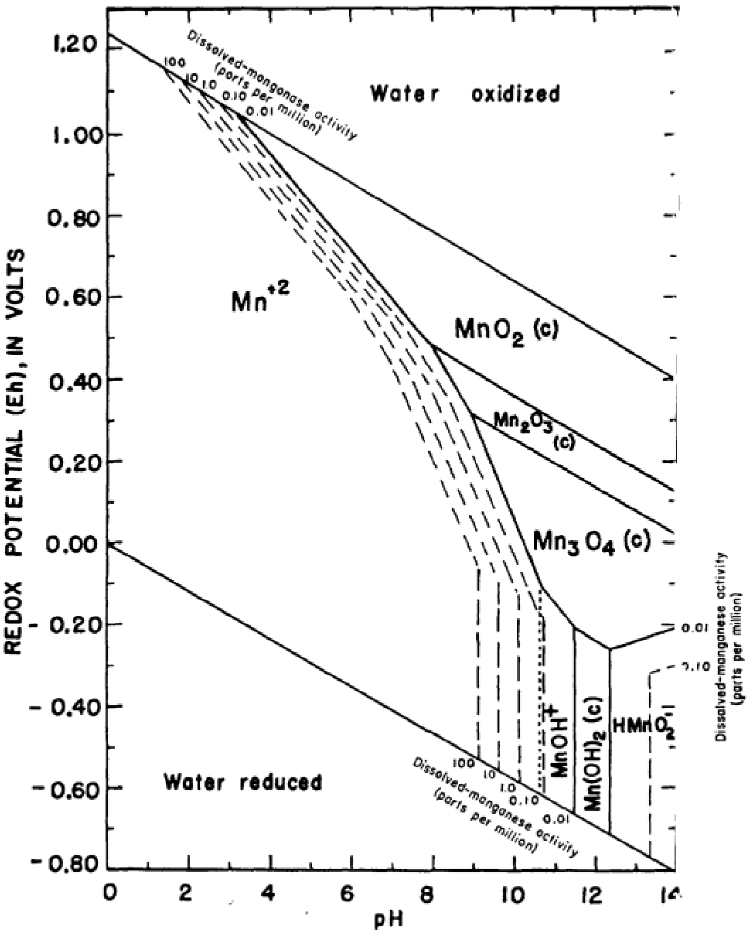


Figure 2. 2 Stability fields of manganese species in aqueous solution free of bicarbonate and sulfate ions Total dissolved-manganese activity ranges from 0.01 to 100 ppm. (Source: Chemistry of Manganese in natural Water, 1963)

Comparison of figure 2.9 with a similar diagram for a system involving water and ferric and ferrous hydroxides (Hem and Cropper, 1959) indicates some interesting points of difference. If the pH of a system is held near 7.0 and the redox potential is increased, the activity of dissolved iron is decreased to less than 0.01 ppm when the Eh exceeds 0.22 v. To decrease the solubility of manganese to the same extent, however, requires an Eh of nearly 0.60 v at a pH of 7.0. Literature on water conditioning and practical experience of water plant operators in the removal of iron and manganese have shown that removal of manganese by aeration is difficult to accomplish and, in any event, requires a high pH.

In some types of water, the results of aeration and removal of iron will include a decrease of pH, which could halt the precipitation of iron and bring the system to equilibrium at a point where troublesome quantities of iron and probably all the original manganese remain in solution. In water treatment it is essential to maintain conditions that are favorable for rapid-reaction rates. The effect of pH or rates of manganese oxidation will be considered later in this discussion.

2.10.3 Iron and Manganese Removal by physical-chemical methods

As for iron, the origin of manganese, in water, is at the same time natural (dissolution of the reduced form Mn^{2+}) and industrial (mining, the iron and steel industry, etc.). The same goes for its removal from water. Manganese does not present a danger to human health, nor for the environment but it is unpleasant. In fact, the water gets a black color and a metallic taste.

Similar to iron, the manganese removal by physical-chemical way can be carried out by the oxidation of Mn^{2+} in Mn^{4+}, which precipitates then in manganese dioxide (MnO_2). The precipitation is then separated from water by filtration on sand.

$$Mn^{2+} \xrightarrow[\text{oxidation}]{} Mn^{4+} \xrightarrow[\text{precipitation}]{} MnO_2$$

The only difference (with the iron), is in the reagent used. Indeed, oxidation by oxygen is in many cases not sufficient for manganese at neutral pH. Stronger oxidants can be used in complement such as chlorine dioxide (ClO_2), chlorine (Cl_2), potassium permanganate ($KMnO_4$) or ozone (O_3) (http://www.lenntech.com/processes/iron-manganese/manganese/manganese-removal-physical-chemical-way, 2017).

2.11. Aeration Methods

Structures or equipment for aeration or air stripping may be classified into four general categories, waterfall aerators, diffusion or bubble aerators, mechanical aerators, and pressure aerators. The waterfall type of aeration accomplishes gas transfer by causing water to break into drops or thin films, increasing the area of water exposed to air. The more common types are (Walker 1978).

(i) Spray aerators

(ii) Multiple-tray aerators

(iii) Cascade aerators

(iv)Cone aerators

2.11.1 Spray Aerators

Spray aerators see Figure 2.10 direct water upward, vertically or at an inclined angle in a manner that causes water to be broken into small drops. Installations commonly consist of fixed nozzles or a pipe grid located over an open-top tank (American Water Works Association. 1997). Spray aerators are usually efficient with respect to gas transfer such as carbon dioxide removal or oxygen addition. However, they require a large installation area. Spray aerators are effective provided they can be economically designed. As a decorative fountain they can be attractive. They do however have some limitations. To produce an atomizing jet, a large amount of energy is required (Hindle, 2002).The losses and the nuisance problems from the wind carry-over of the spray can be considerable. Climatic conditions, particularly in cold regions, limit their usefulness.

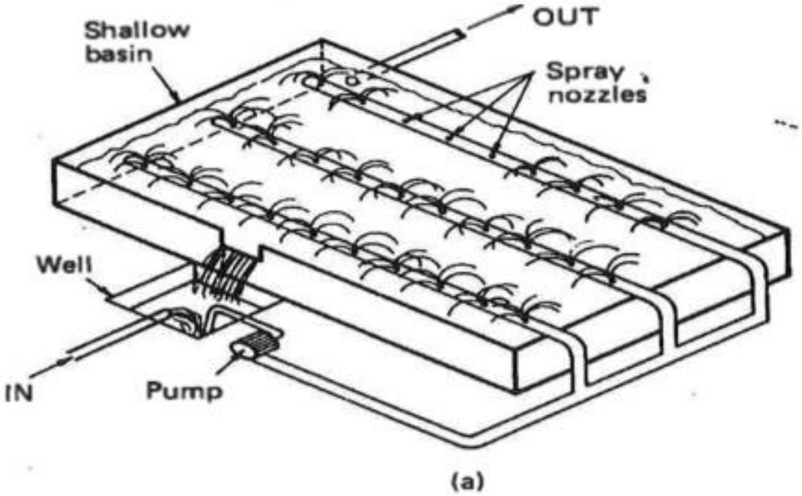


Figure 2. 3 Spray Aerator

2.11.2 Multiple-Tray Aerators

Multiple-tray aerators consist of a series of trays equipped with slatted, perforated, or wire-mesh bottoms. Water is distributed at the top, cascades from each tray, and is collected in a basin at the base. It is important to have an even distribution of water from the trays to obtain optimum unit efficiency.

2.11.3 Cascade Aerators

With cascade aerators, an increase in exposure time and area-volume ratio is obtained by allowing water to flow downward over a series of steps or baffles. The simplest cascade aerator is a concrete step structure that allows water to fall in thin layers from one level to another (Hindle, 2002). See Figure 2.11. The exposure time of air to water can be increased by increasing the number of steps, and the area-volume ratio can be improved by adding baffles to produce turbulence. As with tray aerators, operating problems include corrosion and slime and algae buildup.

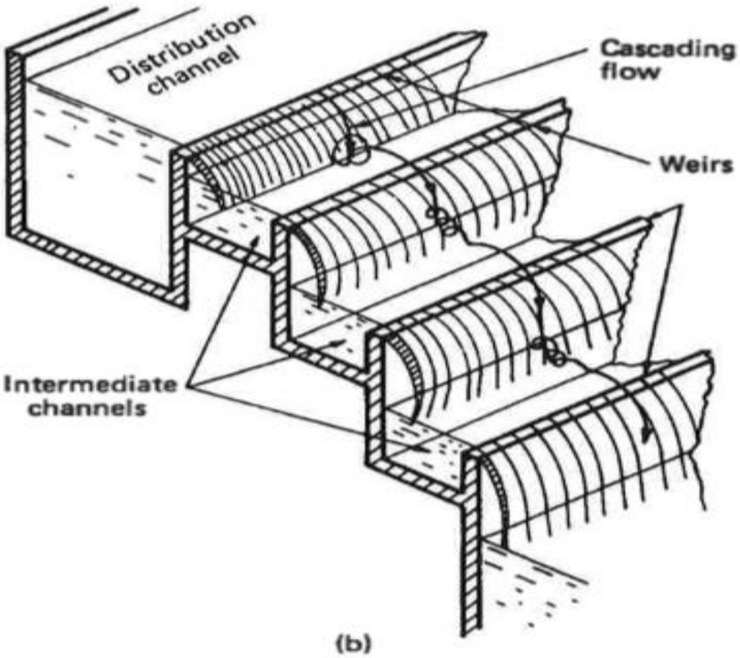


Figure 2.4 Cascade Aerator

2.11.4 Cone Aerators

Cone aerators are similar to cascade aerators. They have several stacked pans arranged so that water fills the top pan and cascades down to each succeeding pan. Figure 2.15 shows such an arrangement.

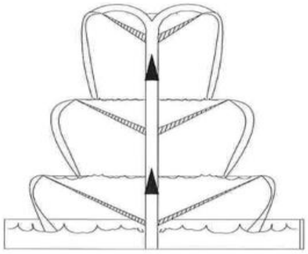


Figure 2. 5 Schematic of a Typical Cone Aerator

2.11.5 Chemical Oxidation Followed by Filtration

This treatment uses oxidizing agents such as chlorine, potassium permanganate, or hydrogen peroxide. The precipitated Fe and Mn are then filtered out. High levels of dissolved Fe and Mn greater than 10 mg/l can be treated by chemical oxidation. If colloids are present, aluminum sulphate (alum) is sometimes added to the water to aid filtration by allowing larger Fe and Mn particles to form, This process is called flocculation. The oxidizing chemicals are put into the water in a similar manner to the phosphate treatment method. A special metering pump is employed for this task, as the quantities of chemicals added must be carefully monitored. If there is excess chlorine in the water, the result is an unpleasant taste and, in the case of potassium permanganate, if it is not mixed correctly, a poisonous compound is produced. Consideration must be given to the pH of the raw water. For chlorination to work well the ideal pH is between 6.5 and 7.5. A pH greater than 9.5 is required for complete oxidation of water with high levels of manganese; it is therefore not suitable in this case (Gray 1996Wolfe, 1990).

2.12 The most common treatment processes of iron and manganese

The majority of iron and manganese treatment systems employ the processes of oxidation/ filtration. The oxidant chemically oxidizes the iron or manganese (forming a particle), and kills iron bacteria and any other disease-causing bacteria that may be present. The filter then removes the iron or manganese particles. Oxidation followed by filtration is a relatively simple process. The source water must be monitored to determine proper oxidant dosage, and the treated water should be monitored to determine if the oxidation process was successful. Oxidation Before iron and manganese can be filtered; they need to be oxidized to a state in which they can form insoluble complexes. Oxidation involves the transfer of electrons from the iron, manganese, or other chemicals being treated to the oxidizing agent. Ferrous iron (Fe^{2+}) is oxidized to ferric iron (Fe^{3+}), which readily forms the insoluble iron hydroxide complex $Fe(OH)_3$. Reduced manganese (Mn^{2+}) is oxidized to (Mn^{4+}), which forms insoluble (MnO_2). The most common chemical oxidants in water treatment are chlorine, chlorine dioxide, potassium permanganate, and ozone. Oxidation using chlorine or potassium permanganate is frequently applied in small groundwater systems. The dosing is relatively easy, requires simple equipment, and is fairly inexpensive. Chlorination is widely used for oxidation of divalent iron and manganese. However, the formation of trihalomethanes (THMs) in highly colored waters may be a problem. Chlorine feed rates and contact time requirements can be determined by simple jar tests. As an oxidant, potassium permanganate (KMnO4) is normally more expensive than chlorine and ozone, but for iron and manganese removal, it has been reported to be as efficient and it requires considerably less equipment and capital investment. The dose of potassium permanganate, however, must be carefully controlled. Too little permanganate will not oxidize.

3. RESEARCH METHODOLOGY

The study methodology adopted is shown in the flow chart given in Figure.3.1

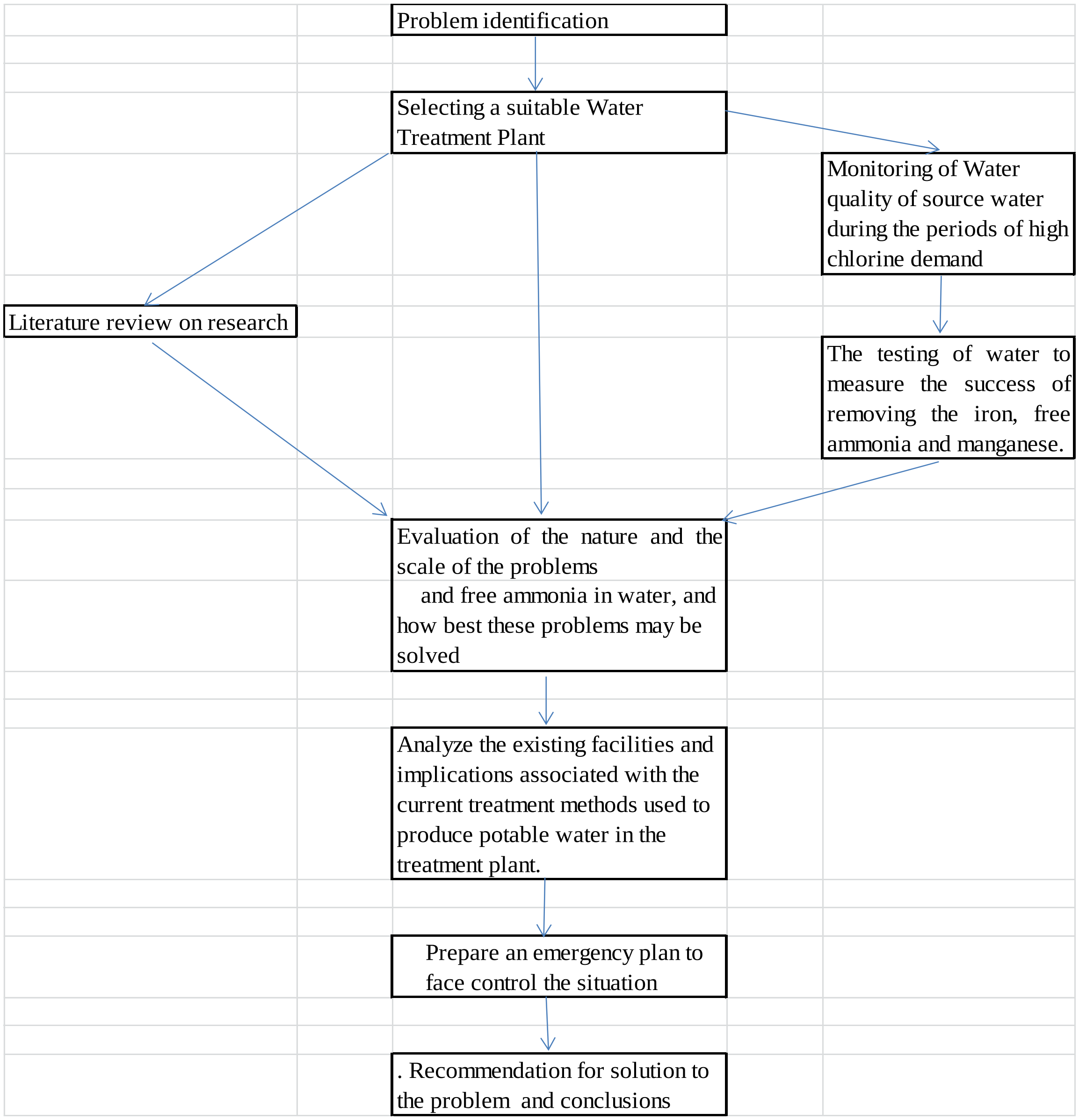


Figure 3.1 Study Methodology

The research work was conducted using both a theoretical and experimental approach.

The theoretical method of this approach was based on;

1. Literature review of research conducted by others and study of the effects of iron, free Ammonia, manganese and other water hazards/diseases and health risk of high chlorine demand. The experimental approach involved:

(i). The sampling of a number of water sources during the periods of high chlorine demand (to disinfect and maintain the RCL in the treated water) and establishing which sources have manganese, iron, Ammonia and TOC contamination or all four.

(ii). Investigation of variation of manganese, iron, Ammonia and TOC of the water in the treatment plant and Kelani river, Pattiwila Ela and Ragahawatta Ela. (Please refer the appendices J, K and L for the test methods).

Three chlorine demand increased incidents at BWTP were considered and Samples were collected within a short period of time at following locations.

- The intake (raw water),
- Treated water tank (treated Water),
- Pattiwila canal and suspected points of connected Marshy area,
- Along the Kelani River up to 5km upstream and
- Along the Ragahawatta Ela up to BOI waste water treatment plant outlet

In addition, few samples were sent to Bureau Veritas Consumer Products Services Lanka Ltd for TOC analysis (Test method APHA22nd Edn.2012, 5310B).

(iii).The laboratory scale testings' of the water to measure the success of removing the iron, Ammonia and manganese using aeration by using a fish tank oxygen pump.

2. Analyze existing facilities at BWTP and the implications associated with the current Treatment methods used to produce potable water.
3. Evaluation of the nature and the scale of the problems associated with dissolved iron, Mn and ammonia in the water, and how best these problems may be solved.
4. Prepare an emergency plan to face control the situation
5. Conclusion and recommendation for the solutions to the problem

4. BACKGROUND OF SOURCE OF WATER

The subject water for this study is drawn from the Kelani River. It is the major source of raw water Supplying domestic, municipal and industrial water to the city of Colombo, its surrounding and towns North of Colombo. Raw water is abstracted from the river at Ambatale about 16 km upstream from the river mouth, by two pumping stations, both located on the left bank at Ambatale. In additions to abstraction at Ambatale, Biyagama Water Treatment Plant is abstracting a further 189,000 m^3/day from the Kelani river at Pattiwila, 2km upstream of Ambatale. The second stage of the same is in the process of construction, and it will abstract a further 180,000 m3/day from the river in 2019.

Flow in Kelani River is controlled at the upstream CEB Ruecastle and Maussakale Hydroelectric generating reservoirs. These reservoirs control about 15% of the Kelani River (Semi-Permanent Salinity Barrier, 2009). During the dry season water resources used to generate power need to be conserved to address energy shortfalls, which can lead to low flows in Kelani River, particularly if during drought. The flows of $20m^3$/sec are available most of the years (Semi Permanent Salinity Barrier, 2009). Flow measured hourly at Hanwella indicate adequate flows for abstraction. Dry weather flows well in excess of 20m3/sec are available most years. Minimum measured flows in 1992 indicate a flow of 11.1 m^3/sec and low flows of $13m^3$/sec were recorded in 2004 (Semi Permanent Salinity Barrier, 2009). These flows, if repeated for a length of time, are insufficient to maintain demand from water treatment plants, and maintain a residual flow sufficient for cleansing salinity from the river.

4.1 Kelani River Catchment

The Kelani river Basin has 20 sub water sheds comprising of 71 minor watersheds. It originates from the Western face of the central highlands in the Horton Plain National Park Peak Wilderness Sanctuary.

The Kelani River Basin is home to more than 25% of the Sri Lankan population. It provides drinking water for the greater Colombo area, Towns North of Colombo area and millions of people living in the river basin.

During the year 2016, International Union for Conservation of nature (IUCN) has measured key water quality parameters (BOD, COD, pH, E.Coli, heavy metals etc.) at each minor watershed (Figure 4.1).

Based on the water quality at each minor watershed the level of pollution related to drinking water, aquatic life and swimming water were computed and recorded the pollution source in the form of health cards. Based on the above cards, the river basin was divided into three management areas. The area indicated in figure 4.2 in dark brown is where the pollution level is highest and this study is focused to part of the same. The light brown area indicates worsening conditions that need attention. The yellow area is the least polluted, but adequate attention to safeguard the area.

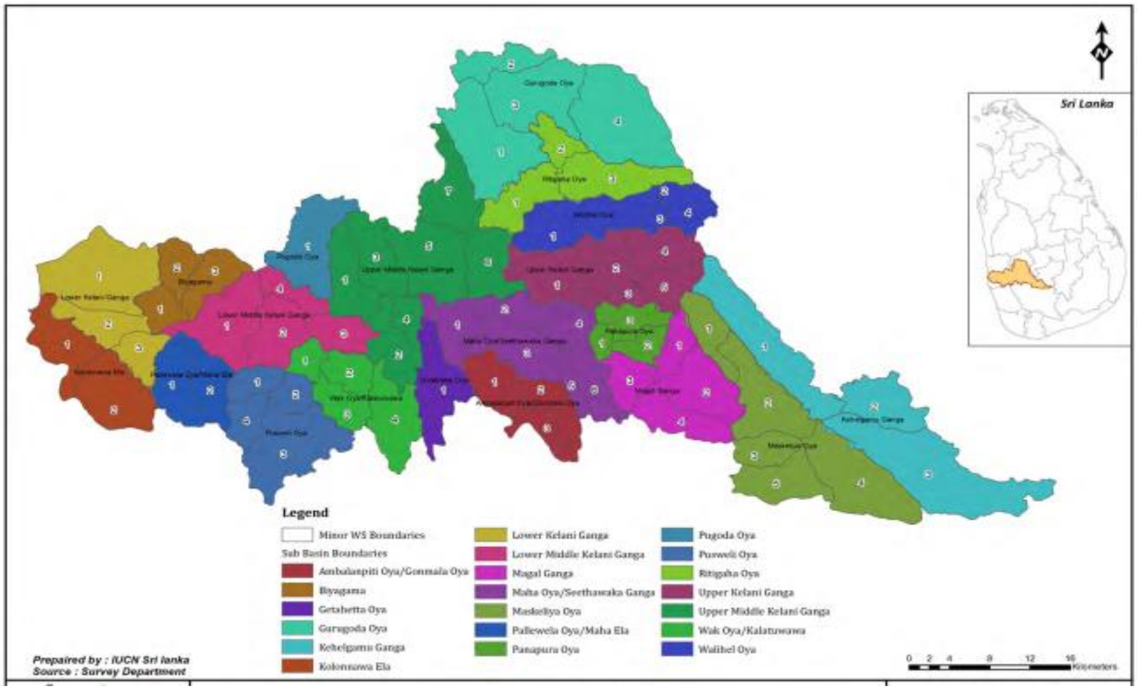


Figure 4. 1 Water Quality Monitoring Stations (Source: IUCN)

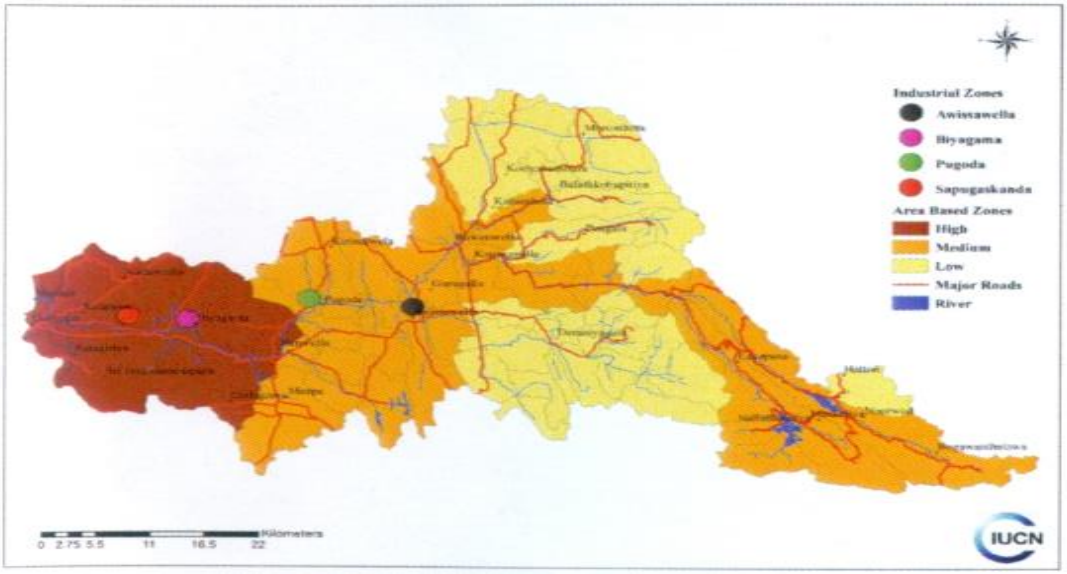


Figure 4.2 Water quality based priority areas (Source: IUCN)

At present, two main concerns in connection with the river are flooding during the monsoon and saline intrusion in the dry season. In addition; Kelani River water levels affect the flood risk to Colombo, the capital of Sri Lanka, to a considerable extent. One reason is that part of the city and suburbs of Colombo lie on the lower flood plain of the river. Exposure of Colombo and the upper catchments of the Kelani River to the same monsoon, i.e. South West Monsoon, is another reason.

Figure 4.3 Kelani River at Ambatale, Semi permanent salinity Barrier (Source; NWSDB)

The problems are related: the saline intrusion is enhanced by the deepening of the river caused by the sand mining. Regulation in order to prevent the saline intrusion can reduce the water quality in other ways, and can increase the flood risk. (http://en.wikipedia.org/wiki/Kelani_River, 2017)

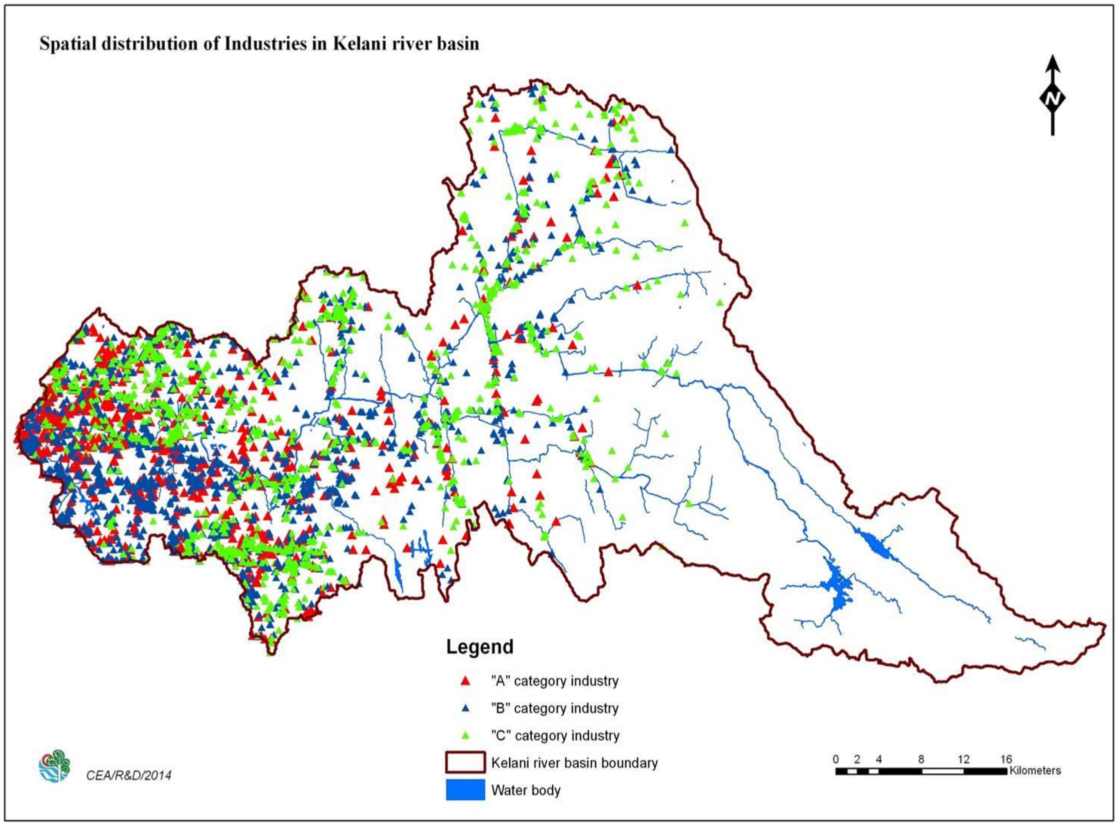


Figure 4.4 Spatial Distribution of Industries in Kelani River Basin (Source; WSP, BWTP)

Spatial distribution of Industries in Kelani river basin is primarily classified, as ‘high polluting’ or ‘low polluting’ industries by the central environmental Authority (CEA) (Figure 4.4). The impact of the effluents from these industries, on the quality of drinking water, depends on the constituents and quantities of the effluents discharged.

The high polluting industries are classified further into two types, viz. Type A- Industries that discharge effluents which are toxic and harmful to human health and

Type B - Industries that discharge effluents with high pollution loads (Cabinet Paper No. 10/0335/324/008). According to the cabinet paper CEA and NWSDB jointly chaired regulation shall be: Type - A industries will be permitted to be located upstream of drinking water intakes. The effluents from the Type - B industries should be treated to the designated national effluent standards prior to discharge. (Appendix B).

According to the land act of Sri Lanka, 6 m distance from the centre of the River on both sides (Left and right banks) should be protected as river reservation. But both sides of the Kelani River catchment area are used for human settlements and industries. Now became as a highly sensitive area due to the encroachments and the pollutions. (WSP,BWTP, 2016)

4.2 Pattiwila Ela

Intake of the Biyagama water treatment plant is situated at 9km away from Colombo. The marsh drains to the Kelani River through Pattiwila Ela immediately upstream of the Right Bank Water Treatment Plant of National Water Supply and Drainage Board (NWSDB). The Pattiwila earth canal bringing water from a lowland area adjacent to the treatment plant is falling just upstream of the Kelani Right Bank Project (KRBP) intake. Almost all this water is entering the Intake, due to natural flow pattern.

Patiwila Ela is a man dug, low gradient, meandering water canal running across the Marshy flood plains of the Kelani River draining through the marsh and discharging into the Kelani River just upstream of right bank water Intake. Under normal weather conditions, the canal is almost a stagnant to slow flowing water segment, which usually covered a with heavy growth of Japan Jabara, (Eichhornia), and invasive aquatic plant. As stated previously the main objective of this study is to remove dissolved Fe, Mn and Ammonia from raw water extracted from the Kelani River through the Pattiwila intake. The water under examination is extracted from Pattiwila canal and Ragahawatta canal through the Kelani River. The majority of the upper exposed surface of the Pattiwila catchment area is peat abandoned paddy land. The concentration of humic and fulvic acid are high, therefore creating ideal conditions for producing ferruginous water.

4.3 Ragahawatta Ela

Ragahawatta Ela is also an earth canal. It is one of the major pollution sources to Kelani River and bringing water from lowland areas and effluent from Waste water treatment Plant at Biyagama Investment Promotion Zone (BIPZ) to 13km upstream of the Kelani River. In addition, there are lots of industries in the area, including Biyagam Investment promotion Zone (BIPZ), which discharges 15000m3/day of wastewater to the Kelani River through the Ragahawatta Ela.

4.4 Biyagama Water Treatment Plant

According to the past water quality data, colour, turbidity, BOD, faecal coliform, free ammonia, DO, total iron, nitrate, sulphate content, etc. of raw water were rapidly varying with the occurrence of extreme events such as sudden rainfall following prolonged dry season, a few days after flooding events etc. In addition, it was found that black colour and foul odour is present in the raw water which has been abstracted from the Kelani River during the drought season and right after flooding event. It was observed that during the above extreme incidents, Chlorine demand at Biyagama Water Treatment Plant is increased and intermediate chlorination has been implemented to maintain the optimum RCl level recently. Hence, BWTP is selected for this research study.

The Biyagama Water Treatment Plant project is implemented to augment the supply of treated water to the National Water Supply & the Drainage Board of Sri Lanka. The Water Treatment Plant is design hours a day to produce 40 MGD (181.8 MLD) of treated water comply Standards 614-1983 for potable water (Appendix C) and WHO's "Guidelines for Drinking Water Quality" 2nd edition, 1993 (Appendix D) at the right bank of the Kelani River in Pattiwila secretariat in Gampaha District in the Western Province in Sri Lanka. The intake located on a 0.38 Ha site on the right bank of Kelani river and the treatment plant site is located on a 5.1 Ha site about 200m distance from the intake.

Figure 4.5 Intake Wells, Low lift Pumps and Pumping Main (Source; NWSDB)

This treatment Plant generally comprises of the following components.

- Intake and Raw Water Pumping Plant
- Raw Water Pumping Main to Treatment Works
- Water Treatment Plant
- Treated Water Pumping Station
- Treated Water Pumping Main to Connection Points.
- Sludge Treatment Plant

Figure 4.6 Treatment Plant (Source; NWSDB)

Raw water is extracted from Kelani River and pumped to the raw water regulation tank and pre chlorine may be dosed at the raw water regulation tank via submerged distributor to prevent algae growth in the process unit entry distributor and facilitated by the mechanical flash mixers.

Dosed water shall be distributed equally to six numbers of flocculation tanks by means of weir plates installed at the inlet of the flocculation tanks. Polyelectrolyte (polymer) doses at the inlet of each flocculation tank, if required, depending on the raw water quality.

After flocculation, flocculated water enters six numbers of respective lamella clarifier tanks where a fine flocks group together to form heavier flocks assisted by polyelectrolyte dosed. Flocks, which settle on lamella plates, forms a sludge layer which slides down on lamella plates and settle into the sludge compartment underneath lamella plates. Settled water is directed to outlet channel over an adjustable V clarified water channel around filter plant. Clarifier sludge shall be discharged from sludge hoppers under hydrostatic pressure through a discharge pipe into external sludge collection channels and flow into the balancing tank where the sludge from the clarifier desludging is homogenized with settled residuals or sludge from the waste wash water tank.

Settled water from lamella clarifier distributes equally to eight (8) nos. of filter tanks by means of weir plate and filtered in eight numbers of constant flows, constant head rapid gravity sand filters. After filtration, filtered water is collected to common filtered water channel and is then gravitated into contact consists of two compartments with its own contact tank/compartment.

Filtered water chlorinates prior entering the contact tank of the Clear Water Tank (CWT). Lime adds at the outlet of the contact tank for pH correction. Treated water shall be pumped by treated water pumps (Church Hill pump sets and Ambatale pump sets) to the connection points.

Filter media backwashing is performed by a combination of air scouring and water washing. Water will be pumped from CWT and air shall be generated by air blowers installed in treated water pumping station for backwashing of the filter media. Waste/wash water shall discharge into wash water collecting channel and gravitate into wash water recovery tank. Supernatant from the wash water recovery tank shall be pumped back to the raw water regulation tank and the settled residuals or sludge shall balancing tank where the sludge from the clarifier desludging is homogenized with settled residuals or sludge from the waste wash water tank.

Homogenized residuals or sludge shall then be pumped into the sludge thickener tank. Thickened residuals or sludge from thickener tank shall be collected in the thickened sludge tank before tank being further dewatered by the decanters installed in decanter building.

Intake / Raw Water Pumping Station and Water Treatment Plant receive 33kV primary power via Overhead Transmission Lines from CEB respectively. CEB tariff metering shall be installed at Intake / Raw Water Pumping Station and Water Treatment Plant respectively. 30kVA generator set is installed at Intake / Raw Water Pumping Station and 100kVA generator set is installed at the Water Treatment Plant for lighting back essential power supply.

Various field instruments such as electromagnetic flow meters, ultrasonic level transmitters, pressure transmitters, differential pressure transmitters, installed various part of the plant for control and monitoring purposes. SCADA system via distributed control system (DCS) is installed in each of the plants for plant control and data acquisition. DCSs or SCADA panel at various for communication network and terminates at the filter plant control room. From the control room, both intakes / raw water pumping station and water treatment plant process can be supervised and monitored. (Operation Manual, BWTP) Organization chart of BWTP is given in (Appendix E).

4.4.1 Water Treatment Flow Diagram

The treatment plant having conventional Water treatment techniques.Process Flow diagram of the treatment plant is depicted in figure 4.7

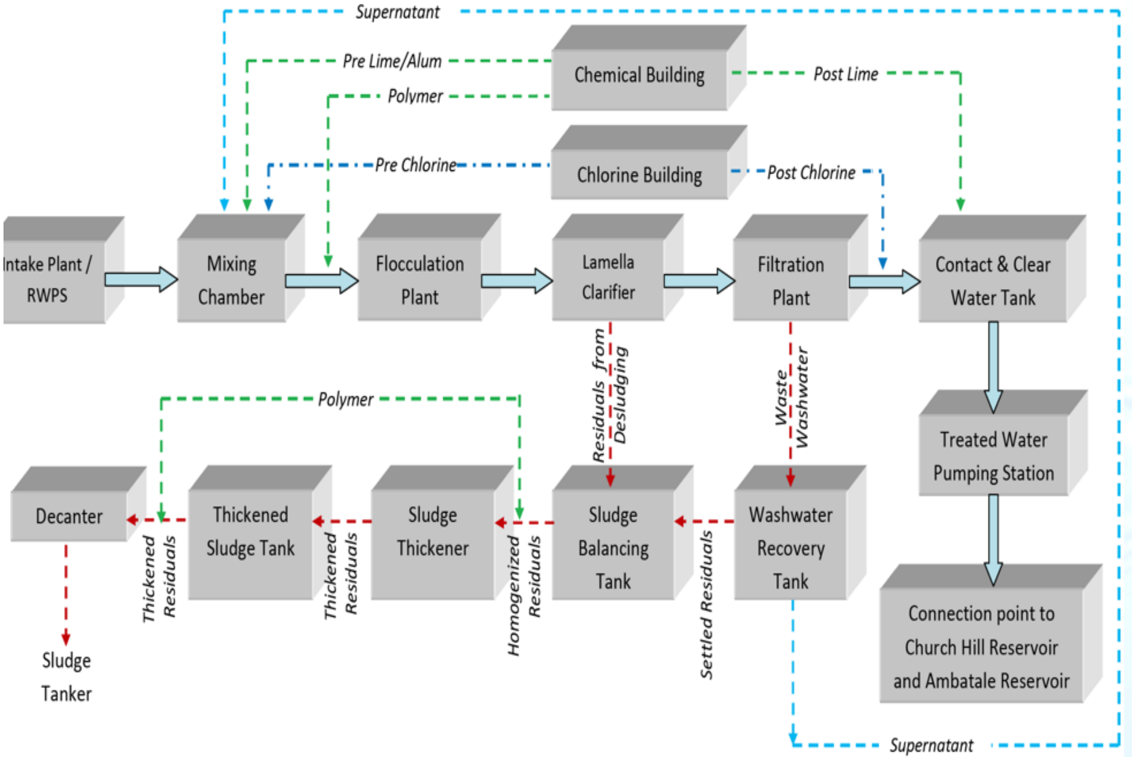


Figure 4.7 Water Treatment Flow Diagram

4.4.2 Range of Clarified water Quality

Table 4. 1 Range of clarified water quality (Operation Manual, BWTP)

Parameters	Desirable	Permissible
Turbidity NTU	12	25
Total Aluminium (mg /L)	1.0	2.0
Soluble Aluminium (mg/ L)	0.1	0.2
True Colour Pt-Co	-	30

Design range of Clarified water quality of the BWTP is given in the table 4.1

4.4.3 Range of Filtered water quality

Table 4. 2 Range of filtered water quality (Operation Manual, BWTP)

Parameters	Desirable	Permissible
Turbidity NTU	2	8
Total Aluminium (mg/L)	0.005	0.2
pH	7.85	6.5-9
True Colour Pt-Co	5	15

Design range of filtered water quality of the BWTP is given in the Table 4.2

4.4.4 Raw Water Quality of Biyagama Water Treatment Plant

The water quality of the source which is used for the supply of drinking water should meet the requirements of SLS 722 (Appendix F). According to the past water quality data raw water quality of the Intake well in Biyagama Water Treatment plant confirms the SLS requirements except Oil and Grease. According to the past water quality data during the year 2015 to 2016, Colour, Turbidity, Iron free ammonia Manganese& Oil and Grease of raw water vary in high levels with the Rainfall variation.(Appendix A) Treated water was confirmed the standard level of drinking water requirement as specifications of SLS 614:2013 (Appendix C).

4.4.5 Water Quality Targets

- Raw water is abstracted from Kelani River. Turbidity of Kelani River varies within the range of 3- 200NTU. This water treatment plant has different treatment facilities. Alum, Poly Aluminum Chloride, Poly acrylamide can be used as coagulants for the removal of Turbidity.

- The settled water Turbidity should be less than 12NTU after the Sedimentation followed by the flocculation.
- Filtered water Turbidity should be 0.0 – 2.0 NTU which is the requirement for Chlorination.
- Disinfected final water enters the distribution should meet the requirements of SLS **614:2013.**

4.4.6Regulatory Requirement & Water Quality Standard

Water quality in the water sources, use as raw water for public water supply should always

conform to the National standards published under the SLS 722. Nonconformities should be regularly monitored and controlled with proper control measures. Water pollution should be controlled at the source of origin. This can be easily done with having a proper catchment management plan.

Similarly Drinking water quality should conform to the Tolerance limits of National drinking water quality standard published under the SLS 614: 1985.

4.5 Incident on increasing chlorine demand in BWTP on 19.10.2016

It was reported that the chlorine demand of Biyagama and Ambatale water treatment plants were increased at 5.00 pm on 19.10.2016 onward up to unexpected level. As a result of this chlorine demand variation, expected residual chlorine level (0.8 ppm) couldn’t able to maintain in the plant.

Subsequently, monitoring of raw water quality was conducted on 20.10.2016 and samples for this study were collected on a stretch of 5 km from Biyagam Water treatment Plant Intake to Kaduwela Bridge. The results of the above samples were given in the Table 4.3.

According to the results obtained on 20.10.2016 survey, it was found that the Ragahawatta Ela exceeded SLS 722 standard for free ammonia content, nitrate, sulfate etc.

Hence, monitoring of raw water quality was conducted and water samples were collected along the Rakgahawatta Ela to BOI BIP Zone on 21.10.2016. The results of the above samples are given in Table 4.5. The above Samples were analyzed by BWTP & Ratmalana Waste Water Treatment Plant Laboratories.

Table 4. 3 Raw water quality variation in Kelani River on 20/10/2016. (Source: BWTP Laboratory)

Sample Location	**Time**	**pH**	**Dissolved Oxygen (mg/L)**	**Free Ammonia (mg/L)**	**Nitrate (mg/L)**	**Nitrite (mg/L)**	**Phosphate (mg/L)**	**Sulphate (mg/L)**	**Iron (mg/L)**	**E.Cconductivity (μS/cm)**
1-3.Under Kaduwela bridge	10.35 am	7	Left-6.1	0.11	0.5	0.002	0.09	6	0.18	85.1
			Mid-6.7							65.1
			Right-6.52							61.3
4.Under Highway bridge (Low level bridge	10.20 am	6.9	6.6	0.14	0.6	0.003	0.15	9	0.34	130
5.Downstream of Coca Cola-upstream to Biyagma village Hotel	11.00 am		6.4							66.3
6.Downstream of Beer outlet	11.15 am		6.5							65.3
7.RakgahawattaEla	11.27 am	6.6	2.6	3.4	16	0.03	1.4	80	1.0	502
8.Emalka Hotel (Downstream of Rakgahawatta)	11.45 am		5.6							141.2
9.BWTP intake	10.30 am	6.9	5.0	0.1	0.5	0.02	0.26	15	0.32	95.5

Table 4. 4 Chlorine Demand variation in BWTP from 19/10/2016 to 21 .10.2016 (Plant Technicians Data sheet, BWTP)

Date	Time	Pre Chlorine Dosage (ppm)	Post chlorine Dosage (ppm)	Total chlorine dosage(ppm)	Raw water Flowm^3/hr	Residual Chlorine (ppm)
19/10/2016	1.00 A.M	0.8	2.6	3.4	8015	0.7
19/10/2016	3.00A.M	0.8	2.6	3.4	8011	0.7
19/10/2016	5.00A.M	0.8	2.6	3.4	8058	0.7
19/10/2016	7.00A.M	0.8	2.8	3.6	8094	0.6
19/10/2016	9.00A.M	0.8	2.4	3.2	8077	0.9
19/10/2016	11.00A.M	0.8	2.4	3.2	8063	0.8
19/10/2016	13.00A.M	0.8	2.4	3.2	8057	0.7
19/10/2016	15.00P.M	0.8	2.4	3.2	8087	0.7
19/10/2016	17.00P.M	0.8	3.4	4.2	8225	0.6
19/10/2016	19.00P.M	0.8	4.2	5	8048	0.7
19/10/2016	21.00P.M	0.8	4.4	5.2	8177	0.6
19/10/2016	23.00P.M	0.8	4.4	5.2	8188	0.3
20/10/2016	1.00 A.M	0.8	4.4	5.2	8149	0.3
20/10/2016	3.00A.M	0.8	4.4	5.2	8123	0.4
20/10/2016	5.00A.M	0.8	4.4	5.2	8091	0.4
20/10/2016	7.00A.M	0.8	4.4	5.2	8390	1
20/10/2016	9.00A.M	0.8	4.4	5.2	8217	0.8
20/10/2016	11.00A.M	0.8	4.4	5.2	8872	0.8
20/10/2016	13.00A.M	0.8	4.2	5	8245	0.9
20/10/2016	15.00P.M	0.8	4.2	5	8172	0.8
20/10/2016	17.00P.M	0.8	4.2	5	5651	0.6
20/10/2016	19.00P.M	0.8	4.2	5	8145	0.8
20/10/2016	21.00P.M	0.8	4.3	5.1	8016	0.8
20/10/2016	23.00P.M	0.8	4.3	5.1	8109	0.9
21/10/2016	1.00A.M	0.8	4.3	5.1	8018	0.9
21/10/2016	3.00A.M	0.8	4.3	5.1	7984	0.8
21/10/2016	5.00A.M	0.8	4.3	5.1	7948	0.8
21/10/2016	7.00A.M	0.8	4.3	5.1	8332	0.8
21/10/2016	9.00A.M	0.8	4.2	5	8269	0.6
21/10/2016	11.00A.M	0.8	4.2	5	8034	1
21/10/2016	13.00A.M	0.8	4.2	5	8148	0.8
21/10/2016	15.00P.M	0.8	4.2	5	7981	0.9
21/10/2016	17.00P.M	0.8	4.2	5	8200	0.9
21/10/2016	19.00P.M	0.8	4.2	5	5695	0.9
21/10/2016	21.00P.M	0.8	4.2	5	8159	0.9

Table 4. 5 Water quality variation in Rakgahawatta Ela On 21/10/2016 (Source; BWTP Laboratory)

Sample No:	**Sample Location**	**Time**	***DO (mg/L)**	**Conductivity (µS/cm)**	**Colour(m-1)**	**COD (mg/L)**	**Total –N (mg/L)**	**NH3-N (mg/L)**	**NO3-N (mg/L)**	**TSS (mg/L)**
					Y R B					
1	Under Rakgahawatta Bridge	11.20 AM	2.62	682	11.1,7.8,6.0	31.3		3.62	2.1	417
2	Near Holiday home New KelaniNadee	11.49AM	2.32	765						
3	Kidekuburapalama,Bandaranayake mawatta	12.05 PM	2.98	702	5.1,3.8,3.1	43.7		3.57	2.8	2
4	Under the bridge on Kottunna road	12.14 PM	1.55	877	5.2,3.6,2.9	35.8	11.9	5.76	4.6	13
5	Cannel contaminated by BOI waste which is connected to RakgahawattaEla (13 mile post,Biyagama (close to Siyabalape junction)	12.41PM	1.02	2410	8.2,5.4,4.3	108	44.7	19.3	23	17
6	100m downstream of Rakgahawattaela after joining BOI waste canal	13.00 PM	3.41	952	5.9,4.0,3.2	58.5	22.2	6.47	9.1	17
7	Bridge at Galahitiyawa road	13.10 PM	5.55	217						
8	BOI BIP Zone waste water out let	13.40 PM	5.65	2590	7.0,4.7,3.5	175	50.9	20.6	20	43
9	Under the bridge close to Biyagama walking track (Upstream of Rakgahawatta)	12.30 PM	5.85	217	7.0,4.7,3.6	36.7	38.8	0.59	0.4	1

*Minimum acceptable DO level as per the SLS; 722 is 5mg/l.

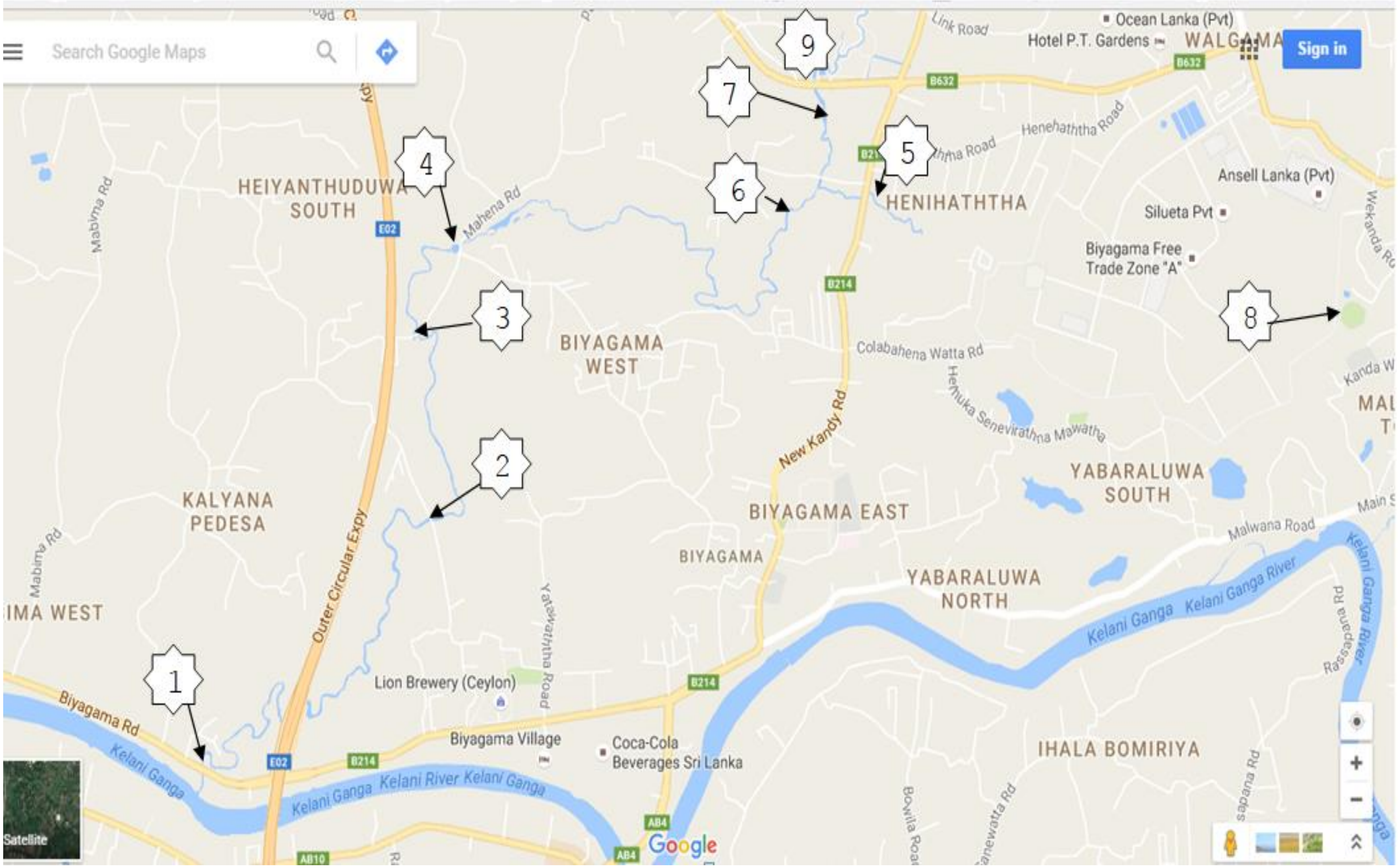


Figure 4.8 Sample location on Google map

Table 4. 6 Raw water quality variation in BWTP (Source; BWTP Laboratory)

Date	**Time**	**NO_3^-**	**NO_2^-**	**PO_4^{3-}**	**Conductivity**	**pH**	**Turbidity**	**Fe**	**Free NH_3**	**SO_4^{2-}**
16/10/19	10.15 AM	0.7	0.003	0.07	81.3	6.9	9.2	0.13	0.09	8
16/10/19	11.40 PM	1.8	0.024	0.48	108	6.8	11.7	0.43	0.4	12
16/10/20	02.30 AM	1.4	0.03	0.65	110	6.8	-	0.23	0.36	-
16/10/20	5.30 AM	0.6	0.02	0.15	107.5	-	-	0.29	0.4	14
16/10/20	6.10 AM	-	-	-	110	-	-	-	0.35	-
16/10/20	09.00 AM	-	-	-	106	-	-	-	0.35	-
16/10/20	10.30 AM	0.5	0.017	0.26	95.5	6.9	10.7	0.32	0.1	15

Table 4. 7 Treated Water Quality variation in BWTP (Source;BWTP Laboratory)

Date	**Time**	**NO_3^-**	**NO_2^-**	**PO_4^{3-}**	**Conductivity**	**pH**	**Turbidity**	**Fe**	**RCl**	**Free NH_3**	**SO_4^{2-}**
16/10/19	10.20 a.m	0.7	0.003	0.1	102	7.5	0.42	0.05	0.9	0.03	11
16/10/20	00.00	1.3	0.003	0.05	132	6.9	0.51	0.1	0.4	0.01	-
16/10/20	02.00 a.m	-	-	-	-	-	-	-	0.4	-	-
16/10/20	5.30 a.m	1.2	0.003	0.1	136	-	-	0.02	0.4	ND	20
16/10/20	6.10 a.m	-	-	-	133	-	-	-	0.4	ND	-
16/10/20	09.00 a.m	-	-	-	131	-	-	-	0.8	0.04	-
16/10/20	10.30 am	0.8	0.003	0.22	132	7.5	0.70	0.01	0.5	0.04	20

Table 4. 8 Laboratory Test Report on 21/10/2016 Analysis of TOC in Raw Water in Kelani River (Source; Appendix G-Laboratory Test Report on 21/10/2016)

Sample No	**Date of Sampling**	**Source**	**Result TOC mg/l**
1	21/10/2016	SPH Sump Ambatale	3.1
2	21/10/2016	Intake Well Ambatale	5.0
3	21/10/2016	Kaduwela Bridge	5.2

4.6 Observations of incident Number 2 on 07th November 2016

On 07th November 2016, it was informed bad odour in the water. Hence, powdered activated carbon dosing has been started from the midnight. All of a sudden, RCL level in the treated water decreased and chlorine demand at the water treatment drastically increased more than the design capacity of the existing chlorine dosing system. In order to control the water quality, intermediate dossing of Bleaching powder had been started at Churchil reservoirs .Subsequently, Consumer complaints were received about bad smell in treated water. On 10th November 2017, It was identified that highly polluted water is entering the NWSDB water intake at BWTP from Pattivila Ela which is just upstream of the intake. During the site inspection on 13th November 2016, it was noticed that the black colour water is entering to the Pattiwila canal through an underpass from the water pond in the premises near the laugf gas factory. With, the immediate effect arrangement has been organized to block the above black water entering point temporary. Water Samples were collected from the following locations and reported water quality results is given in the Table 4.9, 4.10 and 4.11.

Table 4. 9 Chlorine Demand variation on 7th November 2016 onward (Plant technicians data sheet, BWTP)

Date	**Time**	**Pre Chlorine Dosage (ppm)**	**Post chlorine Dosage (ppm)**	**Total Dosage(ppm)**	**Raw water Flow(m^3/hr)**	**Residual Chlorine (ppm)**
7/11/2016	0	1	2.5	3.5	5532	0.8
7/11/2016	4	1	2.5	3.5	7813	0.8
7/11/2016	8	1	2.9	3.9	7905	0.9
7/11/2016	12	1	2.9	3.9	8075	0.8
7/11/2016	16	1	2.9	3.9	5744	0.8
7/11/2016	20	1	2.4	3.4	7894	0.9
8/11/2016	0	1	2.7	3.7	7755	0.9
8/11/2016	4	1	2.7	3.7	7732	0.8
8/11/2016	8	1	2.3	3.3	7812	0.8
8/11/2016	12	1	2.3	3.3	7859	0.9
8/11/2016	16	1.5	3.43	4.93	7864	0.8
8/11/2016	20	1.5	3.43	4.93	7873	0.8
9/11/2016	0	1.5	2.3	3.8	7769	0.8
9/11/2016	4	1.5	2.3	3.8	8144	0.9
9/11/2016	8	1.5	2.3	3.8	8074	0.8
9/11/2016	12	1.5	2.3	3.8	7956	0.8
9/11/2016	16	1.5	2.3	3.8	7917	0.8
9/11/2016	20	1.6	2.3	3.9	7895	0.9
10/11/2016	0	1.3	2.3	3.6	7846	0.9
10/11/2016	4	1.2	2.3	3.5	7609	0.9
10/11/2016	8	1	2.3	3.3	7802	0.9
10/11/2016	12	1	2.3	3.3	7853	0.8
10/11/2016	16	1	2.4	3.4	5600	0.8
10/11/2016	20	1	2.4	3.4	7900	0.8
11/11/2016	0	1.4	2.4	3.8	7800	0.8
11/11/2016	4	1.4	2.4	3.8	8000	0.7
10/11/2016	8	1.4	2.4	3.8	7900	0.7
10/11/2016	12	1.4	2.4	3.8	7980	0.8
10/11/2016	16	1.4	2.4	3.8	8000	0.8

Table 4. 10 Raw water quality variation from 7/11/2016 to 11/11/2016(Web base Information system, BWTP)

Date	**7/11/2016**	**8/11/2016**	**9/11/2016**	**10/11/2016**	**10/11/2016**	**11/11/2016**	**11/11/2016**
pH	6.7	6.4	6.5	0	6.3	0	6.4
Colour /(Pt-Co)	37	28	20	79	79	0	55
Conduc /(us/cm)	75	81	89	0	0	0	80.5
Res Al/(mg/l)	0	0	0	0	0	0	0
Fr Ammonia /(mg/l)	0.09	0.13	0.06	0	0.07	0.12	0.1
Nitrate as N /(mg/l)	0.8	0.8	0.8	0	0.8	0	0.7
Nitrite as N /(mg/l)	0.003	0.003	0.004	0	0.003	0	0.002
Iorn /(mg/l)	0.93	1.19	0.95	0.69	0.69	1.16	0.99
Sulphate /(mg/l)	3	4	3	0	5	0	4
RCL /(mg/l)	0	0	0	0	0	0	0
Fluoride/(mg/l)	0.06	0	0	0	0	0	0
Turbidity /(mg/l)	28	15.3	14	0	30.1	0	11.8
T Hardness /(mg/l)	24	20	32	0	32	0	36
Oil & Grease /(mg/l)	0.7	0	0	0	0	0	0
T Phosphate /(mg/l)	0.25	0.31	0.07	0	0.05	0	0.07
Chloride /(mg/l)	7.8	7.8	7.8	0	5.9	0	7.8
Total Coliform	17,000	0	0	0	0	0	0
TotalE.Coli	2,000	0	0	0	0	0	0

2016.11.07.

Treated water iron concentration has increased and chlorine consumption at the BWTP was in increasing trend

2016.11.08

In order to maintain the Residual chlorine level treated water, chlorine dosage has been increased up to its maximum of 4.93ppm.

2016.11.09

Treated water iron concentration has deccreased and chlorine consumption was in decreasing trend.

2016.11.10

Final water iron concentration was back to normal and raw water iron reduces down to 0.7 ppm. The river level has increased and fresh water came to intake due to increase of dilution ratio with high flow rate in the river. Therefore, pre chlorine dosage reduced to 1ppm. But the iron concentration in Pattiwila canal was still in 3.7 ppm. Therefore, continuous attention should be given to the river level and raw water color.

2016.11.11 – 09.30 am

The raw water iron concentration increased up to 1.16 ppm. Settle water and treated water iron concentration recorded as 0.44 ppm and 0.04 ppm respectively. Meanwhile free ammonia concentration increased up to 0.12 ppm in raw water and it was not detected in treated water due to the presence of pre chlorine.

Table 4. 11 Treated water quality variation from 11/7/2016 to 11/11/2016 (Web Based Information system, BWTP)

Date	7/11/2016	8/11/2016	9/11/2016	10/11/2016	10/11/2016	11/11/2016	11/11/2016
pH	6.9	7.4	7.4	0	7.4	0	7.7
Colour /(Pt-Co)	5	6	0	0	0	0	0
Conductivity /(us/cm)	113	112	111.9	0	113	0	110.3
Res Al/(mg/l)	0.06	0.05	0.06	0	0.06	0	0.06
Fr Ammonia/(mg/l)	0	0.02	0	0	0.01	0	0
Nitrate as N/(mg/l)	0.9	0.8	0.7	0	0.9	0	0.8
Nitrite as N/(mg/l)	0.003	0.002	0.002	0	0.002	0	0.002
Iorn /(mg/l)	0.07	0.12	0.13	0.01	0.01	0.04	0.03
Sulphate /(mg/l)	9	10	9	0	10	0	11
RCL /(mg/l)	0.8	0.9	0.8	0	0.7	0	0.9
Fluoride/(mg/l)	0.04	0	0	0	0	0	0
Turbidity/(mg/l)	1.37	1.01	1.33	0	0.93	0	0.93
T Hardness/(mg/l)	25	25	25	0	30	0	30
Oil & Grease /(mg/l)	0	0	0	0	0	0	0
T Phosphate/(mg/l)	0.2	0.23	0.09	0	0.07	0	0.08
Chloride/(mg/l)	9.8	9.8	9.8	0	9.8	0	9.8
Tot Coliform	0	0	0	0	0	0	0
Tot E.Coli	0	0	0	0	0	0	0

Table 4. 12 Study on Raw Water Quality Variation in Pattiwila Catchment area 6 - 10/11/2016 (Source; BWTP Laboratory)

Sampling point	Nitrate as N/(mg/l)	Iron /(mg/l)	Conductivity /(us/cm)	Apparent Colour /(Pt-Co)	Free Ammonia/(mg/l)
BWTP Intake 6/11/2016	1.4	0.47	97.1	67	0.27
RagahawattaEla 6/11/2016	55	2	1330	135	10
Kaduwela Bridge 6/11/2016	1.6	0.28	69	35	0.17
15km post at Siyabalape Junction 6/11/2016	55	1.5	2680	-	22
Pattiwila Marsh(near the Laughf gas factory) 6/11/2016	1.2	4.06	144	375	0.03
Pattiwila canal 6/11/2016	0.6	3.64	160	227	0.1
Patiwila canal 10/11/2016		3.7			

Table 4. 13 Heavy metal analysis reports 13/11/2016 & 14/11/2016 (Appendix H)

Sampling No.	Sampling point	Manganese(as Mn/(mg/l)
	Tolerance limit for treated water	0.1
1	BWTP raw water sampling tap 13/11/2016	0.153
2	BWTP Treated water sampling tap 13/11/2016	N.D.<0.001
3	Heenela close Pattiwilachanel 13/11/2016	0.291
4	Heenela close Pattiwilachanel 14/11/2016	0.311
5	Upstream of Pattiwila canal(1.5km away from the Laughf gas factory) 14/11/2016	0.125
6	Mabima east 14/11/2016	0.011
7	Heenela (under the bridge at laughfengineering site	0.192
8	BWTP raw water sampling tap 14/11/2016	0.106
9	BWTP Treated water sampling tap 14/11/2016	0.007

The above analysis was done to trace the root cause of black contamination of raw at BWTP. According the above analysis and the site inspection proved that the source of manganese contamination of the raw water at the Biyagama water treatment plant was Mabima catchment. Although, the sample taken at 1.5 km upstream of the Pattiwila canal was 0.125mg/l of Manganese, black colur water could not found beyond that point upstream of the Pattiwila canal.

4.7 Contaminated Raw water incident No.3 at Biyagama Water Treatment Plant

On 4th June 2017, the Plant technician on duty has informed that bad odour and colour are present in the raw water. Apart from that bad odour and taste were noticed in the drinking water. Subsequently, became aware that the Pattiwila canal was full of black water and which was being contaminated the raw water through Kelani River. In addition, DO level of raw water has decreased up to 1.18ppm on the analyzer rack.

4.7.1 Immediate actions taken

1. Closed the Raw Inlet Penstocks at 1st stage and opened the Inlet Penstocks at 2nd stage
2. Started activated carbon dosing in the treatment Plant
3. Increased the Pre chlorine dossing until 0.1 RCL present in filtered water. Chlorine Demand variation from 4th to 9th June 2017 is given in Table 3.12
4. Requested to be standby to dose post chlorine at Churchill when it is required

No complaints were received from consumers at this time.

On Sunday 4th June 2017, Manager (TNC) was requested to commence the intermediate chlorination from Churchill for maintaining Rcl in treated water and flood gates were closed.

Complaints were received regarding bad odour and taste from consumers at this time. Highest recorded iron content in the raw water at BWTP was 2.58ppm so far. DO remain same as previous day.

4.7.2 Further actions taken

On Monday 5th June 2017, Sand bags have been packed at the flood gates to control the contaminations of canal water to Kelani river and raw water in the intake. One village man opposed to closing of flood gates by using sand bags. The central environment authority was alerted about this incident

On Tuesday 6th June 2017, dewatering the canal by pumping has been arranged. 6’’ pump and stand by pipeline have been installed and pumping has been started at 11.30 p.m.

On Wednesday 7th June 2017, Kelaniya Police informed that there was a complain regarding the closing of flood gates in the Pattiwila Canal by sand bags. Subsequently, Clarification has been made over the phone on the raw water contamination incident at BWTP to the SSP Kelaniya.

4.7.3 Sampling

On Monday 5th June 2017, Sand bags have been packed at the flood gates to control the contaminations of canal water to Kelani river and raw water in the intake. One village man opposed to closing of flood gates by using sand bags. The central environment authority was alerted about this incident.

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On Wednesday 7th June 2017, Kelaniya Police informed that there was a complain regarding the closing of flood gates in the Pattiwila Canal by sand bags. Subsequently, Clarification has been made over the phone on the raw water contamination incident at BWTP to the SSP Kelaniya.

Samples of raw water and treated water has been taken from 4th June 2017 at 4.30 p.m. onwards and the results of the samples received from the laboratory is given in the tables of 4.13,4.14, 4.15 and 4.16

4.7.4 Criteria for Clearance of drinking water

Although the water in the water sources was bad odour and dark black in colour, the treatment plant was able to conform to the Tolerance limits of National drinking water quality standard published under the SLS 614: 1985 except odour and taste. Therefore, the water supply from the plant has not interrupted.

4.7.5 Follow-up Public Health measures after water clearance

Bad Odor and taste problems were not reported in the treated water after 10th June 2017.

Table 4. 14 Chlorine Demand variation from 4th to 9th June 20179 (Plant technicians, data Sheet, BWTP)

Date	Re. chlorine Dosage (ppm)	Post chlorine Dosage (ppm)	Total Dosage(ppm)	Residual Chlorine (ppm)	Raw water Flow m3/hr
04-06.2017	2.76	1.66	4.42	0.7	7617
04-06.2017	2.71	1.67	4.38	0.6	7741
04-06.2017	3.07	2.32	5.39	0.5	7821
04-06.2017	3.17	1.8	4.97	0.9	7883
04-06.2017	3	2.18	5.18	0.3	7655
04-06.2017	3.04	2.18	5.22	0.3	7588
05-06.2017	3.02	2.2	5.22	0.3	7843
05-06.2017	3.02	2.2	5.22	0.3	7744
05-06.2017	3.02	2.2	5.22	0.3	7738
05-06.2017	3.02	1.28	4.3	0.2	7861
05-06.2017	3.02	1.3	4.32	0.3	7686
05-06.2017	3.02	1.29	4.31	0.4	7721
06-06.2017	3.02	1.28	4.3	0.5	7658

06-06.2017	3.02	1.28	4.3	0.6	7853
06-06.2017	3.02	1.29	4.31	0.6	7779
06-06.2017	3.02	1.28	4.3	0.7	7847
06-06.2017	3.02	1.29	4.31	0.8	7756
06-06.2017	3.02	1.28	4.3	0.8	7796
07-06.2017	3.02	1.28	4.3	0.8	7742
07-06.2017	3.02	1.3	4.32	0.8	7543
07-06.2017	4.0	1.2	5.2	0.9	7547
07-06.2017	3.65	1.16	4.81	0.9	7935
07-06.2017	3.69	1.18	4.87	0.9	7859
07-06.2017	3.8	1.02	4.82	0.9	7626
08-06.2017	3.74	1.17	4.91	0.9	7751
08-06.2017	3.83	1.16	4.99	0.9	7825
08-06.2017	3.79	0.78	4.57	0.9	5808
08-06.2017	3.72	1.03	4.75	0.8	8057
08-06.2017	3.81	1.17	4.98	0.8	7864
08-06.2017	3.88	1.16	5.04	0.9	7730
09-06.2017	3.38	0.9	4.28	0.8	7688
09-06.2017	3.31	0.89	4.2	0.9	7852
09-06.2017	3.31	0.89	4.2	0.7	7862
09-06.2017	3.53	1.43	4.96	0.8	7654
09-06.2017	3.4	1.15	4.55	0.9	7941
09-06.2017	3.56	1.15	4.71	0.8	7592
09-06.2017	3.5	1.15	4.65	0.8	7716

Table 4. 15 Raw Water quality variation at BWTP (Source;BWTP Laboratory)

Date	**6/5/2017**	**6/6/2017**	**6/7/2017**	**6/8/2017**	**6/9/2017**	**6/12/2017**	**6/13/2017**	**6/14/2017**	**6/15/2017**
pH	6.4	6.4	6.4	6.5	6.2	6.6	6.6	6.6	6.7
Colour /(Pt-Co)	69	18	21	12	8	24	12	16	16
Conduc /(us/cm)	76	50	52	53	57	69	63	62	60
Res Al/(mg/l)	0	0	0	0	0	0	0	0	0
Fr Ammonia/(mg/l)	0.05	0.04	0.07	0.05	0	0.15	0.11	0.1	0.08
Nitrate as N/(mg/l)	0.6	0.9	0.8	0.9	1	0.9	0.7	2	0.9
Nitrite as N/(mg/l)	0	0.003	0.001	0.002	0.016	0.005	0.004	0.008	0.004
Iorn /(mg/l)	2.58	1.2	1.2	1.14	1.36	1.63	1.18	1.06	0.95
Sulphate /(mg/l)	0	0	0	3	0	3	1	4	2
RCL /(mg/l)	0	0	0	0	0	0	0	0	0
Fluoride/ (mg/l)	0	0	0	0	0	0	0.03	0	0
Turbidity /(mg/l)	7.06	14.6	13.9	7.31	13.3	10.5	8.7	7.3	10.1
T Hardness /(mg/l)	25	15	15	15	15	20	15	15	15
T Alkalinity/(mg/l)	28	16	16	16	16	16	20	24	24
Oil & Grease /(mg/l)	1	0	0	0	0	0	0	0	0
T Phosphate/(mg/l)	0.07	0.07	0.07	0.09	0.07	0.11	0.14	0.05	0.06
Chloride/ (mg/l)	7.8	3.9	8	8.1	8	8.1	9.6	8.1	9.5
Tot Coliform	7200								
Tot E.Coli	4500								

Figure 4.9 Black water visible in Pattiwila canal and Intake on (Source;NWSDB)

Table 4. 16 Raw Water Quality Variation at BWTP and Pattiwila Canal from 4 to 5/6/2017 (Source; BWTP Laboratory)

Date	**Odour**	**Colour**	**Total Hardness**	**NO_3^-**	**Total Alkalinity**	**DO**	**Manganese**	**NO_2^-**	**PO_4^{3-}**	**Conductivity**	**pH**	**Turbidity**	**Fe**	**Fl-**	**Cl-**	**Free NH_3**	**SO_4^{2-}**
17/6/4 **BWTP**	objectable	186	20	3.7	25	1.18	0.36	0.008	0.4	74.1		14	2.56	0.01	10	0.09	5
17/6/05 **BWTP**	objectable	192	28	0.6	25	3	0.22	0	0.1	76	6.4	7	2.58		8	0.05	0
17/6/4 **Pattiwila canal**	Objectable	292	44	6,8	50	-	0.41	0.018	0.15	135	6.2	22	5.13	0.01	0.15	44	7
17/6/05 **Pattiwila canal**	Objectable	288	60	2.3	0.26		0.38	0.005	0.12	140	6.2	19.5	7.05	-	-	0.26	1

Table 4. 17 Treated Water Variation at BWTP from 4/6/2017 to 5/6/2017(Source; BWTP Laboratory)

Date	Time	Odour	Colour	Total	NO_3^-	Total Alkalinity	Taste	Manganese	NO_2^-	PO_4^{3-}	Aluminium	pH	Turbidity	Fe	Cl-	Free NH_3	SO_4^{2-}
17/6/4 BWTP	16.30	objectable	2	40	7	25	Objectable	0.1	0.01	0.54	0.06	6.8	1.2	0.25	12	0.01	8
17/6/05 BWTP	8.50	objectable	10	36	3	30	Objectable	0.12	0.006	0.08	0.01	7.0	1.1	0.14	10	0.01	4

4.7.6 Removal of Iron and Ammonia Using the Aeration / Sedimentation

Table 4.18 Average and Maximum concentrations in Iron and Manganese occurred in Raw Water at BWTP (WBDMS,BWTP)

Month	Av.total iron content mg/l	Av. Mn content mg/l	Max. Recorded total iron content mg/l	Max. Recorded Mn content mg/l
April 2017	0.59	0.04		
May 2017	0.73	0.05		
June 2017	1.31	0.08	2.58	0.26

Table 4. 19 Minimum DO concentrations occurred in Raw Water at BWTP(WebBWTP,2017)

Date	Minimum recorded DO mg/l(manual)	Minimum recorded DO mg/l(Analyzer rack)
June 2017	3	1.17 (4,&5/6/ 2017)

4.7.7 1Results of the Aeration Test

Table 4.20 Efficiency of Iron and Ammonia Removal by aeration (BWTP Laboratory, 2017)

Date and time		**Raw Water mg/l**	**After 2min aeration mg/l**	**After 3min aeration mg/l**
20/02/2017 15.30pm	DO	6.84	7.35	7.54
20/02/2017 15.30pm	Ammonia	0.31	0.28	0.21

Table 4.21 Efficiency of Ammonia Removal by aeration and sedimentation (BWTP Laboratory, 2017)

Date and time	**Raw Water Dissolved Oxygen mg/l**	**Raw Water Ammonia mg/l**	**Activated Carbon Dosage mg/l**	**Ammonia concentration after 20min mg/l**
20/02/2017 15.30pm	6.84	0.31	0.5	0.24
20/02/2017 15.30pm	6.84	0.31	1	0.21

Table 4.22 Efficiency of Iron and Ammonia Removal by aeration (BWTP Laboratory, 2017)

Date		**Raw Water mg/l**	**after 2min aeration mg/l**	**after 3min aeration mg/l**	**3min aeration+17 min sedimentation mg/l**
5.6.2017	DO	3	5.3	6.8	7.3
5.6.2017	Iron	2.58	2.1	1.8	0.9
15/08/2017	DO	7.25	7.36	7.43	7.69
15/08/2017	Ammonia	0.13	0.02	0.02	0.02
15/08/2017	iron	0.44	0.37	0.37	0.35

5. ANALYSIS OF RESULTS AND DISCUSSION

Mainly three raw water contamination incidents were considered for this study and those will be analyzed and discussed under this chapter. Data were collected through field survey, laboratory testing, and observing the existing facilities and application method at BWTP.

5.1 Analysis of test results on the incident No 1

Table 4.3 (Chapter 4) and Figure 5.1, show the Ammonia, Electrical Conductivity, iron, Phosphate, Sulfate, Nitrate and Dissolved oxygen (DO) concentrations in the water samples taken from different locations along the Kelani River up to 5km upstream from Biyagama Intake. It also shows that the highest electrical conductivity level is recorded in the Ragahawatta Ela.

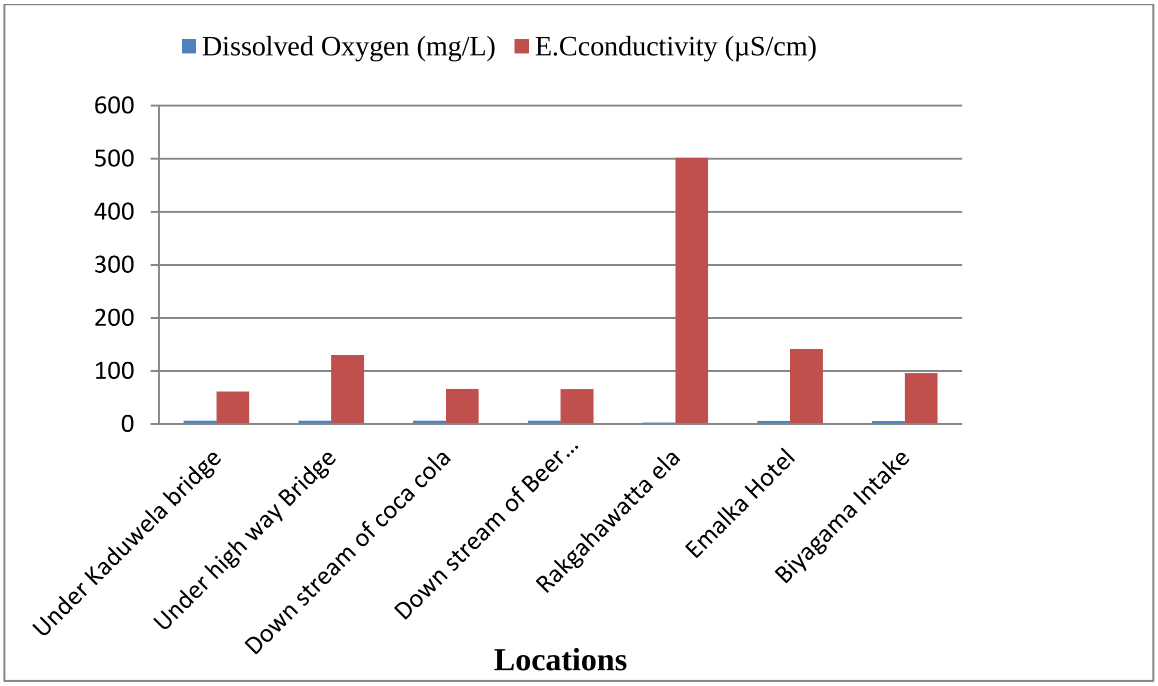

Figure 5. 1: Raw water quality variation in the tributaries of Kelani River on 20/10/2016

Hence, Rakgahawatta Ela was selected for further studies. Accordingly, a new survey was held on 21.10.2017, the DO and electrical conductivity concentrations were tested at

9 locations given in google map figure 5.2. The reported concentrations of DO and electrical conductivity levels are given in figure 5.3.

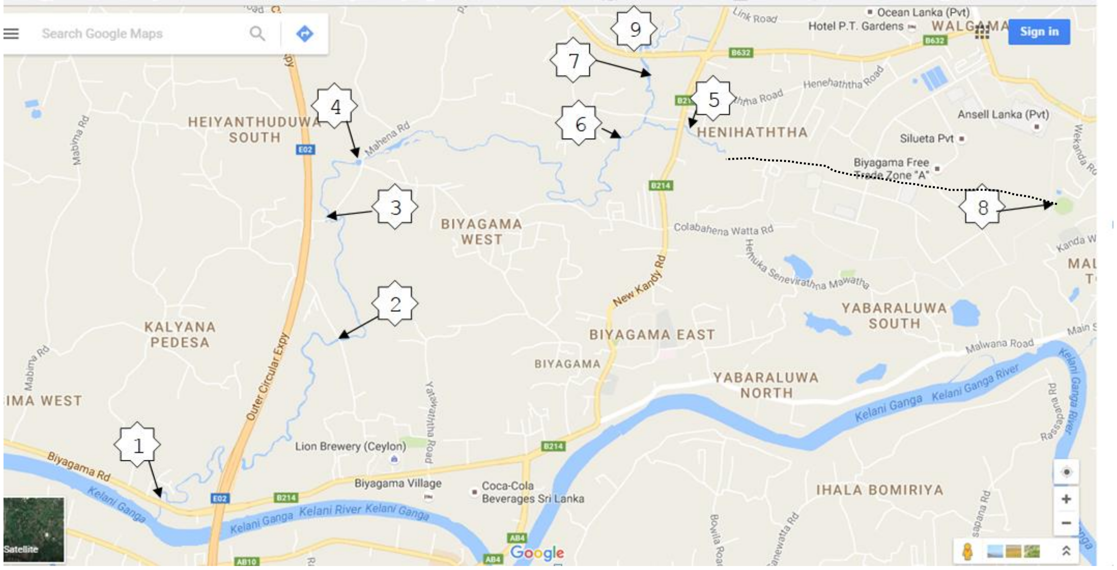

Figure 5. 2 Sample location Map along the Rakgahawatta Ela

Table 5. 1 The legend of Sample locations

Legend	
Sample Location No.	Sample Location
1	Under Rakgahawatta Bridge
2	Near Holiday home New KelaniNadee
3	Kidekuburapalama, Bandaranayakemawatta
4	Under the bridge on Kottunna road
5	Cannel contaminated by BOI waste water (13 mile post)
6	100m downstream of Rakgahawattaela after joining BOI waste canal
7	Bridge at Galahitiyawa road Under the bridge
8	BOI BIP Zone waste water outlet
9	close to Biyagama walking track (Upstream of Rakgahawatta)

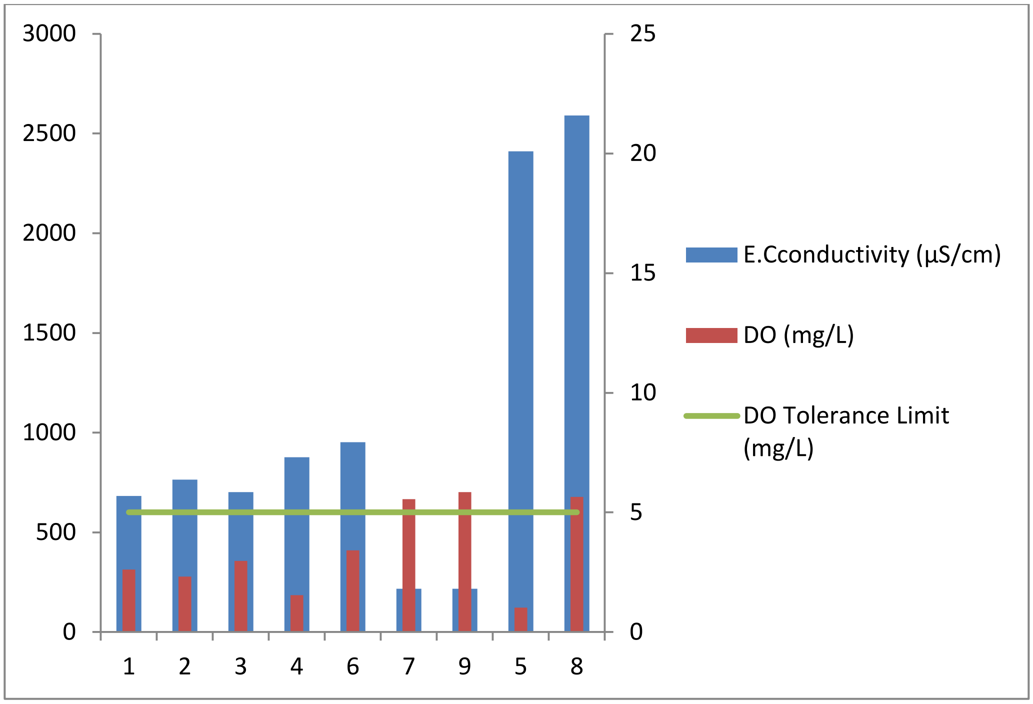

Figure 5. 3 C**o**nductivity and DO variation along the Rakgahawatta Ela on 21/10/2016

(Please refer to location map given in Fig. 5.2)

It was noticed that the Electrical Conductivity level is high in the BOI waste water outlet. It was the outlet of the maturation pond of wastewater treatment plant, there was an aeration provision as shown in the figure 5.5. As a result of it, DO concentration at the BOI waste water outlet is higher than the canal, although possibly contaminated by BOI waste water outlet. As per the figure 5.3, the BOI waste water outlet was recognized as the main source which contributes to the pollution of the Kelani River through the Rakgahawatta Ela. Sample location under the bridge close to Biyagama Walking track and under the bridge at Galahitiyawa road is on the other tributary of Ragahawatta Ela. DO and the Electrical Conductivity levels of those samples reported were within the raw water standard limits. According to the figure 5.4, the main source of NH_4-N contamination in Kelani River was identified as BOI BIP Zone waste water outlet and it was amounting 20.6 mg/l.

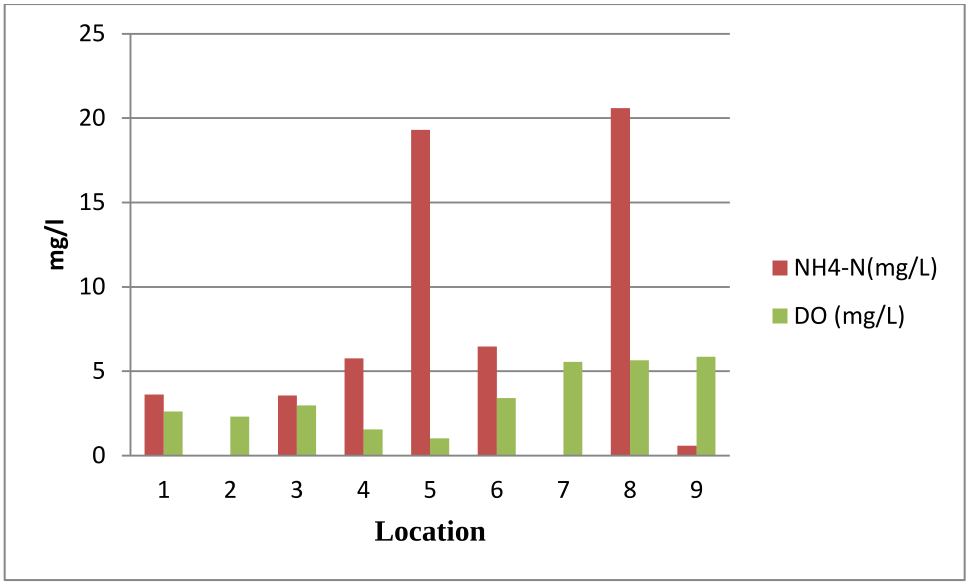

Figure 5. 4 Conductivity and DO variation along the Rakgahawatta Ela on 21/10/2016

Figure 5. 5 BOI BIP Zone waste water outlet

Figure 5.6 shows the chlorine demand variation from 19/11/2016 to 21/10/2016. It clearly shows that the post chlorine demand in the BWTP started to increase on 19/10/2017 and RCl levels in the treated water were in decreasing trend. According to daily records at BWTP, average chlorine consumption in the BWTP is 3.4 ppm. However, it increased to 5.22 ppm on 20/10/2016, which may be due to the presence of extra amounts of Fe^{++} (0.32mg/l), TOC (5.2mg/l) and decrease of DO (5mg/l) level in the raw water.

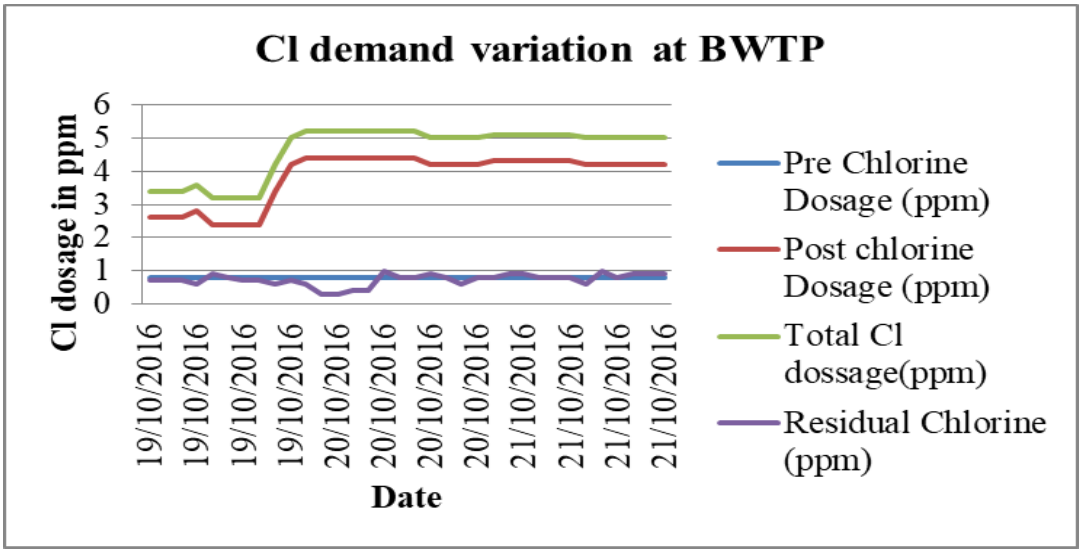

Figure 5. 6 Chlorine Demand variations at BWTP 19 to 21/10/2017

Figure 5.7 shows both the Ammonia and iron concentrations along the 5 locations of downstream of the Kelani River from Biyagama Intake. It was also identified that the NH_4-N and iron (Fe^{++}) levels peaked in the water at Ragahawatta Ela. Then, Rakgahawatta Ela could be identified as the main source of contributing total iron (Fe++) to the raw water at Biyagama Intake (Pattiwila Intake).

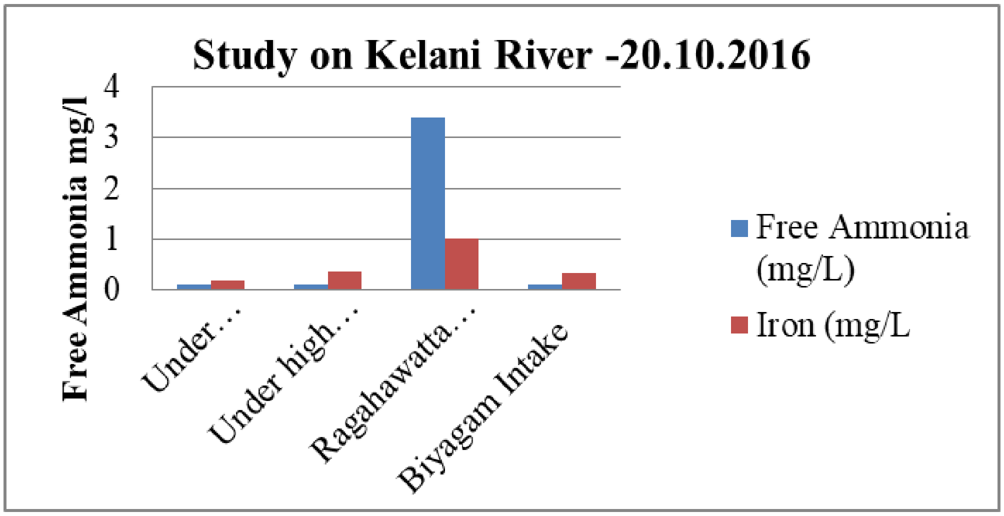

Figure 5. 7 Ammonia and Iron variation in Kelani River on 20.10.2016

According to the Table 4.7 (chapter 4) the amount of ammonia present in the raw water in BWTP intake is 0.1mg/l. This suggests that it is not likely to cause high chlorine demand at BWTP, As per the same table, Iron concentration in treated water was 0.1mg/l and the average raw water flow rate on the same day was 8149 m3/hr.

Raw water flow rate at 00.00 on 20/10.2017	8149 m3/hr
Assumed 2% waste	162.98 m3/hr
Treated water production	9986m3/hr
Iron discharged to distribution	0.8kg/hr

Although, the maximum limit of iron concentration in treated water is 0.2mg/l, according to the consumer complaints, even the concentration of 0.1mg/l in treated water with RCl also makes the red water problem for the consumers (SLS614; 2013). As per the literature review (American Journal of Environmental Engineering, 2013), presence of Fe^{++} (pH 6.9) concentration 0.32mg/l in raw water in BWTP may have led to high chlorine demand for oxidation and the formation of complex soft scales or deposits along the distribution pipe.

5.1.3 Total Organic Carbon (TOC) Concentration in Raw water

It was not possible to check the TOC level in Biyagama intake due to a practical problem. However, as per the table 3.8, the TOC levels in Kelani river water at locations upstream and downstream of BWTP intake (data available at the Ambatale Water Treatment Plant) are 5.2mg/l and 5.0mg/l respectively. The data also revealed that the TOC reduced to 3.1mg/l in treated water at Ambatale. This may be due to chemical oxidation of organic matter by chlorination. The same thing must be happening at BWTP which could be one of the potential root causes for high chlorine demand in water treatment.

5.2 Analysis result of Raw Water contamination Incident No: 2

Figure 5.8 represents the pre, post and total chlorine demand variation at BWTP from 7 to 11/11/2016. According to the Figure 5.7 chlorine demand shows a sudden increase from 3.3ppm to 4.93ppm on 8/11/2016. The data for the above was taken from the daily records of BWTP which prepared by the plant technicians.

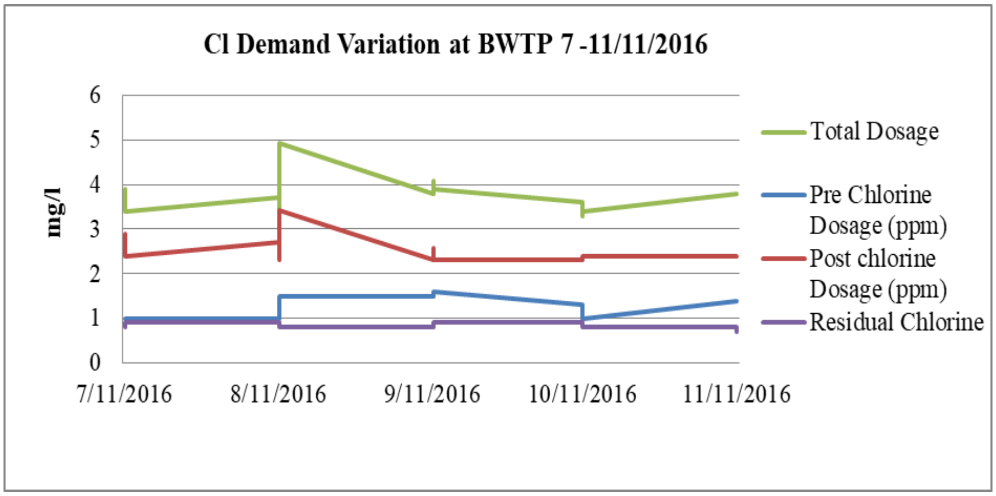

Figure 5. 8 Cl demand variation at BWTP

On 13/11/2016, it was noticed that, black color water was draining to the Pattiwilla Ela across the underpass from the Pattiwila catchment by the side of the Laugf gas factory.

As the Pattwila Ela is draining to Kelani River just adjacent to the Biyagama (Pattiwila) intake, mixing of contaminants through the canal is very high. Hence, sampling survey has been carried out within the Pattiwila catchment. Table 4.13 (chapter 4) and figure 5.9 show the reported Manganese levels of water in the suspected 9 locations of Patiwila catchment on 13/11/2016 & 14/11/2016. The results of the figure 5.9 showed that the Manganese levels of 4 locations exceeding its tolerance limit of 0.1mg/l (SLS722).

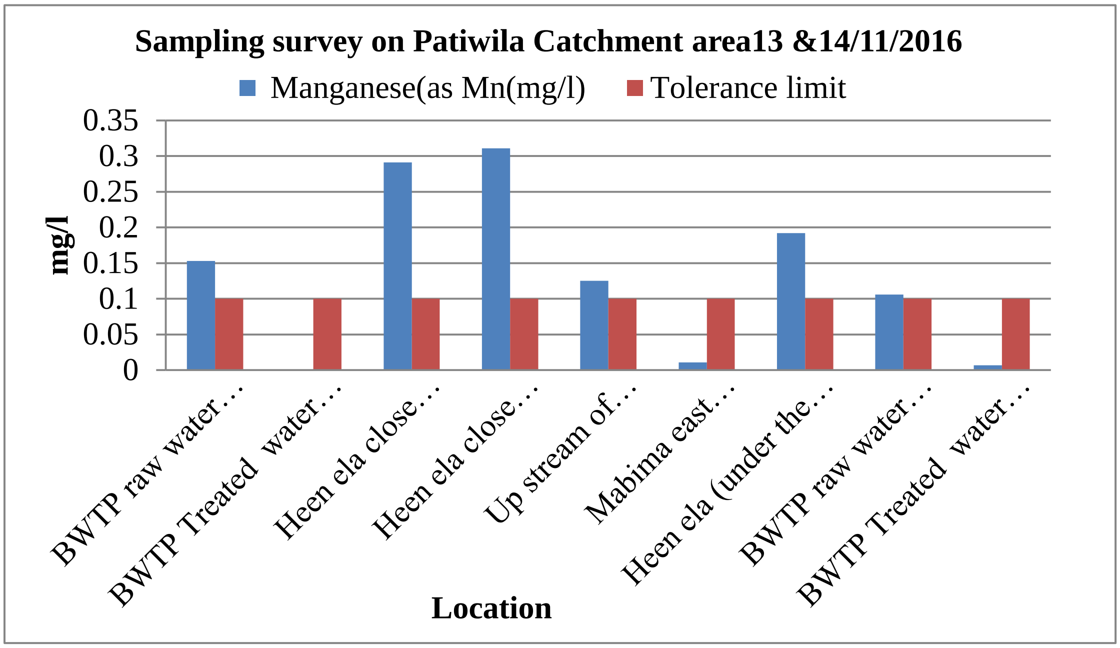

Figure 5. 9 Mn variation in Pattiwila catchment

Figure 5.9 shows the iron concentration variation in treated water at BWTP from 7-12/11/2016.

According to the Figures 5.10 and 5.8, total iron (Fe^{2+}) concentration of treated water at BWTP increased to a significantly high level (1.19mg/l) and chlorine dosage increased to 4.93 ppm on 8.11.2016. As per levels of Fe^{2+} reported in figure 5.10, the treated water contained Fe levels exceeding the SLS614 drinking water standard of 0.2 mg/l during the period from 7/11/2016 to 12/11/2016.

The survey (7/11/2016 to 12/11/2016) shows the iron concentration in Pattiwila canal was the highest. (Figure 5.10 and Table 4.12-chapter 4). Hence, source of Fe^{2+} contamination to Biyagama intake could be identified as Pattiwila canal on incident No.2 and presence of Fe^{2+} in the raw water may have led to high chlorine demand due to chemical oxidation.

As per the figure 5.9, Mn levels in the treated water were found to be higher than the general guideline of 0.05 mg/l for both drinking and aesthetic purposes. Furthermore, the Pattiwila canal through the Mabima East area may be the potential source of iron contamination to Biyagama intake and presence of Mn^{2+} in the raw water may have led to high chlorine demand due to chemical oxidation.

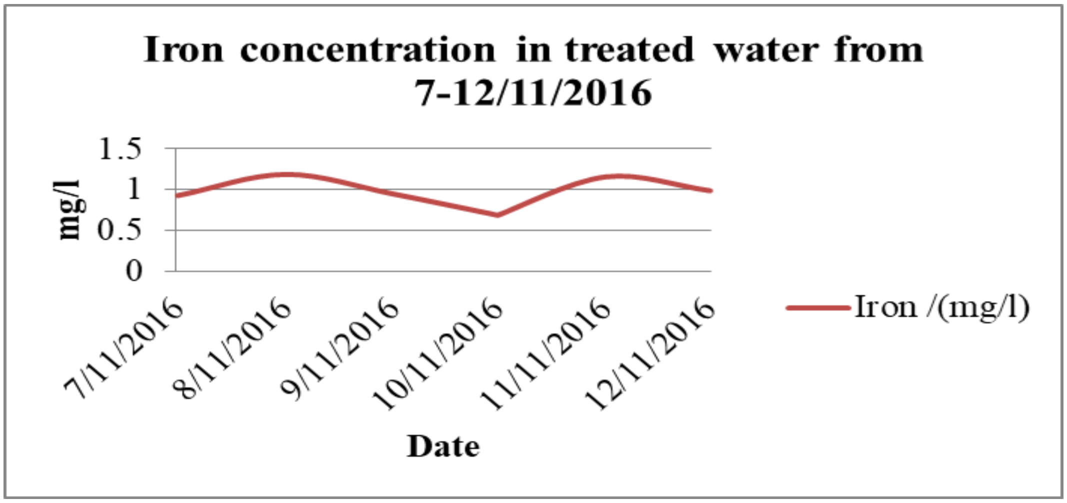

Figure 5. 10 Iron concentration variations in treated water at Biyagama Water Treatment Plant from 07 to 12/11/2016 (Web base information system)

Figure 5.11 shows the concentrations of NH4-N and Fe2+ reported on the study along the Kelani River and Ragahwatta Ela from 6/11/2016 to 10/11/2016. It was noticed that NH4-N levels substantially increased in Ragahawatta Ela and the 13th mile post which is the downstream location of the BOI waste water outlet. It was also noticed that the Fe^{2+} concentration increased in the Pattiwila canal and the Pattiwila marsh.

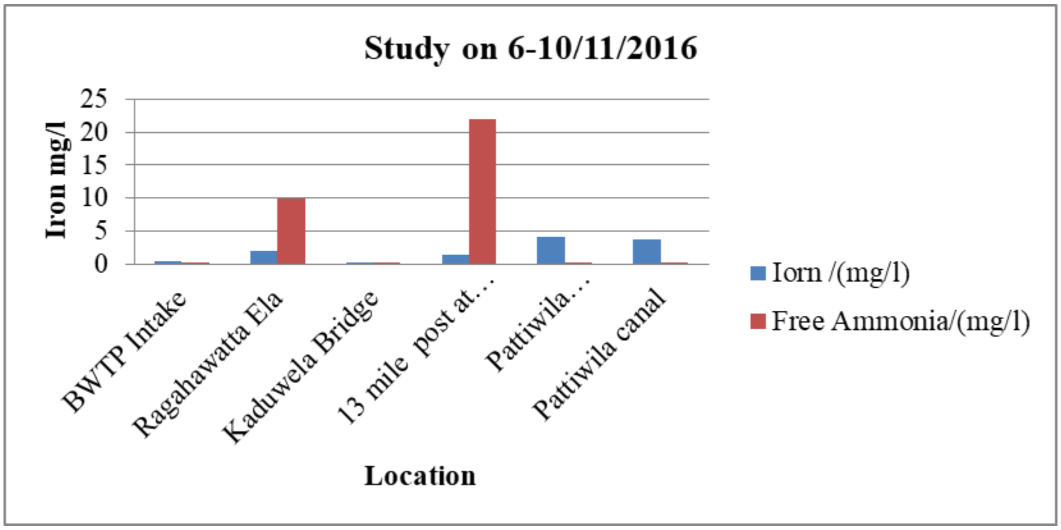

Figure 5.11 Study on 6/11/2017 to 10/11/2017 along the Kelani River and Ragahawatta Ela

Figure 5.12 and table 4.13 (chapter 4) show the Mn Variation in Pattiwila catchment on 13&14/11/2016. The result showed that the Mn levels substantially increased during both days in 5 samples taken from Pattiwila catchment, treated water tank and raw water intake at BWTP. Significant amounts of Mn were present in the raw water and its concentration in the raw water at BWTP exceeded the maximum tolerance limit of SLS72 (0.1mg/l) on both days. Based on the same results and the observations on the site visit, the source of manganese contamination could be identified as Pattiwila canal, Heen Ela, and Mabima East.

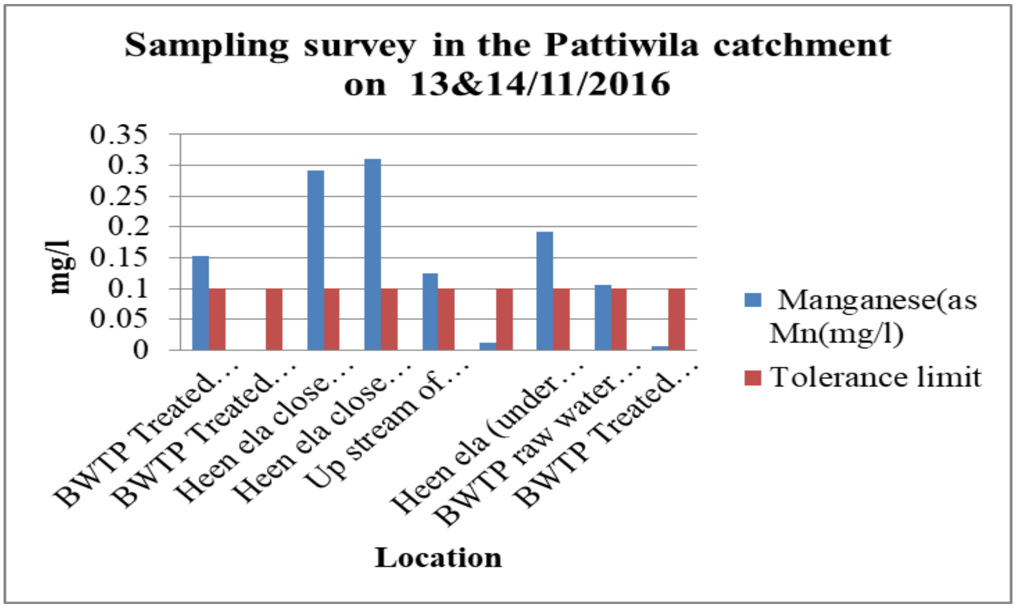

Figure 5.12 Mn Variation in Pattiwila catchment on 13&14/11/2016

5.3 Result analysis of Raw Water contamination Incident No: 3

Since there were consumer complaints of red water during the previous two incidents when the chlorine dosage in post chlorination was increased, it was decided to increase the chlorine dose at pre chlorination in order to oxidize the high Fe2+ and Mn2+ concentrations and remove the precipitated oxidized forms within the treatment plant before post chlorination in this instance.

Figure 5.13 shows, chlorine demand variation at BWTP. It indicated that the chlorine demand started to increase on 4/06/2017. It also showed that the residual chlorine concentration in the BWTP drastically decreased to 0.2mg/l at17.00 hr. on 5/6/2017. On 4/6/2017 the chlorine requirement for post and pre chlorination increased beyond the capacity of the chlorinators at BWTP, which is 5.22 ppm (41kg/hr).

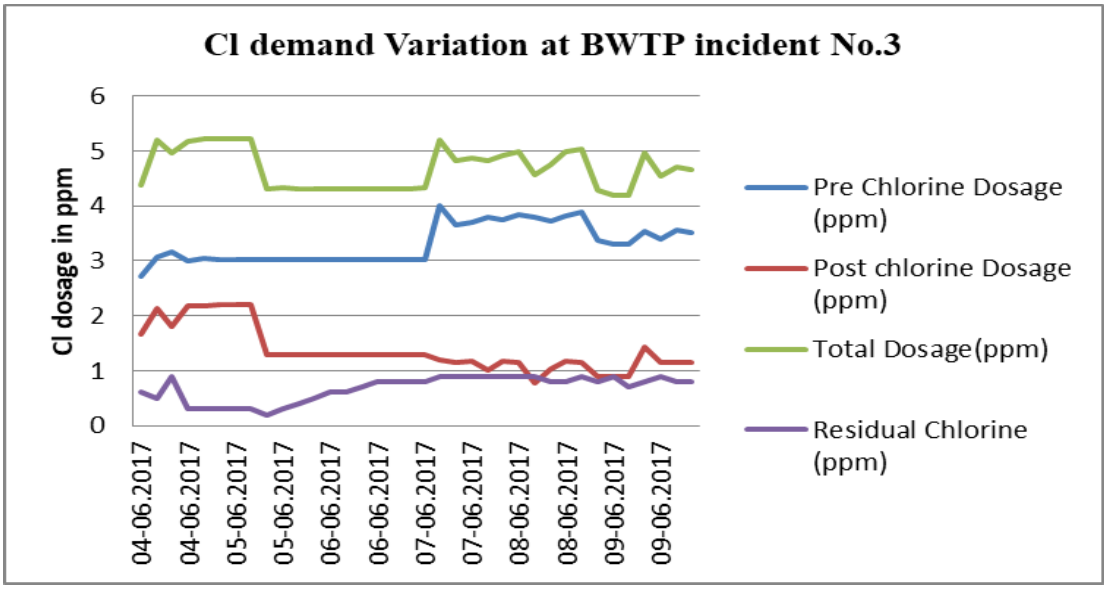

Figure 5.13 Chlorine demand variation at BWTP

Figure 5.14 shows the Iron and the ammonia variation in the raw water at BWTP. The results showed that the concentrations of NH_4-N and Fe2+ increased to 0.15mg/l and 2.58mg/l respectively.

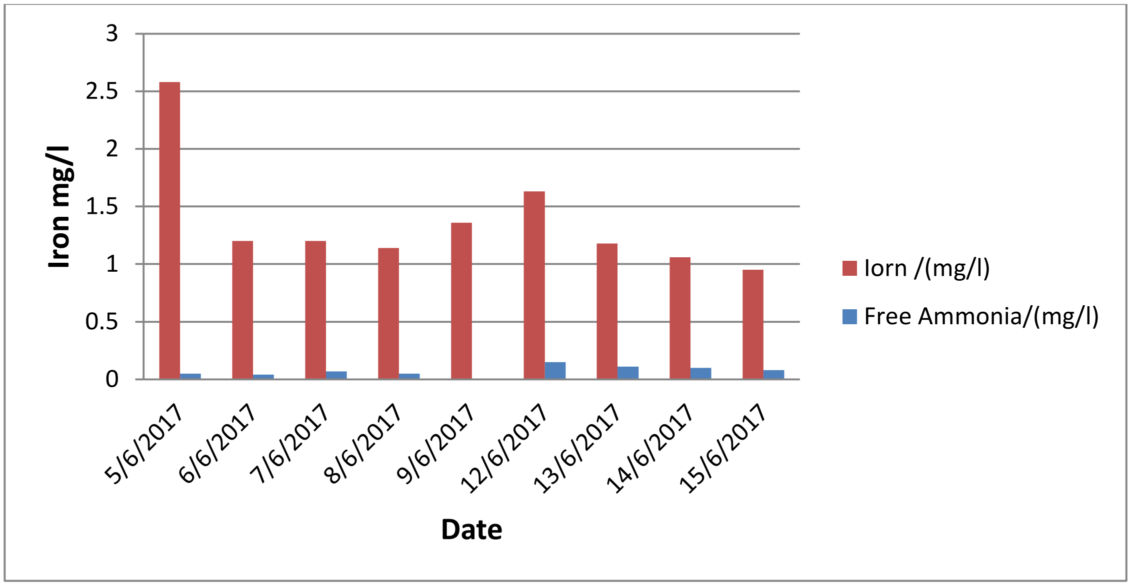

Figure 5.14 Iron and ammonia variation in raw water at BWTP from 5/6/2017 to 15/6/2017

As per the WHO, 1984 threshold level of total Mn in drinking water should be very low (mostly less than 0.05 mg/l) in order to avoid aesthetic problems. However, figure 5.15 shows that while the treated water Mn concentrations is in the range of 0.1 to 0.12 mg/l and Fe concentrations is in the range of 0.25 to 0.14. This makes it very apparent that the colour problems are caused by high Mn and Fe contents.

According the figure 5.14 maximum Fe2+and Mn2+ concentrations were 0.25mg/l and 0.12mg/l respectively. According to the SLS;614 maximum permissible limit of concentration of iron in potable water is 0.2mg/l and concentration of Mn in potable water is 0.05mg/l (WHO,1984).

When these concentrations of iron and Mn are in the treated water, it amounts to 46kg/day of iron (4/6/2016) and 22kg/day of manganese (5/6/2016) being discharged to the distribution system. These minerals will be producing taste and odour problems at the consumer taps.

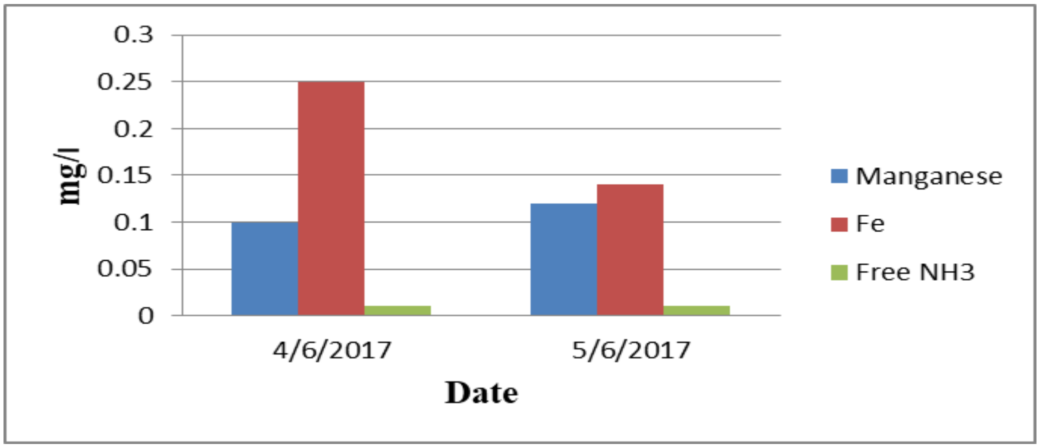

Figure 5.15 Iron, Manganese and Ammonia Variation in treated water at BWTP from 4/6/2017 to 5/6/2017

Figure 5.15 presents the DO, Fe^{2+}, Mn^{2+} and NH_4-N variation in the raw water at BWTP from 4/6/2017 to 5/6/2017. The result showed that the Pattwila canal water quality and raw water quality at BWTP have similarities of DO, iron and Mn concentrations. Hence, Pattiwila canal water may be identified as the main potential source of contaminating

Fe^{2+} and Mn^{2+} to raw water at BWTP. Furthermore, it also noticed that the DO level in raw water decreased to 1.18mg/l (figure 5.15). One possible reason to account for this observation is that removal of Mn through oxidation of Mn^{2+} to form MnO_2 precipitates is significantly lowered by the presence of high levels of Fe^{2+}, which essentially acts as a reducing agent.

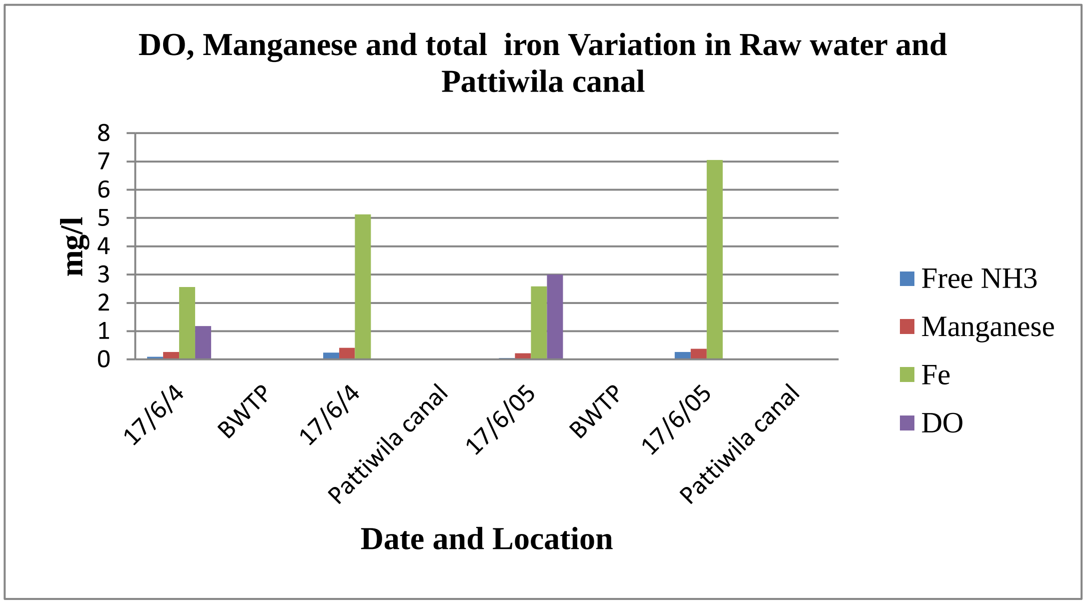

Figure 5.16 DO, Iron, Manganese and free Ammonia Variation in the raw water at BWTP from 4/6/2017 to 5/6/2017

5.4 Result analysis on Removal of Iron and Ammonia Using Aeration / Sedimentation

Table 5.2 shows the efficiency of ammonia removal by aeration. According to the outcome of the table 5.2, 32% ammonia removal could be obtained by aeration of 3 min. Table 5.3 presents the ammonia removal by activated carbon. It indicated that the same result can be obtained by adding 1ppm of activated carbon. Table 5.4 shows the efficiency of iron removal by aeration. The results showed the that the DO content is above the 7.25 mg/l in raw water, DO concentration increase by aeration was small and iron removal by aeration is not significant. It was also noticed that the Ammonia removal by 3min. aeration was 86%.

Table 5.2 Ammonia Removal by Aeration

Date and time		**Raw Water mg/l**	**After 2min aeration mg/l**	**After 3min aeration mg/l**
20/02/2017 15.30pm	Dissolved Oxygen	6.84	7.35	7.54
20/02/2017 15.30pm	Ammonia	0.31	0.28	0.21

Table 5.3 Ammonia Removal by Activated carbon

Date and time	**Raw Water Dissolved Oxygen mg/l**	**Raw Water Ammonia mg/l**	**Activated Carbon Dosage mg/l**	**Ammonia concentration after 20min mg/l**
20/02/2017 15.30pm	6.84	0.31	0.5	0.24
20/02/2017 15.30pm	6.84	0.31	1	0.21

Table 5.4 Iron and ammonia Removal by Aeration

Date and time		**Raw Water mg/l**	**After 2min aeration mg/l**	**After 3min aeration mg/l**	**3min aeration+17min sedimentation mg/l**
5.6.2017	DO	3	5.3	6.8	7.3
5.6.2017	Iron	2.58	2.1	1.8	0.9
15/08/2017	DO	7.25	7.36	7.43	7.69
15/08/2017	Ammonia	0.13	0.02	0.02	0.02
15/08/2017	Iron	0.44	0.37	0.37	0.35

5.5 Analysis of the root causes of the excessive chlorine demand of raw water at BWTP and discussion

Table 5.5 Reasons for high chlorine demand at BWTP and sources of pollutions

Incident	**Amount of Cl demand as a percentage of maximum dosing capacity of Plant***	**Potential Compounds identified as those exerting high chlorine demand in the raw water at BWTP**	**Identified Source of Pollution**
1	65% to 100%	Presence of TOC in Raw water	As per the table 3.8, the TOC levels in Kelani river water at locations upstream and downstream of BWTP intake are in the range of 5mg/l. The test results revealed that the TOC reduced in treated water at Ambatale. This may be due to chemical oxidation by chlorination. The same thing must be happening at BWTP which could be one of the potential root causes for high chlorine demad in water treatment. .
		Presence of Iron and decrease of DO level in raw water	Figure 5.6 shows that the Iron variation is peak and the DO level is below the tolerance limit of SLS722 in the Ragahawatta Ela. Then, it may be considered as the main potential source for contributing iron to the raw at Biyagama Intake (Pattiwila Intake). In addition, presence of Fe2+ in the raw water may have led to high chlorine demand due to chemical oxidation.
2	63% to 94%	Presence of Iron in raw water	The survey shows the iron concentration in Pattiwila canal was the highest. (Figure 5.9

			and Table 4.12). Hence, the Pattiwila canal through the Mabima East area may be the potential source of iron contamination to Biyagam intake and presence of Fe2+ in the raw water may have led to high chlorine demand due to chemical oxidation.
		Presence of Manganese in raw water	According to the Table 4.13 Heavy metal analysis reports 13&14/11/2016 with its graphical illustration (Figure 5.11) shows that the potential source of Mn2+ contamination of the raw water at the BWTP was Mabima catchment and the presence of manganese (Mn2+) in the raw water may have led to high chlorine demand due chemical oxidation.
3	65% to 100%	Presence of Fe2+ in raw water	According to the Figure 5.12 highest recorded iron concentrations in the raw water at BWTP were 2.58mg/l (5/6/2017). Presence of total iron (Fe2+) in the raw water may have led to high chlorine demand due to chemical oxidation.
		Presence of Mn2+ in raw water	According to table 4.13 of Heavy metal analysis reports on 13&14/11/2016, significant amount of Manganese was present in the raw at Pattiwila canal, Heen Ela, and Mabima both days. Based on the same results and the observations on the site visit, the potential source of manganese to Biyagama intake could be identified as through the Pattiwila canal, Heen Ela, and Mabima East and the presence of manganese (Mn2+) in the raw water may have led to high chlorine demand due chemical oxidation.

		Presence of Fe2+ and decrease DO level in raw water	Figure 5.14 showed that the Pattwila canal water quality and raw water quality at BWTP have similarities in DO, total Fe2+ and Mn concentrations. Apart from that, figure 3.8 indicated the Pattiwila canal water was contaminating the raw water at Biyagama Intake and the presence of Fe2+, Mn2+ and decreasing of DO levels in the raw water may have led to high chlorine demand due to chemical oxidation

* Under normal Plant operation conditions, the Chlorine demand is 65% of **maximum dosing capacity of the Plant**

In relation to the data gathered and the subsequent current literature collected it appears that the high chlorine demand is mainly due to the oxidation of Fe^{2+}, Mn^{2+} and TOC. In addition, the colour episodes are mainly due to the formation of iron precipates and manganese precipitation together with co-precipitation with iron complexes and its subsequent detachment because of the occurrence of high flow rates along the distribution system from time to time. This phenomenon is amplified by post-chlorination carried out, by simply oxidizing soluble Fe^{2+} and Mn^{2+} to Fe^{+3} and Mn^{+3} which are sparingly soluble, resulting in colour episodes.

It has been found in the literature that oxidation of soluble manganese (Mn^{+2}) in distribution systems may cause aesthetic problems such as water discolouration, fouling, staining on plumbing fixtures and consumer complaints (WHO, 1984; Sly et al., 1990; Reyes, 2004). The presence of Mn in raw water warrants special problems for water treatment authorities as it, unlike iron, is not oxidized by air at the natural pH unless otherwise precipitated by chemical oxidation in order to provide Mn free waters (Sly et al., 1990). The presence of very low levels of Mn in the treated water may result in deposition of Mn oxides causing consumer complaints (Griffin, 1960; Bean, 1974; Hart, 1974; WHO, 1984; Sly, 1990; Cerrato et al., 2006; Vreeburg et al., In press).

According to the literature review many inorganic and organic molecules that occur in raw water exert a disinfectant "demand," i.e., a capacity to react with and consume the disinfectant. Therefore, higher "demand" waters require a greater dose to achieve a specific concentration of the active species of disinfectant. This demand must be satisfied to ensure adequate biocidal treatment. Ferrous ions, Manganese, nitrites, hydrogen sulfide, and various organic molecules exert a demand for oxidizing disinfectants such as chlorine. Most treatment plants use 1 – 2 parts of chlorine to 1 part of iron to achieve oxidation (John, 1963). Then, it is evident of one of potential cause for high chlorine demand is the presence of Fe in raw water.

Removal of ferrous iron similarly reduces the demand for oxidizing disinfectants as will aeration, which eliminates hydrogen sulfide. It takes 0.14 ppm of dissolved oxygen to oxidize 1 ppm of iron, and 0.27 ppm of dissolved oxygen to oxidize 1 ppm of manganese. Potential reason for rapid decrease of DO level in raw water on, above 3 incidents may be due to oxidation of Fe and Mn in raw water. Aeration is a natural approach to iron and manganese oxidation. Once the water has been oxidized, it is then passed through various filters, which will remove the precipitated Fe and Mn, along with taste and odour if a charcoal filter is used. In aeration processes, air and water are brought into intimate contact with each other to transfer volatile substances to or from the water. Aeration of water has many benefits as follows

(i) Dissipation of free carbon dioxide,
(ii) The introduction of oxygen,
(iii) The precipitation of iron and the removal of certain taste and odours due to volatile substances. (Twort, and Crowley. 1985).

5.6 Investigation of adverse effects of treated water due to high chlorine dosages

BWTP is using chlorine as the disinfectant. According to the test report given in Table 3.8, TOC concentration at Kaduwela Bridge and in Intake well was 5.2mg/l and 5.0mg/l respectively. Hence, TOC concentration in Pattiwila Intake should be equal 5.2mg/l.

The literature reports that Humic substances, when reacting with and consuming applied chlorine, produce chloroform (CHCl3) and other THM's. (Hoehn et al., 1977; Stevens et al., 1975). Water, particularly surface waters, may also contain synthetic organic molecules whose demand for disinfectant will be determined by their structure. Several DBPs have been linked to cancer in laboratory animals and are therefore regulated. Naturally occurring carbon compounds are not hazardous by themselves, but combined with a disinfectant they produce by-products, which pose a health concern. THMs, one class of DBPs, are formed from the interaction of TOC, naturally occurring bromide, and chlorine. Hence, there is a risk of DBP formation when chlorine is added to the raw water at BWTP without removal of the organic compounds.

Ammonia is a major source of water pollution. One of the most common methods for removal of ammonia from water is oxidation. However, the amount of ammonia present in the raw water samples at BWTP were less than 0.2mg/l. This suggests that it is not likely to cause high chlorine demand at BWTP.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. This study revealed that the chlorine demand was increased when iron, Mn or TOC were present alone or together, and DO level was less than 5mg/l in the raw water at BWTP, due to uptake of chlorine for oxidation of organic matter, Fe and Mn.

2. The amount of free ammonia present in the raw water samples at BWTP were less than 0.2mg/l. This suggests that it is not likely to cause high chlorine demand at BWTP,

3. BWTP uses pre chlorine to alter taste- and odor-producing compounds, to suppress growth of organisms in the treatment plant, to remove Fe^{2+} and manganese, and to reduce the interference of organic compounds in the coagulation process. However, according to literature, pre chlorination can affect the treated water quality by the formation of undesirable THM content in the finished water. In addition, as per table 4.3, TOC concentration at BWTP intake was 5.2 mg /l on 21/10/2016. Hence, the organic matter in the raw water at BWTP plus high chlorine dosage may have led to produce chloroform (CHCl3) and other forms of disinfection byproducts.

4. According to the WSP at BWTP, there should be an emergency response plan to risk mitigation due to emergency cases. Hence, it is proposed to use the following emergency response plan for any similar incident happening in future. Apart from that, it is recommended to update the names and the contact numbers of the responsible officers as necessary by the Senior Engineer (O&M). The emergency response plan proposed is given under subtitle 6.2.1

6.2 Recommendations

6.2.1Emergency Response Plan

Incident of Emergency: Detection of foul odor, and black colour contamination in raw water and high chlorine demand in treated water create catastrophic situation.

The following situations are also considered as emergency situations related to Biyagama Water Treatment Plant and the same response plan can be followed in such situations too.

(1) The flood caused interruption in the treatment process

(2) Fire taking place in Water Treatment Plant

(3) Chlorine leak in the Water Treatment Plant

(4) Detection of poison mixed with water in river, treatment plant & distribution system.

(5) Detection of microbiological contamination in treated water

(6) Inability to produce water from the treatment plant (Complete plant shutdown due to breakdown or blackout)

In such situation, contact person list should be displayed as follows.

Name of the Person	Designation	Contact Number	Action to be Taken By
	E.A.(Civil) OIC (Maintenance)	0112986086 0112986086	EA(Mechanical) Plant Technician/ Technical Officer (Electrical)
	Chemist Snr Eng (O&M) Manager (O&M)	0112986086 0112986086 0112986086	Engineering Assistant (Civil) / OIC (M)
	DGM (Western)	0 11 2549199/ 011 2549199	Manager (O&M)
	Add.GM (Western) GM	011 2635999/ 011 4203842 011 2635990	DGM (Production)

In a situation of plant shut down, following officers should be informed for further

Name of the Person	Designation	Contact Number	Action to be Taken By
	Manager - TNC	011 2909854	Snr.Eng (Operation)
	Area Engineer Kelaniya	011 4886815	
	Area Engineer Biyagama	011 4815129	
	Area Engineer – Ja Ela	011 5333068	

If the issue related to water quality following person has to be informed

Name of the Person	Designation	Contact Number	Action to be Taken By
	Chemist	0112986086	Engineering Assistant(Civil)

If the issue related to Public Health this has to inform to following person further.

Name of the Person	Designation	Contact Number	Action to be Taken By
	Assistant Divisional Secretary	0112400314	Sr.Eng.(O&M)
	SPHI	0724990142	
	Police Station (Kelaniya)	0112911922	
	Fire Brigade	0112422222 - 3	

Prepared by: Snr.Engineer (O&M) Recommended by: Manager (O&M)

Approved by: DGM (W/P)

6.2.2 Long Term Recommendations

In order to minimize the high chlorine demand due to presence of Fe2+, Mn2+, TOC and less DO concentrations, following actions have been suggested.

- Aeration is a natural approach to iron and manganese oxidation. To install tailor made bubble aerator to Biyagama Water treatment Plant to use when the DO content is less than 5.0mg/l in raw water, after pilot scale studies.
- To include aeration and activated carbon dossing facility for upcoming Kelani Right Bank Project Stage II.
- To implement the proper catchment management plan to Pattiwila and Mabima Catchment areas to avoid the Manganese and iron contamination
- To implement continuous monitoring system to monitor the free ammonia, Fe and Manganese in the raw water at BWTP.
- To maintain a residual chlorine level of 0.1 to 0.2 mg/l throughout the distribution system all the time. This may require installing booster chlorination equipment at appropriate locations.
- To employee water treatment qualified shift officers to manage the water treatment plant round the clock instead of plant technicians as BWTP is the second largest water treatment plant in Sri Lanka.

6.3 Recommendations for Further researches

- Select suitable location to install the bubble aerator to BWTP
- To analyze the chlorine by products in treated water at BWTP and the Distribution system of the Towns North Of Colombo.

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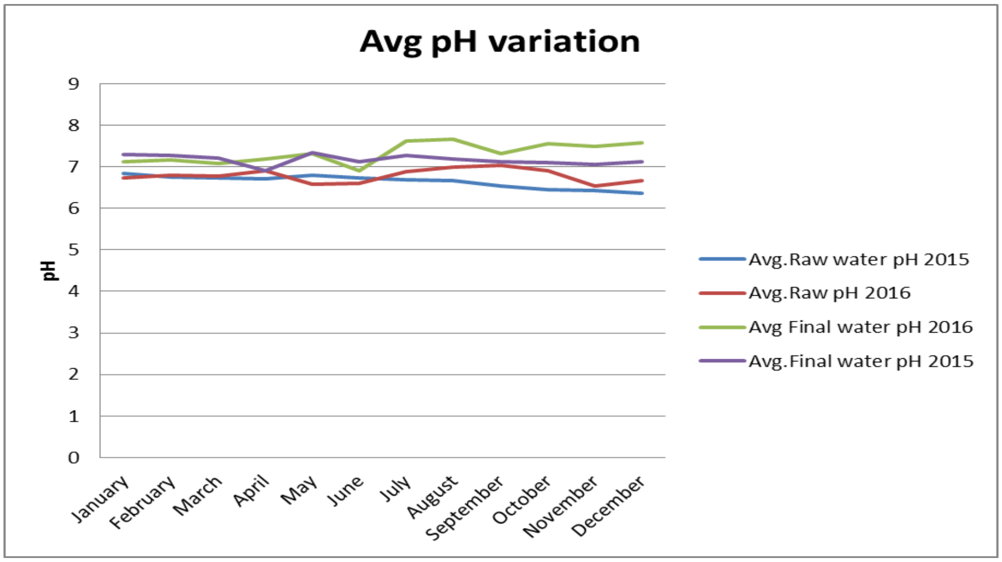
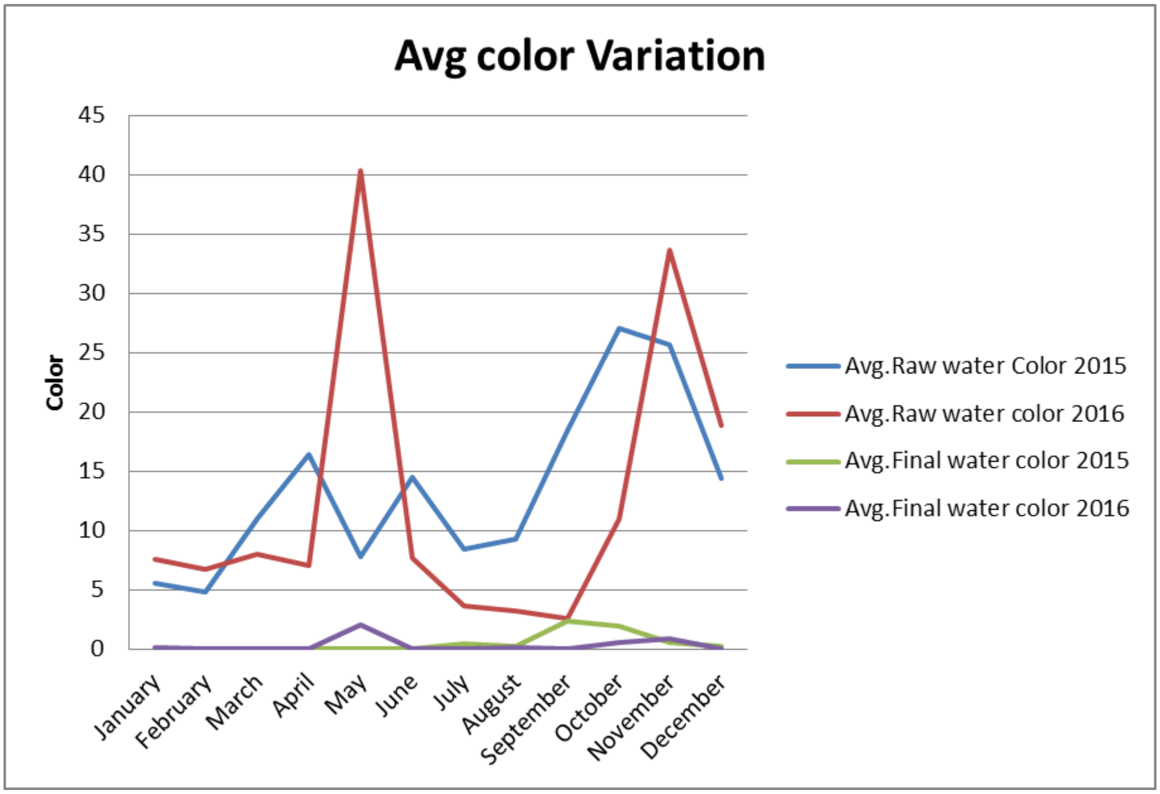
APPENDIX – A

The sampling survey conducted by the BWTP, NWSDB for the period 2015 to 2016

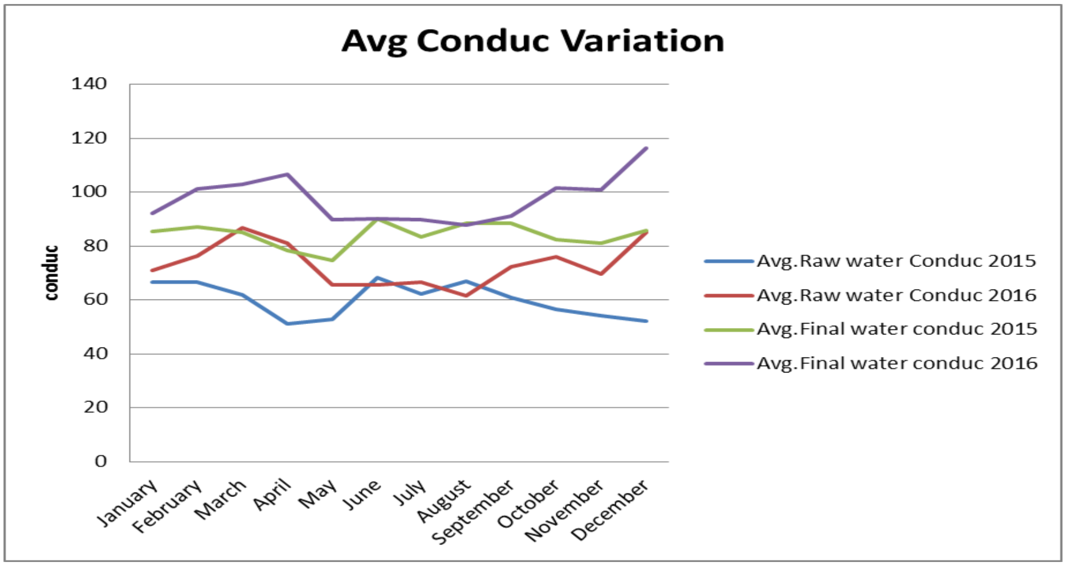
Months	2015 pH Average		2016 pH Average	
	Raw Water	Treated Water	Raw Water	Treated Water
January	6.835294	7.3	6.726316	7.125
February	6.766667	7.272222	6.8	7.175
March	6.733333	7.219048	6.775	7.075
April	6.722222	6.916667	6.9	7.2
May	6.8	7.352941	6.588889	7.311111
June	6.73	7.116129	6.604762	6.914286
July	6.69	7.268421	6.88	7.62
August	6.673684	7.194737	6.9875	7.675
September	6.55	7.127273	7.030435	7.317391
October	6.452381	7.104762	6.917391	7.552174
November	6.433333	7.066667	6.530435	7.495652
December	6.36	7.135	6.68	7.58



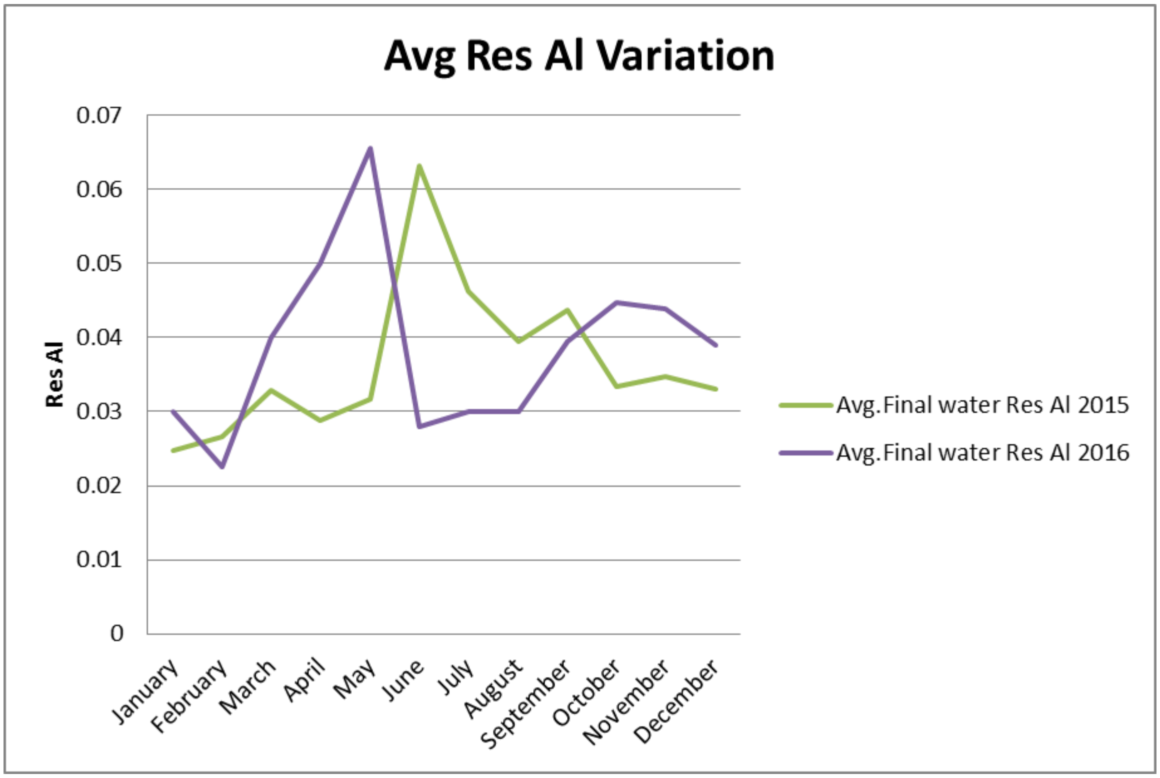
Months	2015		2016	
	Raw Water	Treated Water	Raw Water	Treated Water
	Color Average		Color Average	
January	5.529412	0	7.631579	0.1
February	4.777778	0	6.75	0
March	10.95238	0.047619	8	0
April	16.38889	0	7	0
May	7.764706	0	40.33333	2
June	14.5	0	7.705882	0.047619
July	8.45	0.5	3.666667	0
August	9.263158	0.263158	3.2	0.1
September	18.45455	2.318182	2.571429	0
October	27.04762	1.904762	10.95652	0.521739
November	25.66667	0.590909	33.66667	0.84
December	14.35	0.2	18.89474	0



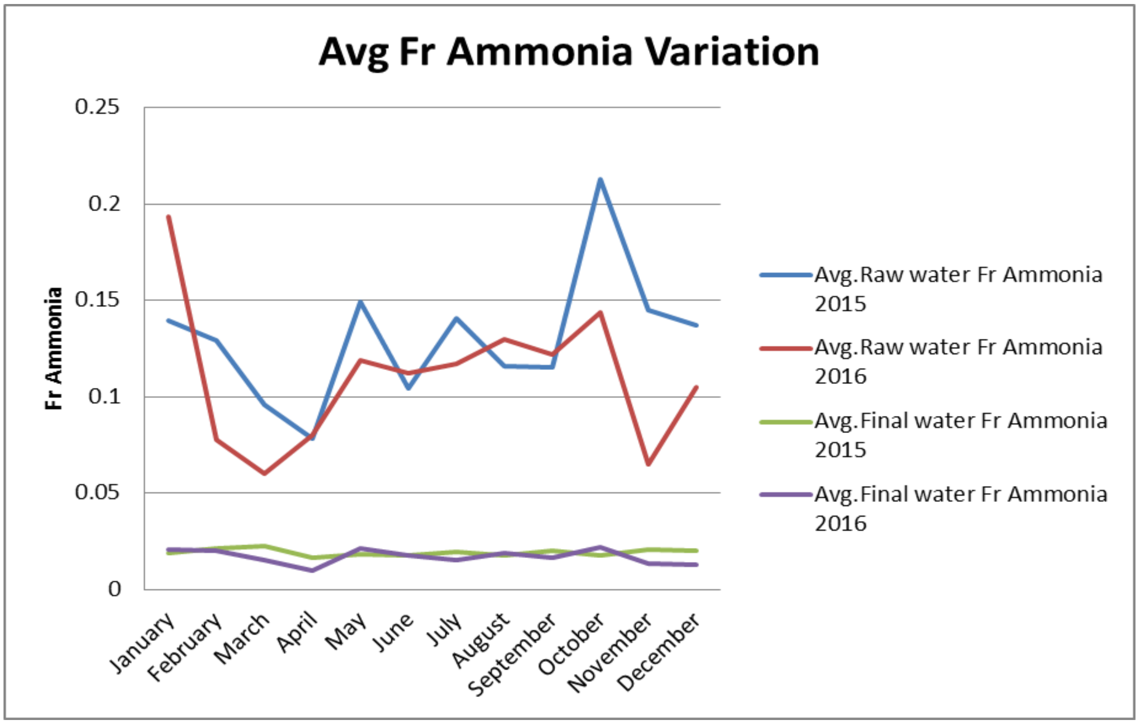
Months	2015		2016	
	Raw Water	Treated Water	Raw Water	Treated Water
	Conductivity Average		Con Average	
January	66.51765	85.44706	70.82632	92.08
February	66.68889	87.03333	76.4	101.325
March	61.86667	85.13333	86.725	102.875
April	51.06111	78.34118	81	106.5
May	52.83529	74.55882	65.48889	89.81111
June	68.34737	90.01613	65.47143	90.12
July	62.13	83.35263	66.735	89.71
August	66.80526	88.57368	61.60625	87.9
September	60.85455	88.39545	72.17391	91.05455
October	56.37619	82.41429	76.04783	101.6696
November	54.09524	81.02381	69.6	100.7826
December	51.995	85.92	85.07	116.455



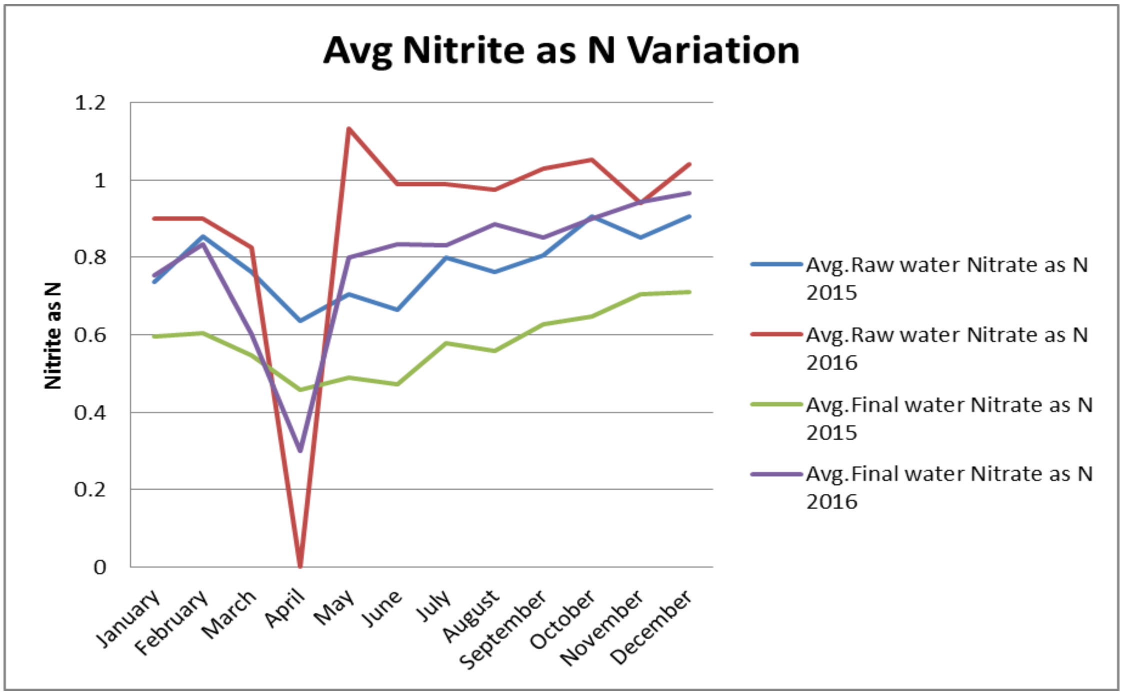
Months	Res. Al Average Treated Water	
	2015	2016
January	0.024706	0.03
February	0.026667	0.0225
March	0.032857	0.04
April	0.02875	0.05
May	0.031765	0.065556
June	0.063226	0.028
July	0.046316	0.03
August	0.039444	0.03
September	0.043636	0.039545
October	0.033333	0.044783
November	0.034762	0.04381
December	0.033	0.039



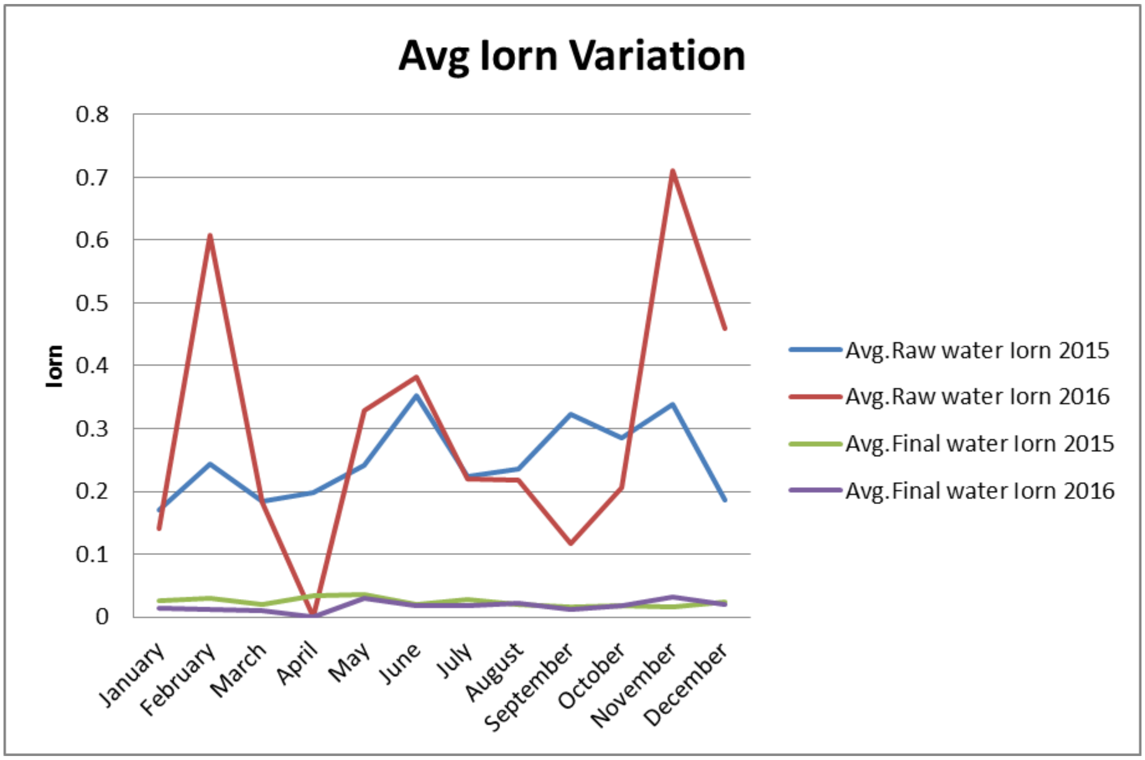
Months	Fr Ammonia Average			
	2015		2016	
	Raw Water	Treated Water	Raw Water	Treated Water
January	0.139412	0.018667	0.193684	0.020714
February	0.129444	0.021111	0.0775	0.02
March	0.095714	0.022857	0.06	0.015
April	0.078235	0.016471	0.08	0.01
May	0.149412	0.018235	0.118889	0.021111
June	0.104211	0.017619	0.1125	0.017895
July	0.1405	0.019412	0.117	0.015333
August	0.115789	0.017778	0.13	0.018889
September	0.115	0.02	0.121739	0.016667
October	0.213	0.017778	0.143478	0.021905
November	0.145238	0.020952	0.065	0.013333
December	0.137368	0.02	0.105	0.012727



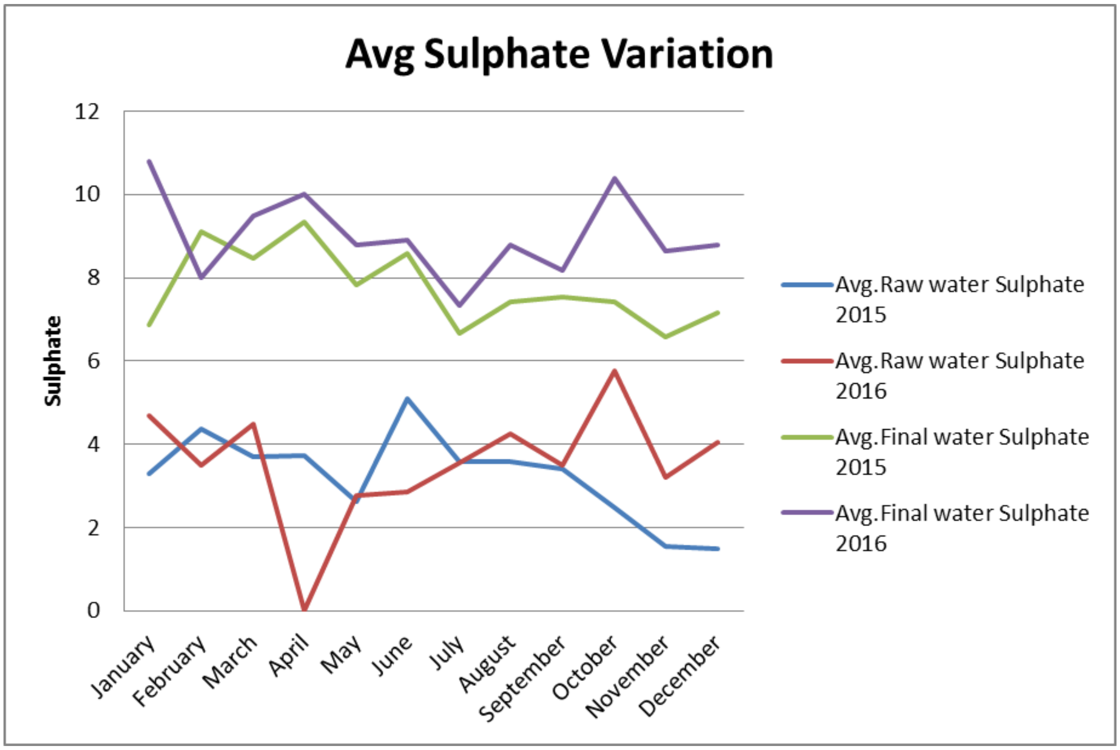
Months	Nitrate as N Average			
	2015		2016	
	Raw Water	Treated Water	Raw Water	Treated Water
January	0.735294	0.594118	0.9	0.755
February	0.855556	0.605556	0.9	0.833333
March	0.761905	0.547619	0.825	0.6
April	0.635294	0.458824	#DIV/0!	0.3
May	0.703529	0.488235	1.133333	0.8
June	0.665	0.471429	0.988235	0.835294
July	0.8	0.577778	0.99	0.83
August	0.761111	0.557895	0.975625	0.885
September	0.804545	0.627273	1.030435	0.85
October	0.904762	0.647619	1.052174	0.9
November	0.852381	0.704762	0.93913	0.943478
December	0.905	0.71	1.04	0.965



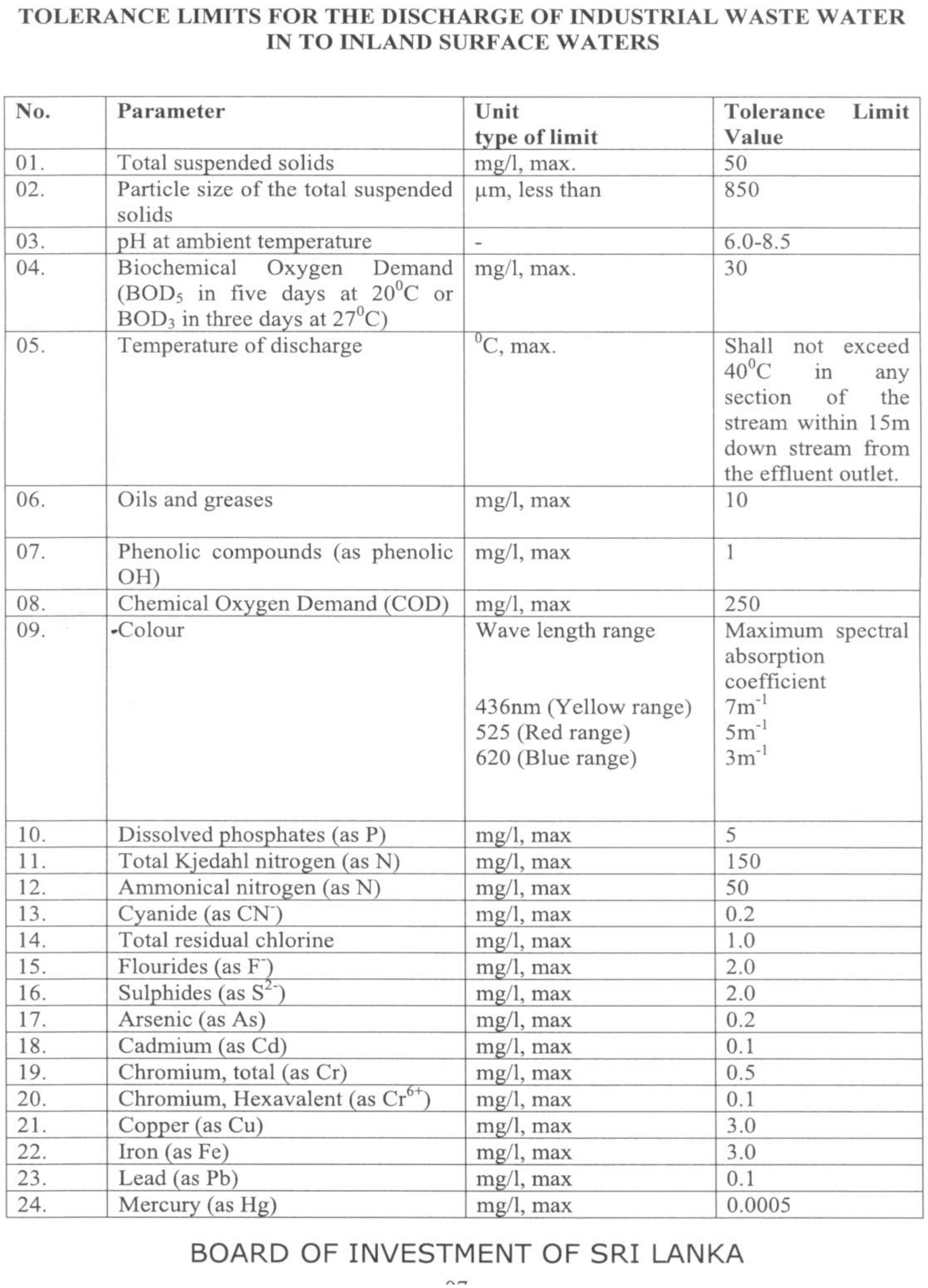
Months	Iron			
	2015		2016	
	Raw Water	Treated Water	Raw Water	Treated Water
January	0.17	0.026471	0.14	0.013529
February	0.243333	0.03	0.606667	0.013
March	0.183333	0.0195	0.1825	0.01
April	0.198235	0.03375	#DIV/0!	#DIV/0!
May	0.242353	0.035294	0.327778	0.03
June	0.352	0.020476	0.383	0.018
July	0.223	0.028333	0.219	0.018421
August	0.234737	0.02	0.21875	0.021667
September	0.322727	0.0165	0.117391	0.012273
October	0.285714	0.019	0.206522	0.017619
November	0.339048	0.01619	0.7096	0.032
December	0.187	0.024	0.46	0.020526



Months	Sulphate			
	2015		2016	
	Raw Water	Treated Water	Raw Water	Treated Water
January	3.294118	6.882353	4.684211	10.8
February	4.366667	9.111111	3.5	8
March	3.714286	8.47619	4.5	9.5
April	3.733333	9.352941	#DIV/0!	10
May	2.625	7.823529	2.777778	8.777778
June	5.1	8.6	2.857143	8.9
July	3.578947	6.666667	3.55	7.35
August	3.578947	7.421053	4.25	8.789474
September	3.409091	7.545455	3.5	8.181818
October	2.473684	7.428571	5.772727	10.3913
November	1.555556	6.571429	3.217391	8.652174
December	1.5	7.15	4.05	8.8



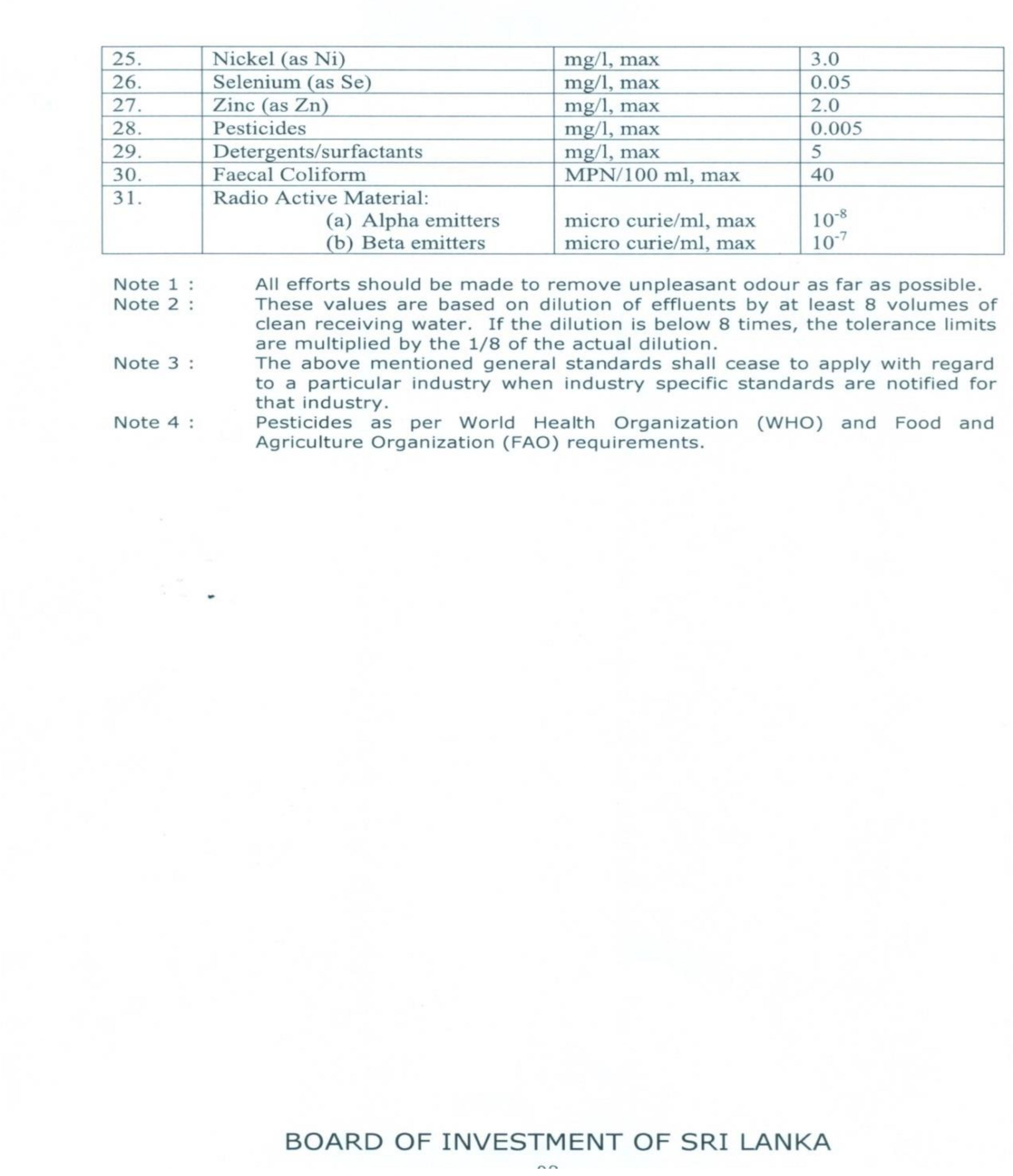
APPENDIX - B



TOLERANCE LIMITS FOR THE DISCHARGE OF INDUSTRIAL WASTE WATER IN TO INLAND SURFACE WATERS

No.	Parameter	Unit type of limit	Tolerance Limit Value
01.	Total suspended solids	mg/l, max.	50
02.	Particle size of the total suspended solids	μm, less than	850
03.	pH at ambient temperature	-	6.0-8.5
04.	Biochemical Oxygen Demand (BOD_5 in five days at 20^0C or BOD_3 in three days at 27^0C)	mg/l, max.	30
05.	Temperature of discharge	^{0}C, max.	Shall not exceed 40^0C in any section of the stream within 15m down stream from the effluent outlet.
06.	Oils and greases	mg/l, max	10
07.	Phenolic compounds (as phenolic OH)	mg/l, max	1
08.	Chemical Oxygen Demand (COD)	mg/l, max	250
09.	Colour	Wave length range 436nm (Yellow range) 525 (Red range) 620 (Blue range)	Maximum spectral absorption coefficient $7m^{-1}$ $5m^{-1}$ $3m^{-1}$
10.	Dissolved phosphates (as P)	mg/l, max	5
11.	Total Kjedahl nitrogen (as N)	mg/l, max	150
12.	Ammonical nitrogen (as N)	mg/l, max	50
13.	Cyanide (as CN^-)	mg/l, max	0.2
14.	Total residual chlorine	mg/l, max	1.0
15.	Flourides (as F^-)	mg/l, max	2.0
16.	Sulphides (as S^{2-})	mg/l, max	2.0
17.	Arsenic (as As)	mg/l, max	0.2
18.	Cadmium (as Cd)	mg/l, max	0.1
19.	Chromium, total (as Cr)	mg/l, max	0.5
20.	Chromium, Hexavalent (as Cr^{6+})	mg/l, max	0.1
21.	Copper (as Cu)	mg/l, max	3.0
22.	Iron (as Fe)	mg/l, max	3.0
23.	Lead (as Pb)	mg/l, max	0.1
24.	Mercury (as Hg)	mg/l, max	0.0005

BOARD OF INVESTMENT OF SRI LANKA



25.	Nickel (as Ni)	mg/l, max	3.0
26.	Selenium (as Se)	mg/l, max	0.05
27.	Zinc (as Zn)	mg/l, max	2.0
28.	Pesticides	mg/l, max	0.005
29.	Detergents/surfactants	mg/l, max	5
30.	Faecal Coliform	MPN/100 ml, max	40
31.	Radio Active Material:		
	(a) Alpha emitters	micro curie/ml, max	10^{-8}
	(b) Beta emitters	micro curie/ml, max	10^{-7}

Note 1 : All efforts should be made to remove unpleasant odour as far as possible.

Note 2 : These values are based on dilution of effluents by at least 8 volumes of clean receiving water. If the dilution is below 8 times, the tolerance limits are multiplied by the 1/8 of the actual dilution.

Note 3 : The above mentioned general standards shall cease to apply with regard to a particular industry when industry specific standards are notified for that industry.

Note 4 : Pesticides as per World Health Organization (WHO) and Food and Agriculture Organization (FAO) requirements.

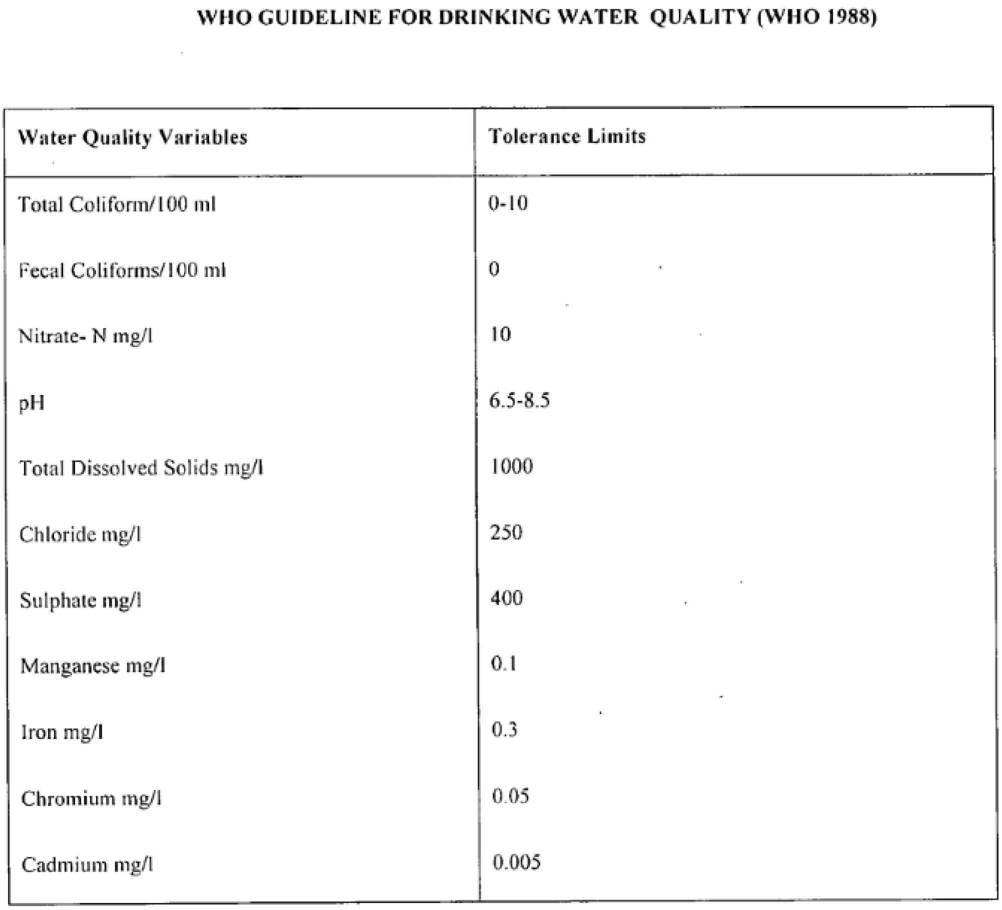
APPENDIX - C

STANDARDS (TOLERANCE LIMITS) OF DRINKING WATER QUALITY AS IN SLS 614:2013/ PHYSICAL AND ORGANIC REQUIREMENT

SI no	Substance or Characteristic	Requirement mg/l (maximum)	Method Of Test	
			Referee method	Alternative method
i.	Aluminum (as Al)	0.2	APHA 3113 B	-
ii.	Ammonia:			
	Free ammonia (as NH3)	0.006	Appendix A	-
	Albuminoid ammonia	0.15	Appendix B	-
iii.	Anionic detergents(as MBAS)	0.2	APHA 5540 C	-
iv.	Calcium (as Ca)	100	APHA 3500 Ca B	-
v.	Chloride (as $Cl^{-)}$	250	APHA 4500 –Cl B	APHA 4110 B
vi.	Chemical oxygen Demand(COD)	10	APHA5220 B	-
vii.	Copper(as cu)	1.0	APHA 3111	ICP-MS (APHA 3125,EPA 200.8)
viii.	Fluoride (as F^-)	1.0	APHA 4500-F^- C	APHA 4110B
ix.	Free residual chlorine	1	APHA 4500-Cl G	-
x.	Iron (as Fe)$^{c)}$	0.3	APHA 3500-Fe B	APHA 3111B
xi.	Magnesium (as Mg)$^{d)}$	30	APHA3500-Mg B	-
xii.	Manganese (as Mn)$^{c)}$	0.1	APHA3111 -B	ICP-MS (APHA,3125,EPA 200.8)
xiii.	Nitrate (as NO_3^-)	50	APHA-4500-NO_3^- E	APHA 4110B
xiv.	Nitrate (as NO_2^-)	3	APHA-4500-NO_2^- B	APHA 4110B
xv.	Nickel (as Ni)	0.02	APHA 3111 B	ICP-MS (APHA,3125,EPA 200.8)
xvi.	Oil and grease	0.2	APHA 5520 B	-
xvii.	Phenolic Compound (asC_6H_5OH)	0.001	APHA 5530 B & D	-
xviii.	Sodium (as Na)	200	APHA 3111 B	_
xix.	Sulphate (as SO_4)	250	APHA 4500 SO_4^{2-} E	APHA 4110 B
xx.	Total alkalinity (as $CaCO_3$)	200	APHA 2320 B	-
xxi.	Total dissolved solids ,mg/l(max)	500	APHA 2540-C	-
xxii.	Total hardness (as $CaCO_3$)	250	APHA 2340- C	-
xxiii.	Total phosphate(as PO_4)	2.0	APHA 4500-PC	APHA 4110 B
xxiv.	Zinc(as Zn)	3.0	APHA 3111 B	-

TABLE 1: 3-10 STANDARDS (TOLERANCE LIMITS) OF DRINKING WATER QUALITY AS IN SLS 614:2013/ CHEMICAL REQUIREMENTS

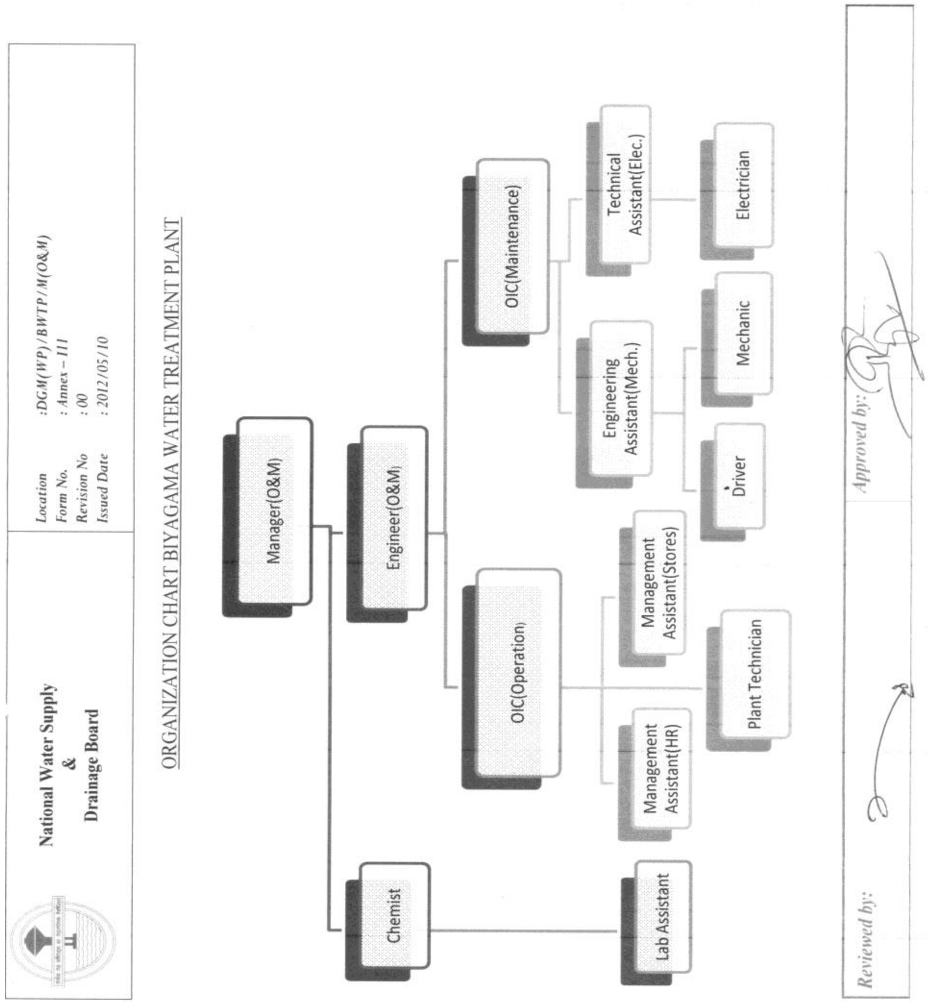
APPENDIX - D



WHO GUIDELINE FOR DRINKING WATER QUALITY (WHO 1988)

Water Quality Variables	**Tolerance Limits**
Total Coliform/100 ml	0-10
Fecal Coliforms/100 ml	0
Nitrate- N mg/l	10
pH	6.5-8.5
Total Dissolved Solids mg/l	1000
Chloride mg/l	250
Sulphate mg/l	400
Manganese mg/l	0.1
Iron mg/l	0.3
Chromium mg/l	0.05
Cadmium mg/l	0.005

APPENDIX - E



National Water Supply
&
Drainage Board

Location *:DGM(WP)/BWTP/M(O&M)*
Form No. *: Annex – III*
Revision No *: 00*
Issued Date *: 2012/05/10*

ORGANIZATION CHART BIYAGAMA WATER TREATMENT PLANT

Reviewed by:

Approved by:

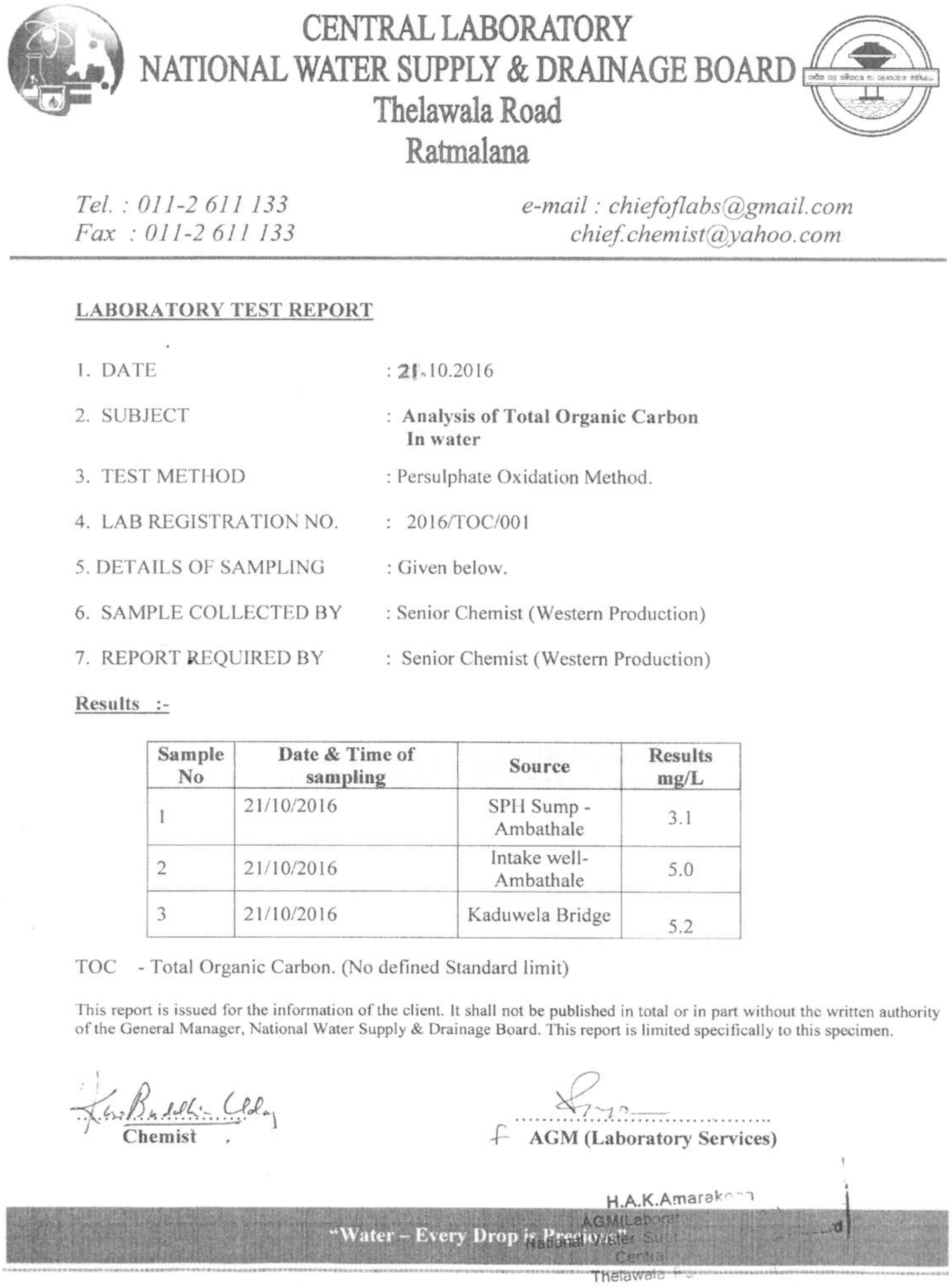
APPENDIX - F

TABLE 2: 3-8 TOLERENCE LIMITS FOR INLAND SURFACE WATERS FOR USE AS RAW WATER FOR PUBLIC WATER SUPPLY ()SLS:722

No.	Determinants	Tolerance limits
1	***Coliform* organisms (monthly average)**	**Not more than 5000, with less than 5 per cent of the samples with value 20 000, and less than 20 % of the samples with the value 5000**
2	**pH range at ambient temperature**	**6.0 – 9.0**
3	Chloride (as Cl^-) mg/l, max.	1200
4	**Nitrate (as N) mg/ l, max.**	**10**
5	Fluoride (as F^-) mg/l, max.	1.5
6	Phenolic compounds (as phenolic OH^-) mg/ l, max.	0.005
No.	**Determinants**	**Tolerance limits**
7	Oils and grease, mg/l, max.	0.1
8	Pesticide residue	As per **WHO/FAO** requirements
9	Arsenic (as As), mg/l, max.	0.05
10	Cyanide (as CN), mg/l, max.	0.05
11	Lead (as Pb), mg/l, max.	0.01
12	Mercury (total as Hg), mg/l, max.	0.001
13	Selenium (as Se), mg/l, max.	0.05
14	Chromium (as Cr), mg/l, max.	0.05
15	Dissolved Oxygen (DO), mg/l, max.	4
16	**Bio Chemical Oxygen Demand (BOD) mg/l, max.**	**5**
17	a) c/ml, max.□Alpha emitters’	10^{-9}
	b) c/ml, max.□Alpha emitters’	10^{-8}

SI NO1)	Characteristic	Requirement	Method of test
i.	Colour ,Hazen units,(max)	15	APHA 2120
ii.	Odour	Unobjectionable	Sensory evaluation [a)]
	Taste	Unobjectionable	Sensory evaluations [b)]
iii.	Turbidity,NTU,*(max)	2	APHA 2130
iv.	pH at 25^0C±2^0C	6.5-8.5	APHA 4500-H^+ B

APPENDIX - G



CENTRAL LABORATORY
NATIONAL WATER SUPPLY & DRAINAGE BOARD
Thelawala Road
Ratmalana

Tel. : 011-2 611 133 *e-mail : chiefoflabs@gmail.com*
Fax : 011-2 611 133 *chief.chemist@yahoo.com*

LABORATORY TEST REPORT

1. DATE : 21.10.2016
2. SUBJECT : **Analysis of Total Organic Carbon In water**
3. TEST METHOD : Persulphate Oxidation Method.
4. LAB REGISTRATION NO. : 2016/TOC/001
5. DETAILS OF SAMPLING : Given below.
6. SAMPLE COLLECTED BY : Senior Chemist (Western Production)
7. REPORT REQUIRED BY : Senior Chemist (Western Production)

Results :-

Sample No	Date & Time of sampling	Source	Results mg/L
1	21/10/2016	SPH Sump - Ambathale	3.1
2	21/10/2016	Intake well-Ambathale	5.0
3	21/10/2016	Kaduwela Bridge	5.2

TOC - Total Organic Carbon. (No defined Standard limit)

This report is issued for the information of the client. It shall not be published in total or in part without the written authority of the General Manager, National Water Supply & Drainage Board. This report is limited specifically to this specimen.

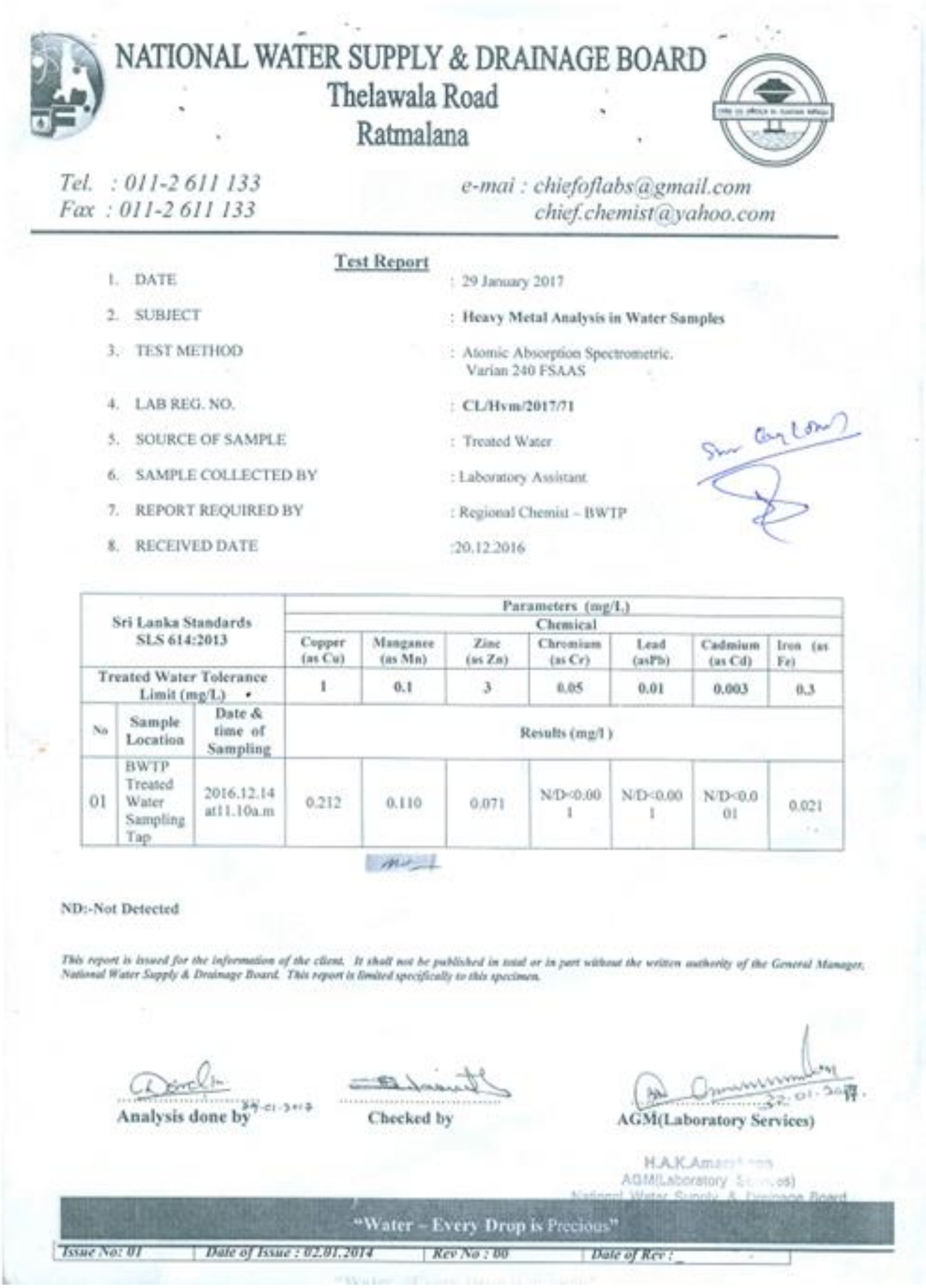
Chemist

f **AGM (Laboratory Services)**

H.A.K.Amarakoon
AGM(Laborat
National Water Su
Central
Thelawala

"Water – Every Drop is Precious"

APPENDIX H



NATIONAL WATER SUPPLY & DRAINAGE BOARD
Thelawala Road
Ratmalana

Tel. : 011-2 611 133
Fax : 011-2 611 133
e-mai : chiefoflabs@gmail.com
chief.chemist@yahoo.com

Test Report

1. DATE : 29 January 2017
2. SUBJECT : **Heavy Metal Analysis in Water Samples**
3. TEST METHOD : Atomic Absorption Spectrometric, Varian 240 FSAAS
4. LAB REG. NO. : **CL/Hvm/2017/71**
5. SOURCE OF SAMPLE : Treated Water
6. SAMPLE COLLECTED BY : Laboratory Assistant
7. REPORT REQUIRED BY : Regional Chemist – BWTP
8. RECEIVED DATE :20.12.2016

[illegible]

Sri Lanka Standards SLS 614:2013			Parameters (mg/L)						
			Chemical						
			Copper (as Cu)	Manganese (as Mn)	Zinc (as Zn)	Chromium (as Cr)	Lead (asPb)	Cadmium (as Cd)	Iron (as Fe)
Treated Water Tolerance Limit (mg/L)			1	0.1	3	0.05	0.01	0.003	0.3
No	Sample Location	Date & time of Sampling	Results (mg/l)						
01	BWTP Treated Water Sampling Tap	2016.12.14 at11.10a.m	0.212	0.110	0.071	N/D<0.001	N/D<0.001	N/D<0.001	0.021

ND:-Not Detected

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27-01-2017
Analysis done by

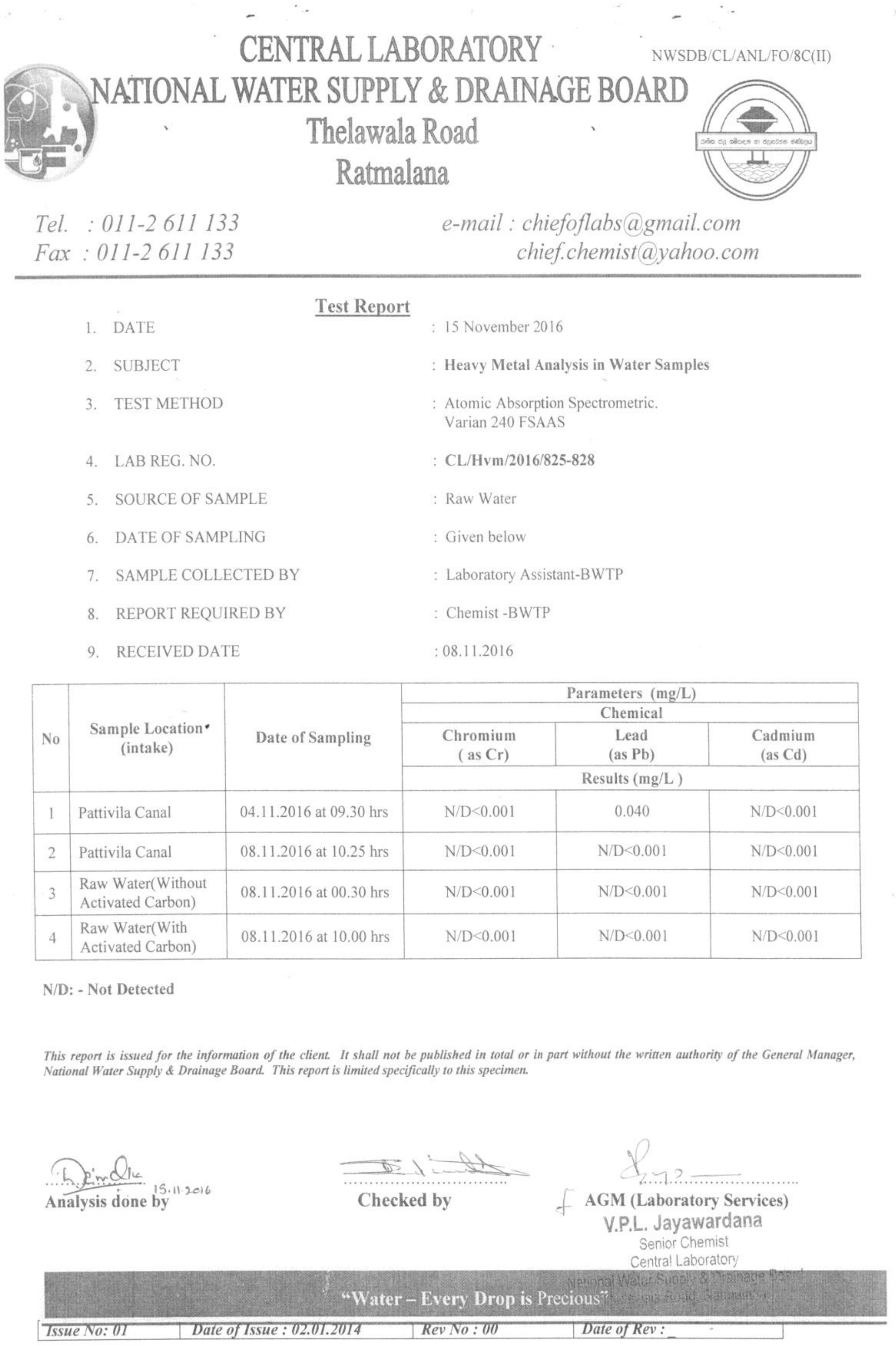
Checked by

3?-01-2017.
AGM(Laboratory Services)

H.A.K.Ama[illegible]
AGM(Laboratory Services)
National Water Supply & Drainage Board

"Water – Every Drop is Precious"

Issue No: 01	Date of Issue : 02.01.2014	Rev No : 00	Date of Rev :



NWSDB/CL/ANL/FO/8C(II)

CENTRAL LABORATORY
NATIONAL WATER SUPPLY & DRAINAGE BOARD
Thelawala Road
Ratmalana

Tel. : 011-2 611 133
Fax : 011-2 611 133
e-mail : chiefoflabs@gmail.com
chief.chemist@yahoo.com

Test Report

1.	DATE	: 15 November 2016
2.	SUBJECT	: **Heavy Metal Analysis in Water Samples**
3.	TEST METHOD	: Atomic Absorption Spectrometric. Varian 240 FSAAS
4.	LAB REG. NO.	: **CL/Hvm/2016/825-828**
5.	SOURCE OF SAMPLE	: Raw Water
6.	DATE OF SAMPLING	: Given below
7.	SAMPLE COLLECTED BY	: Laboratory Assistant-BWTP
8.	REPORT REQUIRED BY	: Chemist -BWTP
9.	RECEIVED DATE	: 08.11.2016

No	Sample Location (intake)	Date of Sampling	Parameters (mg/L) Chemical Chromium (as Cr) Results (mg/L)	Lead (as Pb)	Cadmium (as Cd)
1	Pattivila Canal	04.11.2016 at 09.30 hrs	N/D<0.001	0.040	N/D<0.001
2	Pattivila Canal	08.11.2016 at 10.25 hrs	N/D<0.001	N/D<0.001	N/D<0.001
3	Raw Water(Without Activated Carbon)	08.11.2016 at 00.30 hrs	N/D<0.001	N/D<0.001	N/D<0.001
4	Raw Water(With Activated Carbon)	08.11.2016 at 10.00 hrs	N/D<0.001	N/D<0.001	N/D<0.001

N/D: - Not Detected

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15.11.2016
Analysis done by

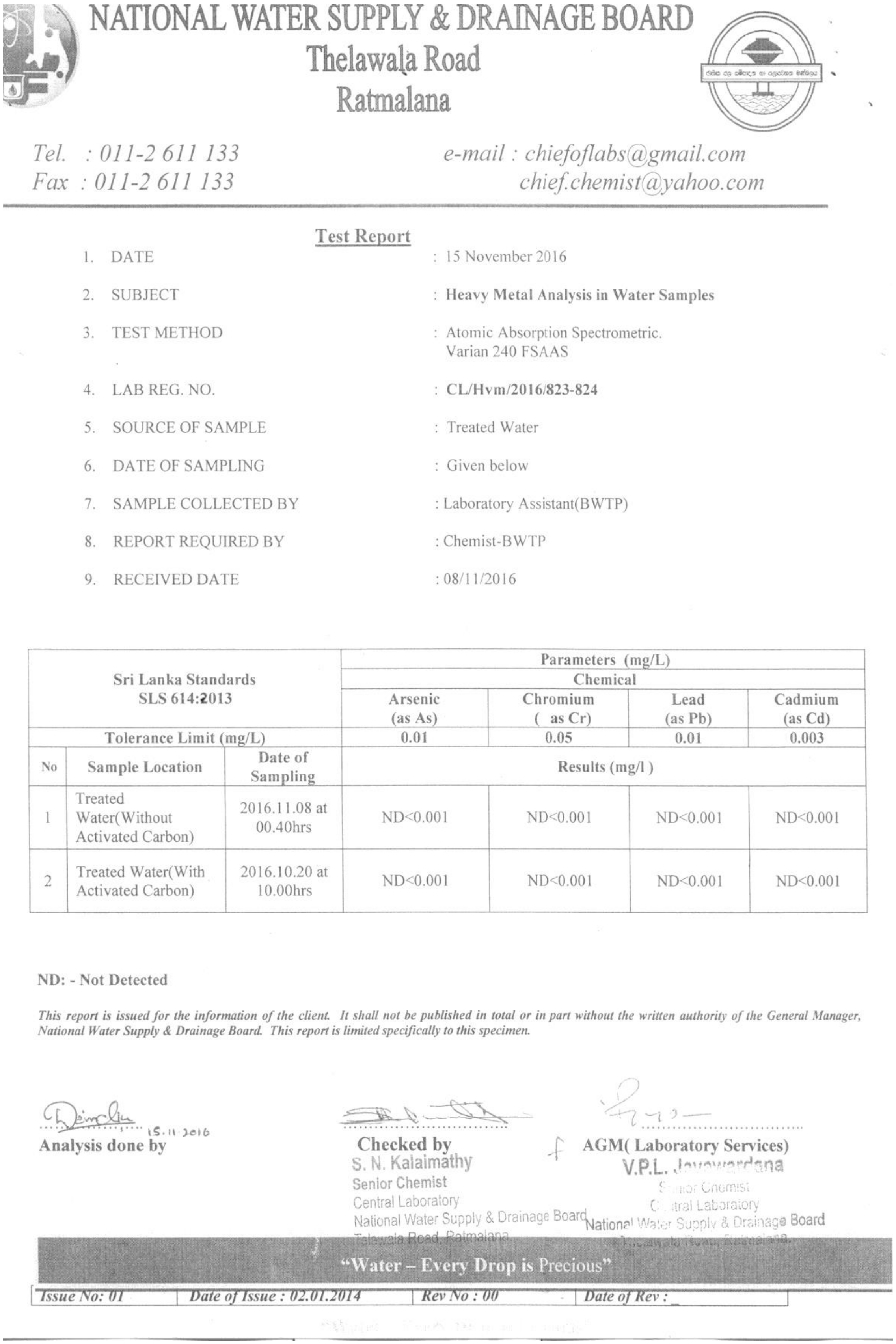
Checked by

AGM (Laboratory Services)

V.P.L. Jayawardana
Senior Chemist
Central Laboratory
National Water Supply & Drainage Board
[illegible] Road, Ratmalana

"Water – Every Drop is Precious"

Issue No: 01	*Date of Issue : 02.01.2014*	*Rev No : 00*	*Date of Rev : _*



NATIONAL WATER SUPPLY & DRAINAGE BOARD
Thelawaḷa Road
Ratmalana

Tel. : 011-2 611 133 *e-mail : chiefoflabs@gmail.com*
Fax : 011-2 611 133 *chief.chemist@yahoo.com*

Test Report

1. DATE : 15 November 2016
2. SUBJECT : **Heavy Metal Analysis in Water Samples**
3. TEST METHOD : Atomic Absorption Spectrometric.
   Varian 240 FSAAS
4. LAB REG. NO. : **CL/Hvm/2016/823-824**
5. SOURCE OF SAMPLE : Treated Water
6. DATE OF SAMPLING : Given below
7. SAMPLE COLLECTED BY : Laboratory Assistant(BWTP)
8. REPORT REQUIRED BY : Chemist-BWTP
9. RECEIVED DATE : 08/11/2016

Sri Lanka Standards SLS 614:2013			**Parameters (mg/L)**			
			Chemical			
			Arsenic (as As)	**Chromium (as Cr)**	**Lead (as Pb)**	**Cadmium (as Cd)**
Tolerance Limit (mg/L)			**0.01**	**0.05**	**0.01**	**0.003**
No	**Sample Location**	**Date of Sampling**	**Results (mg/l)**			
1	Treated Water(Without Activated Carbon)	2016.11.08 at 00.40hrs	ND<0.001	ND<0.001	ND<0.001	ND<0.001
2	Treated Water(With Activated Carbon)	2016.10.20 at 10.00hrs	ND<0.001	ND<0.001	ND<0.001	ND<0.001

ND: - Not Detected

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15.11.2016
Analysis done by

Checked by
S. N. Kalaimathy
Senior Chemist
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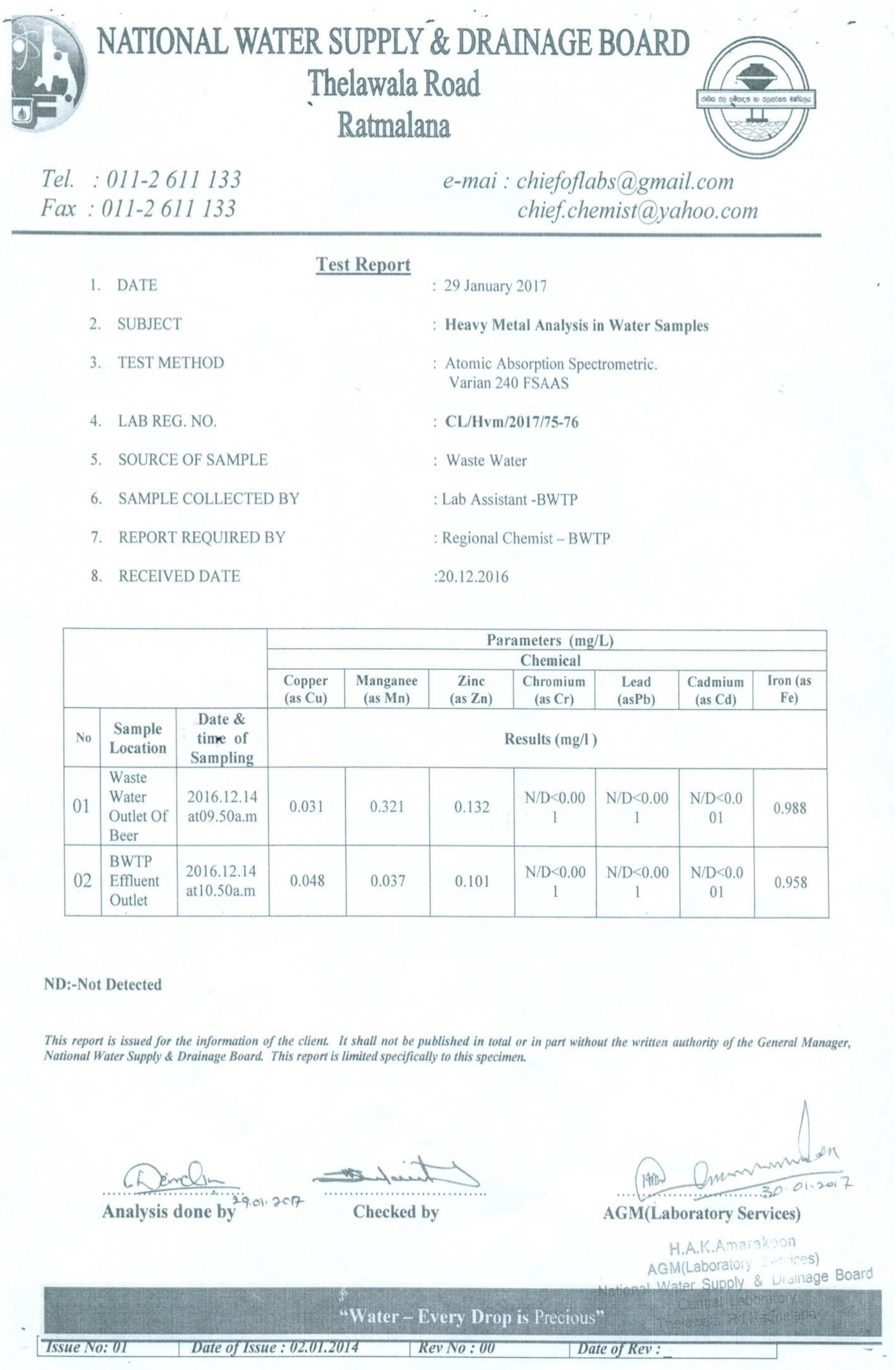
National Water Supply & Drainage Board
Talawala Road, Ratmalana.

AGM(Laboratory Services)
V.P.L. Jayawardana
Senior Chemist
Central Laboratory
National Water Supply & Drainage Board
Talawala Road, Ratmalana.

"Water – Every Drop is Precious"

Issue No: 01	*Date of Issue : 02.01.2014*	*Rev No : 00*	*Date of Rev :*



NATIONAL WATER SUPPLY & DRAINAGE BOARD

Thelawala Road
Ratmalana

Tel. : 011-2 611 133
Fax : 011-2 611 133

e-mai : chiefoflabs@gmail.com
chief.chemist@yahoo.com

Test Report

1. DATE : 29 January 2017
2. SUBJECT : **Heavy Metal Analysis in Water Samples**
3. TEST METHOD : Atomic Absorption Spectrometric.
   Varian 240 FSAAS
4. LAB REG. NO. : **CL/Hvm/2017/75-76**
5. SOURCE OF SAMPLE : Waste Water
6. SAMPLE COLLECTED BY : Lab Assistant -BWTP
7. REPORT REQUIRED BY : Regional Chemist – BWTP
8. RECEIVED DATE :20.12.2016

			Parameters (mg/L)						
			Chemical						
			Copper (as Cu)	**Manganee (as Mn)**	**Zinc (as Zn)**	**Chromium (as Cr)**	**Lead (asPb)**	**Cadmium (as Cd)**	**Iron (as Fe)**
No	**Sample Location**	**Date & time of Sampling**	**Results (mg/l)**						
01	Waste Water Outlet Of Beer	2016.12.14 at09.50a.m	0.031	0.321	0.132	N/D<0.001	N/D<0.001	N/D<0.001	0.988
02	BWTP Effluent Outlet	2016.12.14 at10.50a.m	0.048	0.037	0.101	N/D<0.001	N/D<0.001	N/D<0.001	0.958

ND:-Not Detected

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29.01.2017
Analysis done by

Checked by

30.01.2017
AGM(Laboratory Services)

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Central Laboratory,
Thelawala Rd Ratmalana

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Issue No: 01 | *Date of Issue : 02.01.2014* | *Rev No : 00* | *Date of Rev : _*

APPENDIX - I

Risk Matrix (WSP, BWTP, 2017)

NO	Source of Risk/ Process Step	Hazard	Hazardous Event	Likelihood	Consequence	Risk Rating	Risk Band	Reasons for selecting Likelihood and consequence	Control Measure	Likelihood	Consequence	Residual Risk (with control measure)	Risk Band
C -() C -1	**Catchment**	C M P	Flooding	2	5	10	H	May happen in monsoon season	No Current Control	2	5	10	H
C-2	Beside upstream of the Intake	C P	petroleum & Electricity board Effluents containing oil & Grease contaminants comes from pattivila canal	5	5	25	E	Past water quality data	Floating bloom	5	5	25	E

NO.	Source of Risk/ Process Step	Hazard	Hazardous Event	Likeli hood	Cons Equence	Risk Rating	Risk Band	Reasons for selecting Likelihood and consequence	Control Measure	Likeli hood	Con Sequ Ence	Residual Risk(with control measure)	Risk Band
C -3	Beside upstream of the Intake	C M P	Janitorial out lets , Agro chemicals due to farming , blackish water (with high Fe& Mn)comes from pattivila canal	5	5	25	E	Past water quality data And Visual inspection by WSP team during visit	Bacteria and Color removing by Chlorination	5	5	25	E
C-4	Beside upstream of the Intake	C M P	Dumping Solid waste near pattivila Canal	4	5	20	E	Visual inspection by WSP team during visit	Corse Screen and fine screen can remove solid waste	4	5	20	E
C-5	100 m Upstream from intake at right bank side	C M p	Waste Water out let of Biyagama Industrial Zone contaminating surface water	5	2	10	H	Past water quality data	bacteria and Colour removing by Chlorination Continuously measuring DO, pH	5	2	10	H

									,Conductivity				
NO	Source of Risk/ Process Step	Hazard	Hazardous Event	Likelihood	Cons Equence	Risk Rating	Risk Band	Reasons for selecting Likelihood and consequence	Control Measure	Likelihood	Con Sequ Ence	Residual Risk(with control measure)	Risk Band
C -6	150 m Upstream from intake at right bank side	C M P	Waste water outlet of Beer Industry contaminating surface water	5	2	10	H	Past water quality data And Visual inspection by WSP team during visit	bacteria and Colour removing by Chlorination Continuously measuring DO,conductivity,pH	5	2	10	H
C-7	600m Upstream from intake at right bank side	C M P	Waste water outlet of Coca Cola contaminating surface water	5	1	5	M	Visual inspection by WSP team during visit	bacteria and Colour removing by Chlorination Continuously measuring DO,conductivity,pH	5	1	5	M

C-8	Along the Kelani River	C	Changing the Raw water quality in the Intake well due to Changing the Ground water of intensive sand mining	4	2	8	M	Visual inspection by WSP team during visit	Can be tolerate high range turbidity by using polymer	4	1	4	L

NO	Source of Risk/ Process Step	Hazard	Hazardous Event	Likelihood	Consequence	Risk Rating	Risk Band	Reasons for selecting Likelihood and consequence	Control Measure	Likelihood	Con Sequ Ence	Residual Risk(with control measure)	Risk Band
C -9	2 km down stream from intake at left bank side	C M P	Solid waste dumping site (Pradeshiya. Sabha) near Kelani Bridge	3	2	6	M	High dialution, Visual inspection by WSP team during visit	Chlorination,sedimentstion	3	1	3	L
C-10	Intake		blackish water (with high Fe& Mn)comes from pattivila canal	5	3	15	VH	Past water quality data	Pre Chlorination	5	2	10	H

APPENDIX - J

1. Application

1.1 The method is applicable for water, wastewater and seawater. Distillation is required for wastewater and seawater

2. Summary of method

2.1 The Mineral Stabilizer complexes hardness in the sample. The Polyvinyl Alcohol Dispersing Agent helps the color formation in the reaction of Nessler Reagent with ammonia and certain other amines. A yellow color is formed that is proportional to the ammonia concentration. The measurement wavelength is 425 nm.

3. Sampling

3.1 Collect samples in clean glass or plastic bottles.

3.2 If the sample contains chlorine, add one drop of 0.1 N sodium thiosulfate for each 0.3 mg/L chlorine in 1 liter of sample.

3.3 Let the sample temperature increase to room temperature before analysis.

3.4 Before analysis, adjust the pH to ~7 with 5 N sodium hydroxide solution.

3.5 Correct the test result for the dilution caused by the volume additions.

4. Preservation

4.1 To preserve samples for later analysis, adjust the sample pH to less than 2 with concentrated sulfuric acid (approximately 2 mL per liter). No acid addition is necessary if the sample is tested immediately.

4.2 Keep the preserved samples at or below 6 °C (43 °F) for a maximum of 28 days.

4.3 Let the sample temperature increase to room temperature before analysis.

5. Apparatus

5.1 Mixing cylinder, graduated, 25-mL with stopper 1

5.2 Pipet, serological, 1-mL, glass 1

5.3 Pipet filler, safety bulb

5.4 Pipet, 0.1–1.0 mL

6. Reagents and chemicals

6.1 Ammonia Nitrogen Reagent Set, includes:

- Nessler Reagent 2 mL
- Mineral Stabilizer 6 drops

6.2 Polyvinyl Alcohol Dispersing Agent 6 drops

6.3 Sodium Hydroxide Standard Solution, 5.0 N

6.4 Sodium Thiosulfate, 0.1 N

6.5 Sulfuric Acid, ACS

6.6 Water, deionized

7. Preparation of standards and reagents

7.1 All the standardized reagents required for the test, are available (ready to use) to be purchased from the HACH Company as;

Description	Unit	Item no.
Nitrogen Ammonia Standard Solution, 1.0-mg/L NH3–N	500 mL	189149

Therefore, separate preparation and standardization is not needed.

8. Procedure

8.1 Start program 380 N, Ammonia, Ness. For information about sample cells, adapters or light shields.

Note: Although the program name can be different between instruments, the program number does not change.

8.2 Prepare the sample: Fill a mixing cylinder to the 25- mL line with sample.

8.3 Prepare the blank: Fill a mixing cylinder to the 25-mL line with deionized water.

8.4 Add 3 drops of Mineral Stabilizer to each mixing cylinder.

8.5 Put the stopper on the mixing cylinders. Invert the mixing cylinders several times to mix.

8.6 Add 3 drops of Polyvinyl Alcohol Dispersing Agent to each mixing cylinder.

8.7 Put the stopper on the mixing cylinders. Invert the mixing cylinders several times to mix.

8.8 Use a pipet to add 1.0 mL of Nessler Reagent to each mixing cylinder. 2 Nitrogen-Ammonia, Nessler Method (2.50 mg/L)

8.9 Put the stopper on the mixing cylinders. Invert the mixing cylinders several times to mix.

8.10 Start the instrument timer. A 1-minute reaction time starts.

8.11 Pour 10 mL from the blank cylinder into a sample cell.

8.12 When the timer expires, clean the blank sample cell.

8.13 Insert the blank into the cell holder.

8.14 Push ZERO. The display shows 0.00 mg/L NH3–N.

8.15 Pour 10 mL from the sample cylinder into a second sample cell.

8.16 Clean the prepared sample cell.

8.17 Insert the prepared sample into the cell holder.

8.18 Push READ. Results show in mg/L NH3–N.

9. Validation

9.1 Use the standard additions method (for applicable instruments) to validate the test procedure, reagents and instrument and to find if there is an interference in the sample. Items to collect:

- 50-mg/L Nitrogen-Ammonia Standard Solution 4 Nitrogen-Ammonia, Nessler Method (2.50 mg/L)
- Mixing cylinders, 25-mL (3x)
- TenSette Pipet and pipet tips

9.2 Use the test procedure to measure the concentration of the sample, and then keep the (unspiked) sample in the instrument.

9.3 Go to the Standard Additions option in the instrument menu.

9.4 Select the values for standard concentration, sample volume and spike volumes.

9.5 Open the standard solution.

9.6 Prepare three spiked samples: use the TenSette pipet to add 0.1 mL, 0.2 mL and 0.3 mL of the standard solution, respectively, to three 25-mL portions of fresh sample. Mix well.

9.7 Use the test procedure to measure the concentration of each of the spiked samples. Start with the smallest sample spike. Measure each of the spiked samples in the instrument.

9.8 Select Graph to compare the expected results to the actual results.

Note: If the actual results are significantly different from the expected results, make sure that the sample volumes and sample spikes are measured accurately. The sample volumes and sample spikes that are used should agree with the selections in the standard additions menu. If the results are not within acceptable limits, the sample may contain interference.

10. Calculations

No calculations needed, Results show in mg/L NH_3–N in the instrument.

APPENDIX - K

1. Application

1.1 The method is applicable for water, wastewater and seawater. Digestion is required for determining total iron

2. Summary of method

2.1 FerroVer Iron Reagent converts all soluble iron and most insoluble forms of iron in the sample to soluble ferrous iron. The ferrous iron reacts with the 1-10 phenanthroline indicator in the reagent to form an orange color in proportion to the iron concentration. The measurement wavelength is 510 nm for spectrophotometers or 520 nm for colorimeters.

3. Sampling

3.1 Collect samples in clean glass or plastic bottles that have been cleaned with 6 N (1:1) hydrochloric acid and rinsed with deionized water.
3.2 To measure only dissolved iron, filter the sample immediately after collection and before acidification.
3.3 Before analysis, adjust the pH to 3–5 with 5 N sodium hydroxide solution.
3.4 Correct the test result for the dilution caused by the volume additions.

4. Preservation

4.1 To preserve samples for later analysis, adjust the sample pH to less than 2 with concentrated nitric acid (approximately 2 mL per liter). No acid addition is necessary if the sample is tested immediately.
4.2 Keep the preserved samples at room temperature for a maximum of 6 months.
4.3 Before analysis, adjust the pH to 3–5 with 5 N sodium hydroxide solution.

5. Apparatus

5.1 Beaker, 50-mL

5.2 Mixing cylinder, graduated, 50-mL

5.3 Filter, glass fiber membrane, 1.5-micron, 47-mm

5.4 Filter membrane filter holder, 47-mm

5.5 Flask, volumetric, Class A, 100-mL glass

5.6 Pipet filler, safety bulb Pipet, 0.1–1.0 mL
5.7 Pipet, volumetric, Class A, 2-mL

6. Reagents and chemicals

6.1 FerroVer® Iron Reagent Powder Pillow1 , 10-mL

6.2 Hydrochloric Acid, concentrated

6.3 Nitric Acid, concentrated

6.4 Sodium Hydroxide Standard Solution, 5.0 N

agent is used initially to reduce all oxidized forms of
manganese to Mn2+. An alkaline-cyanide reagent is added to mask any potential interferences. PAN Indicator is then added to combine with the Mn^{2+} to form an orange-colored complex. Test results are measured at 560 nm.

Sample Collection, Storage, and Preservation

Collect samples in a clean plastic container. Adjust the pH to 2 or less with Concentrated Nitric
Acid* (about 2 mL per liter). Preserved samples can be stored up to six months at room temperature. Adjust the pH to between 4–5 with 5.0 N Sodium Hydroxide* before analysis.

Correct the test result for volume additions.

1. Blank Preparation:

Pour 10.0 mL of deionized water into a square sample cell.

2. Prepared Sample:

Pour 10.0 mL of sample into another square sample cell. Fill a square sample cell with 10 mL of sample. Add the contents of one Ascorbic Acid Powder Pillow to each cell. Stopper and invert to dissolve the powder.

3. Add 12 drops of Alkaline-Cyanide Reagent Solution to each cell. Swirl gently to mix. A cloudy solution may form. The turbidity should dissipate after step.

4. Add 12 drops of PAN Indicator Solution, 0.1%,to each sample cell. Swirl gently to mix. An orange color will develop in the sample if manganese is present.

5. Press **TIMER>OK**.

A two-minute reaction period will begin.

6. When the timer expires, wipe the blank and insert it into the cell holder with the fill line facing right.

07. Press **ZERO**.

The display will show: 0.000 mg/L Mn