Development of a Laboratory Scale Drainage Wastewater Treatment Plant for Khulna Municipality

Md. Rasel Sheikh

Department of Civil Engineering
Khulna University of Engineering & Technology
Khulna-9203, Bangladesh
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by

Md. Rasel Sheikh

A thesis submitted in partial fulfillment of the requirements for the degree of
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Declaration

This is to certify that the thesis work entitled "Development of a Laboratory Scale Drainage Wastewater Treatment Plant for Khulna Municipality" has been carried out by Md. Rasel Sheikh in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

Dr. Md. Saiful Islam	Md. Rasel Sheikh
Professor	Roll No.: 1401505
Department of Civil Engineering	
KUET, Khulna-9203	

Approval

This is to certify that the thesis work submitted by Md. Rasel Sheikh entitled " Development of a Laboratory Scale Drainage Wastewater Treatment Plant for Khulna Municipality" has been approved by the board of examiners for the partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh on 6th August 2017.

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(Md. Rasel Sheikh)

Abstract

Cities in developing countries are experiencing unparalleled growth and rapidly increasing water supply and sanitation coverage that will continue to release growing volumes of wastewater. Wastewater is increasingly being used for irrigation in urban and peri-urban agriculture, and even in distant rural areas downstream of the very large cities. The present study was conducted to analyse municipal wastewater quality parameters of the existing drainage outlets over Mayur River around Khulna city and to develop a laboratory scale treatment plant for safe disposal and prevent environmental pollutions. To fulfil the purpose of the research, wastewater samples from three municipal drain outlets were collected and analysed for selecting treatment system and the evaluation of effluent's suitability for irrigation use as well as safe disposal into surface water bodies. From the analysis of physico-chemical characteristics of wastewater, it can be seen that pH, EC, BOD, COD, alkalinity, hardness, chloride, nitrate and sulfate values were not fully satisfy the irrigation standard limit as the wastewater was highly polluted. The BOD and COD concentration of wastewater sample were varied from 57-226 mg/l and 320-435 mg/l respectively and the total coliform ranged from 70000-98050 N/100ml. Chloride and hardness values were of high range as the collected samples were heavily polluted by organic matter and microorganisms. Therefore, a laboratory scale treatment technology has been developed for the treatment of this wastewater. Treatment technologies adopted are primary sedimentation followed by aeration, chemical precipitation and filtration. In treated wastewater BOD_5, COD and TDS were found to be in the range of 40-115 mg/l, 160-256 mg/l and 1356-1500 mg/l respectively. These test results suggest that the performance of the developed treatment plant was not adequate to fulfil the acceptable limit (ECR'97) for safe disposal into surface water bodies. Based on preliminary treatment results, some modifications of developed laboratory scale treatment plant were done by activated sludge process followed by granular media filtration. As a result, the final BOD, COD and TDS concentration of effluents were found 1.38-1.78 mg/l, 32-128 mg/l and 590-1667 mg/l respectively which satisfy ECR'97 standard limits for safe disposal into inland water bodies. Comparing with national (ECR'97) and international (FAO'85) wastewater quality standards, the effluents of modified treatment plant may be reused for irrigation purposes that would be able to meet the increasing water demand for the farmers and can be safely disposed into the surrounding water bodies of Khulna city.

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Abbreviation/Acronyms

BWDB- Bangladesh Water Development Board

EDTA-Ethylene Diamine Tetraacitic Acid

KCC- Khulna City Corporation

KWASA- Khulna Water Supply and Sewerage Authority

MLD- Million Litres per Day

MLSS- Mixed-liquor Suspended Solid

SAR- Sodium Absorption Ratio

Chapter I

Introduction

This chapter covers background of the study including background, statement of problem, rational for the study, objectives of the study, scope of the study, and organization of the study.

1.1 Background

The increasing pace of industrialization, urbanization and population growth that our planet has faced over the last one hundred years has considerable increased environmental pollution and habitat destruction, and negatively affected water, air and soil qualities. In this context within which wastewater treatment has become one the most important environmental issues of the day, insofar as it reduces or prevents pollution of natural water resources –i.e. inland surface waters, groundwater, transitional water and coastal water –promotes sustainable water re-use, protects the aquatic environment and improves the status of aquatic ecosystems.

As urban population in developing countries increase and residents seek better living standards, larger amounts of freshwater are diverted to domestic, commercial, and industrial sectors, which generate greater volumes of wastewater (Lazarova and Bahri, 2005; Qadir *et al*., 2007; Asano *et al*., 2007). Consequently, as UNESCO (2003) reported, over 80% of the wastewater generated in developing countries is discharged untreated into the environment, and approximately 50% of the population depends on polluted water sources for various uses. However, using urban wastewater in agriculture can conserve water, recycle nutrients, ensure reliable water supply to farmers, and prevent pollution of surface water that would otherwise be used for the disposal of wastewater (Van der Hoek *et al*., 2002; Jimenez, 2005). The use of wastewater for irrigation has now become a reality rather than a matter of choice. As Huibers and Van Lier (2005) reported, such a reality exists not only in arid and semi-arid regions but also in humid areas where seasonal water storage occurs. Some studies suggest that at least 3.5 Mha are irrigated globally with untreated, partially treated, diluted or treated wastewater (IWMI, 2006). Cultivators in urban and peri-urban areas of nearly all developing countries who are in need of water for irrigation divert this wastewater in a partially treated, diluted or untreated form and use it to grow a range of crops (Ensink *et al*., 2002). Despite farmers good reasoning, this practice can severely harm human health and the environment (Qadir *et al*., 2007) mainly due to not only the associated pathogens, but also heavy metals and other undesirable constituents depending on the source.

The Economic and Social Commission for Asia and the Pacific (ESCAP, 2000) reported an annual production of 725 Mm^3 of wastewater from the urban areas of Bangladesh. So, it is plausible and convincing that the use of this water for irrigation can be integrated in a holistic approach for the management of water quantity and quality (Mojid *et al*., 2010). In Bangladesh, urban and peri-urban communities in different cities, i.e. Bogra,Chittagong, Comilla, Dhaka, Gazipur, Jamalpur, Khulna, Khustia, Mymensingh, Rajshahi, Pabna, Natore, Sherpur and Sylhet, have already been using wastewater for irrigation (Jayakody *et al*., 2007; Mojid *et al*., 2010). They are using mostly untreated wastewater which may aggravate the negative attributes of wastewater irrigation. However, the productive use of wastewater or wastewater polluted water sources should be ensured in agriculture that will increase food production by more irrigation coverage and improve the livelihood of farmers at urban and peri-urban areas of Bangladesh (Mojid *et al*., 2010). The evaluation of wastewater quality is one of the important primary steps in well-planned utilization of wastewater for use in irrigation.

Khulna, the third largest city of Bangladesh consists of a total of 31 wards with a population of about 976000 as of 2010 (ADB, 2010). According to a land use survey undertaken for the preparation of Khulna Master Plan, about 79% of the city area is classified as "built-up" and the remaining 21% is mostly covered by agricultural land. Due to the regular activity of city dwellers and rapid urbanization, huge amount of grey water is being produced. It has been noticed that the drainage wastewater is mostly generated from the water used in households, restaurants, educational institutes, offices, hospitals and industries in the city. Moreover, the average annual rainfall in the Khulna during 2004-2010 was 1924 millimetres (mm) and more than 90% of this occurs between May and October (ADB, 2010). This water flows through numerous concrete and earthen open drains and finally disposes off to the peripheral rivers and canals without treatment. The drains are also somewhere directly connected with the septic tank system which has been creating severe effect on environment. Because of broken and uncovered drains, sometimes different solid waste are disposed into the drain which causes blockage of drains and increase the mosquito breeding. Mayur River is one of the imperative portion of Khulna city, in which most of the drainage water discharges. A large number of poor farmers residing particularly in western fringe of Khulna city apply untreated wastewater in irrigation crop fields and people living besides the Mayur river use the polluted water. However, the use of this unconventional water for irrigation by poor farmers and local people is not yet documented. Microbiological characteristics of municipal drainage wastewater have received much attention in recent research (Briks and Hills, 2007). Because of their capacity to cause human illness, microbial pathogens are often considered the most significant health concern associated with municipal drainage wastewater reuse. Satisfactory disposal of this drainage wastewater, whether by surface, subsurface methods or dilution, is dependent on its treatment prior to disposal. Adequate treatment is necessary to prevent contamination of receiving waters to a degree which might interfere with their best or intended use, whether it be for water supply, recreation, or any other required purpose. Therefore, this study is carried out to assess the characteristics of Khulna municipal drainage wastewater and to develop a Laboratory scale treatment plant of drainage wastewater treatment for use in irrigation and other purposes. This helps in planning effective wastewater management system for the city area in Bangladesh.

1.2 Statement of Problem

The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. Irrigation with wastewater is both disposal and utilization and indeed is an effective form of wastewater disposal (as in slow-rate land treatment). However, some degree of treatment must normally be provided to raw municipal wastewater before it can be used for agricultural or landscape irrigation or for aquaculture. The quality of treated effluent used in agriculture has a great influence on the operation and performance of the wastewater-soil-plant or aquaculture system. In the case of irrigation, the required quality of effluent will depend on the crop or crops to be irrigated, the soil conditions and the system of effluent distribution adopted. Through crop restriction and selection of irrigation systems which minimize health risk, the degree of pre-application wastewater treatment can be reduced.

Protecting the surface water resources from wastewater pollution plays a vital role for the development. The disposal of wastewater into the surface water bodies leads to serious problems and affects the people in health aspects. Especially in the urban areas, the pollution of domestic effluent discharges into the nearby surface water bodies created problems for the public. There are many ways of safe disposal of wastewater. But improper management of wastewater generation in the urban areas find its own way of getting into the surface water. Hence, the effluent discharge affects the surface water bodies. The water quality changes in the surface water bodies created many health problems to the public.

Drainage system in Khulna City Corporation (KCC) is not well-developed. The wastewater effluents, generated in KCC area, flow through the numerous concrete and earthen drains which finally dispose of to the nearby water bodies, i.e. the Mayur River, Rupsha River, etc. There are about 18 big and small canals and drains that drain out the effluents from KCC area to the Mayur River which is located at western fringe of the city. This triggered the reduction in fish population, increased the prevalence of disease, etc. The wastewater is now polluting the river water as the treatment facilities are not yet established in Khulna. As the quality of wastewater is not satisfactory, problems like pollution of surrounding rivers and the streams, deterioration of the environment, and health sanitation have become alarming.

A study on wastewater treatment technologies is very significant facet of water pollution studies. Different types of research works were carried out on water pollution studies, but a very few research is carried out on development of wastewater treatment technology in reference to Khulna municipality. Such research works are very much helpful for the development of a drainage wastewater treatment plant for Khulna city.

1.3 Rationale for the Study

Drainage wastewater reuse is the most promising immediate and economically attractive option to secure more water for agriculture sector (Allam *et al.*, 2015). Treatment and safe disposal of wastewater is necessary. This will facilitate protection of environment and environmental conservation, because the wastewater collected from cities and towns must ultimately be returned to receiving water or to the land. Once the minimum effluent quality has been specified, for maximum allowable concentrations of solids (both suspended and dissolved), organic matter, nutrients, and pathogens, the objective of the treatment is to attain reliably the set standards. The role of design engineer is to develop a process that will guarantee the technical feasibility of the treatment process, taking into consideration other factors such as construction and maintenance costs, the availability of construction materials and equipment, as well as specialized labor.

Primary treatment alone will not produce an effluent with an acceptable residual organic material concentration. Almost invariably biological methods are used in the treatment systems to effect secondary treatment for removal of organic material. In biological treatment systems, the organic material is metabolized by bacteria. Depending upon the requirement for the final effluent quality, tertiary treatment methods and/or pathogen removal may also be included.

Today majority of wastewater treatment plants uses aerobic metabolism for the removal of organic matter. The popularly used aerobic processes are the activated sludge process, oxidation ditch, trickling filter, and aerated lagoons. Stabilization ponds use both the aerobic and anaerobic mechanisms. In the recent years due to increase in power cost and subsequent increase in operation cost of aerobic process, more attention is being paid for the use of anaerobic treatment systems for the treatment of wastewater including sewage. Recently at few places the high rate anaerobic process such as Up-flow Anaerobic Sludge Blanket (UASB) reactor followed by oxidation pond is used for sewage treatment (Chong et al., 2012). Considering the field condition of Khulna city this study attempts to develop a treatment plant for protecting the natural surface water body surrounded the city.

1.4 Objectives of the Study

The specific objectives of this study are outlined as below:

a) To investigate the characteristics of Khulna municipal drainage wastewater.
b) To develop a laboratory scale treatment plant for Khulna municipal drainage wastewater.
c) To observe the performance of developed laboratory scale treatment units.
d) To assess the effluents for potential reuse in irrigation purposes and safe disposal.

1.5 Scope of the Study

This study is focused on two aspects. The first one is the characterization of drainage wastewater of Khulna municipality. The second one is the development of laboratory scale drainage wastewater treatment plant in order to use the effluents for irrigation and other purposes.

1.6 Organization of the Study

The study has been presented in five distinct chapters comprising different aspects of this study. The chapters portray the physical, chemical and biological characteristics of wastewater, development of simple drainage wastewater treatment unit, drainage wastewater reclamation, uses of reclaimed drainage wastewater for irrigation purposes, operation and maintenance problems of developed drainage water treatment unit and recommendations.

Chapter One: The first chapter deals with the general understanding on the drainage wastewater and uses in various aspects, objectives of the study, problem statements, rational of the study and research scope of the study and organization of the study.

Chapter Two: The second chapter comprises of a comprehensive literature review encompassing the background of Khulna city regarding wastewater generation and existing state of wastewater in Bangladesh, wastewater classification, conventional wastewater treatment process, classification and application of wastewater treatment methods, physical, chemical and biological characteristics of wastewater, parameters of agricultural significance, factors affecting drainage wastewater quality and water quality concerns for different uses.

Chapter Three: The third chapter contains elaborate description of the research design including preliminary field investigation, site selection and wastewater sample collection, sampling size and sampling procedure, development of laboratory drainage wastewater treatment techniques and tools, operation and maintenance, laboratory investigation and data tabulation and analysis.

Chapter Four: The fourth chapter represents experimental results in terms of physical, chemical and biological drainage wastewater quality to judge the suitability of the wastewater for its extending reuse.

Chapter Five: The fifth chapter covers the performance study of developed laboratory scale treatment plant as well as modified one and also the comparison between the raw water and treated water. This chapter also includes evaluation of reclaimed wastewater for agricultural use and for discharging into surface water bodies.

Chapter Six: The sixth chapter covers of conclusion about the raw and treated wastewater quality, recommendation for the drainage wastewater reuse and operation and maintenance problems of the proposed treatment unit.

In the last part of the study, photographs of the study area, experimental setup and list of references have been included. Necessary appendices are also included after references.

Chapter II

Review of Literature

This chapter includes background problem of the study, classification of wastewater, characteristics of wastewater including parameters of agricultural significance, factors affecting the drainage water quality and water quality concerns for uses, conventional wastewater treatment process, classification and application of treatment methods.

2.1 Background

Khulna the third largest city of Bangladesh and situated at the Southwest region of the country having about 1.50 million people living in 45.65 kilometres area (KCC, 2017), has been also facing growing urban environmental problems due to daily generated wastewater. Rapid population growth and industrial development has generated to a large amount of domestic and industrial wastewater. Due to the management of large amount of wastewater, there is no wastewater treatment system in Khulna city.

According to a land-use survey undertaken for the preparation of Khulna Master Plan, about 79% of the city area is classified as “built-up” and the remaining 21% is mostly covered by agricultural land. About 46% of the built-up area is occupied by residential housing, about 15% land is under industrial use and small percentage (about 5%) of land is under commercial use. The remaining land use in the built-up area consists of transport infrastructure, official buildings, community and defense, facility parks and water bodies.

2.1.1 Population

Population of the Khulna City Corporation (KCC) area is about 1.5 million and the growth rate is 5% which is mainly due to rural-urban migration. Economic activities in Khulna are mainly centered on its rich natural resources – fisheries and forestry. Around 1.9 % of the population of Bangladesh lives in Khulna, however, it contributes a slightly higher percent in terms of Gross Domestic Product (GDP) (2.5% of national GDP) (ADB, 2009). The service sector dominates the economic activities of the area (54%) following agriculture (26%) and industries (20%) (BBS, 2007).

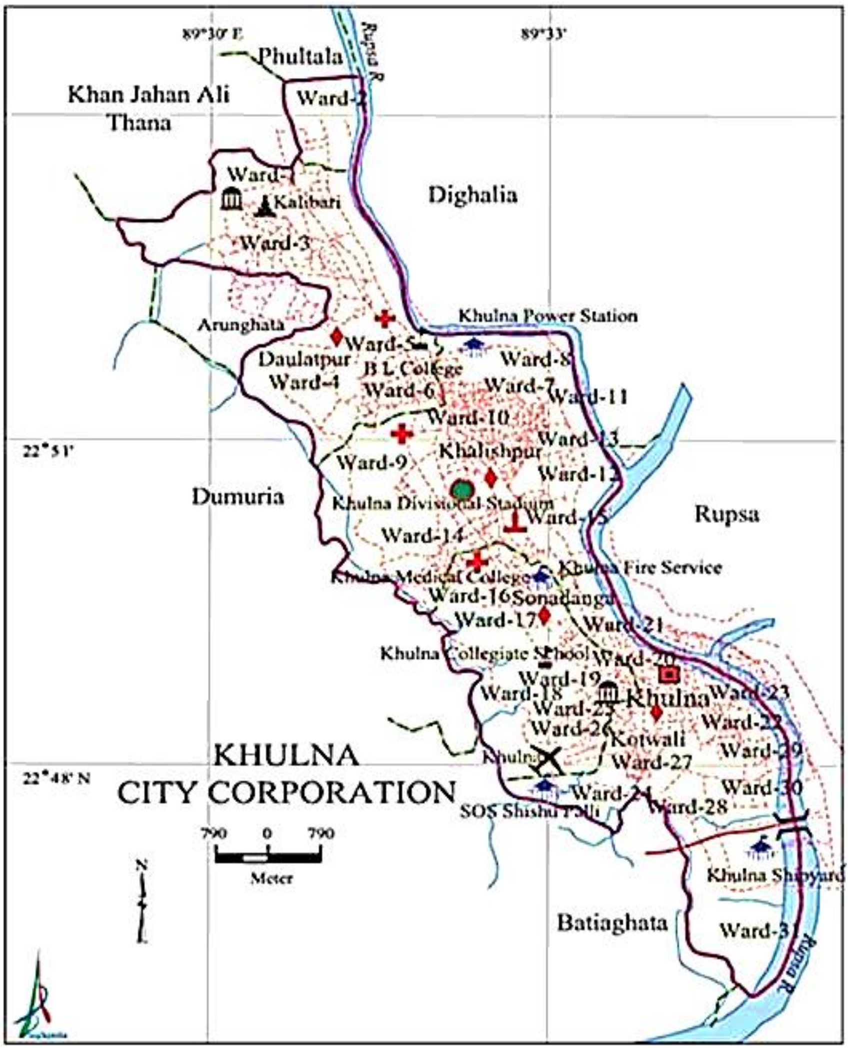

Figure 2.1: Khulna city corporation (KCC) area (Source: KCC, 2017)

The principal factor for determining the future water needs of a city are its population and its industry production. As these factors increase, the use of water and the disposal of wastewater will increase. The present and estimated future population is presented in the Table 2.1.

Table 2.1: Expected population growth in the Khulna City Corporation

Sl. No.	Method	Year			
		2010	2020	2030	2050
1.	Arithmetical method	976000	1190000	1450000	2155000
2.	Geometrical increase method	980300	1194800	1455300	2160800
3.	Incremental increase method	978150	1192400	1452650	2157900

(Source: ADB, 2010)

2.1.2 Present Water Supply

Dwellers of the KCC area, usually, consume water for domestic purpose, commercial and industrial purposes, and public sector. The coverage is only 30% of households with piped water supply. The rest is self-managed and many of the people face water crisis. Considering other demands as 10% of the consumer demand and leakage through the network as 20% of water supply, it was estimated that the water supply requirement was 165 liter per capita per day. As such, the water supply requirement was found to be 242 million liters per day (MLD) for 1.47 million people in 2007. It was assumed that the prevailing population growth would continue and the population of Khulna would be around 2.9 million by the year 2030, which would make the water requirement 478 MLD. Groundwater is the main source of water supply in KCC area. Total 56 production wells operated by Khulna Water Supply and Sewerage Authority (KWASA) and about 12,000 hand tube wells (deep and shallow tube wells) operated by private owners have combined production of around 125 MLD. However, the actual total production is about 90 MLD considering low production efficiency, malfunctioning of wells, etc. The critical situations with water supply becomes more critical each day, regarding that the demands for quality water are constantly increasing and the available water of satisfactory quality is shorter in supply, because of its uneven distribution in terms of space and time, and because of the intensive pollution.

2.1.3 Drainage System Details

Drainage system in Khulna City is not well-developed. The wastewater effluents, generated in KCC area, flow through the numerous concrete and earthen drains which finally dispose of to the nearby water bodies, i.e. the Mayur River, Rupsha River, etc. There are about 18 big and small canals and drains that drain out the effluents from KCC area to the Mayur River which is located at western fringe of the city. This triggered the reduction in fish population, increased the prevalence of disease, etc. The wastewater is now polluting the river water as the treatment facilities are not yet established in Khulna. As the quality of wastewater is not satisfactory, problems like pollution of surrounding rivers and the streams, deterioration of the environment, and health sanitation have become alarming.

2.1.4 Wastewater Generation

Expansion of urban populations and heterogeneous land-use pattern, improved standard of livings, and increased coverage of water supply and sewerage give rise to greater quantities of municipal wastewater (MWW) in Khulna. MWW means domestic wastewater or the mixture of domestic wastewater from commercial establishments and institutions including hospitals with industrial wastewater and storm water run-off, which flow into the sewerage system.

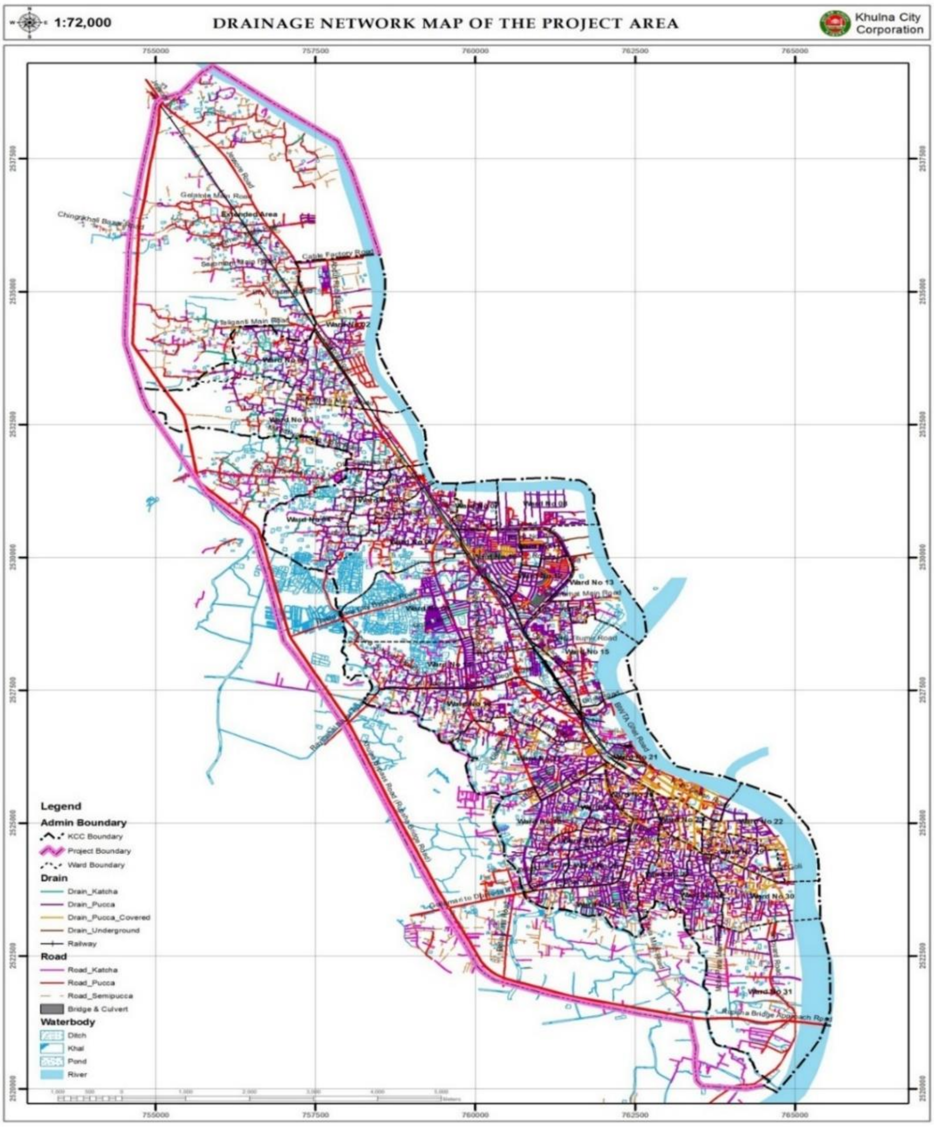

Figure 2.2: Drainage network map of Khulna city (Source: KCC, 2012)

It contains a broad spectrum of contaminants resulting from the mixing of wastewaters from aforesaid sources like households, restaurants, educational institutions, offices and hospitals. Due to limited industrial development, domestic effluent and urban run-off now contribute the bulk of wastewater generated in KCC area. Domestic wastewater usually contains grey water (sullage) which is generated from washrooms, laundries, kitchens etc. and can also contain *black water*, which is generated in toilets. Black water might contain besides urine and faeces/excreta (together sometimes called night soil) also some flush water. Notice that the region between Mayur and Bhairab River is heavily urbanized at the head while the Tail side is more or less covered by agricultural land.

Figure 2.3: Satellite image of Mayur river

The present water supply to the city dwellers is mainly from ground water sources drawn from both deep and shallow aquifers. It was estimated that the water supply requirement in 2010 was 174 million liters per day (MLD) that would be around 251, 328 and 485 MLD in 2020, 2030 and 2050 respectively (ADB, 2010). Assuming a return flow of 80% from total water supply requirement, presently around 140 MLD of wastewater is generated in the city area that would increase to around 201, 262 and 388 MLD in 2015, 2020, 2030 and 2050, respectively (Table 2.2).

Table 2.2: Future water supply and wastewater generation

Sl. No.	Year	Population	Water supply (MLD)	Wastewater generation (MLD)
1.	2010	976000	174	140
2.	2020	1190000	251	201
3.	2030	1450000	328	262
4.	2050	2155000	485	388

(Source: ADB, 2010)

More than 80% of the total wastewater flows toward the KhudiKhal-Mayur River system that was once the only irrigation water source for crop production in the western fringe of the city. However, providing safe and sufficient drinking water and proper sewerage system remains as the challenging tasks in the city.

2.1.5 Rainfall and Temperature

The average annual rainfall in Khulna during 2004-2010 was 1924 millimeters (mm), and more than 90% of this occurs between May and October (ADB, 2011). The highest average maximum temperature of 33˚C and above is usually recorded during March and May, and the lowest average minimum temperature of about 15˚C is usually recorded in December and January.

Table 2.3: Long-term average rainfall data of Khulna city

Rainfall (mm) - Long-Term Average												
Station Name	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Khulna	683	1521	2798	4869	11606	21983	22935	19592	16996	9741	1834	257

(Source: BARC, 2017)

From Table 2.3, it is clear that lowest amount of rainfall was occurred in November to March. So, the wastewater quality degrades much in November to March than the other time of year. As the surface runoff is low is during period, this study was conducted during the month of December to April for observing the real scenario of wastewater quality of Khulna municipality.

2.1.6 Agricultural Science

According to the crop calendar of Bangladesh in relation to precipitation and temperature, the study area enjoys three seasons which are Kharif-I (mid-April-mid June), Kharif-II (mid-July-mid-November) and Rabi (November-May). Rice is by far the most important crop in the study area, which is grown in almost all seasons. Transplanted aus, aman and boro rice are grown in the Kharif-I, Kharif-II and Rabi seasons, respectively. The first two rice crops are usually grown in rain fed condition. However, the supplementary irrigation is also needed for these rice crops due to the erratic rainfall. Boro rice is commonly practiced during the Rabi or winter season when irrigation is the only way to replenish soil moisture. Mustard, lentil, barley, different kinds of vegetables and jute are also grown in the Rabi and Kharif seasons where soil moisture is adequate.

2.1.7 Existing State of Drainage Wastewater in Bangladesh

At the beginning of the 21st century, Bangladesh is facing a water quality crisis resulting from continuous population growth, urbanization, land use change, industrialization, food production practices, increased living standards and poor water use practices and wastewater management strategies. In Bangladesh, as in many other parts of Asia, the quality and coverage of service provision is generally poor and systems for wastewater management are ineffective. Centralized agencies struggle to keep pace with the rate of urban development and hence many communities suffer from environmental health related problems due to the poor collection and treatment of wastewater.

In Bangladesh there are fewest treatment plants for treatment of domestic wastewater and industrial wastewater but there is no treatment facility for drainage wastewater. There is little concern about drainage waster due to unconsciousness and lack of knowledge of the devastating impact of it on the environment. Disposal of such drainage wastewater into open water sources through local storm sewerage is very common in Bangladesh. Contamination of surface water bodies and groundwater aquifers b pollutants from drainage wastewater along with those from domestic pollution exacerbate water quality problems and endanger both natural ecosystem integrity and public health. Poor water quality affects the availability of fresh water for different uses and has negative impacts on the livelihoods of the poorer communities. Wastewater management has a direct impact on the biological diversity of aquatic ecosystems, disrupting the fundamental integrity of our life support systems, on which a wide range of sectors, from urban development to food production and industry, depend. It is essential that wastewater management be considered as part of an integrated, full life cycle, ecosystem-based management system that operates across all three dimensions of sustainable development (social, economic and environmental), geographical borders, and includes both freshwater and marine waters (United Nations Water, 2015).

2.2 Classification of Wastewater

Classification of wastewater is in two main categories namely, grey and black water. While, grey water is the term used for water from kitchen, baths, laundries and sinks and black water is wastewater contaminated by faeces or urine, and includes wastewater arising from toilet, urinal, or bidet. Both require different degree of treatment and require different treatment mechanism. Wastewater treated in appropriate technology can be reused for a large number of use and reduce intake of freshwater from the supply systems or groundwater. Classification of wastewater are shown in Figure 2.4.

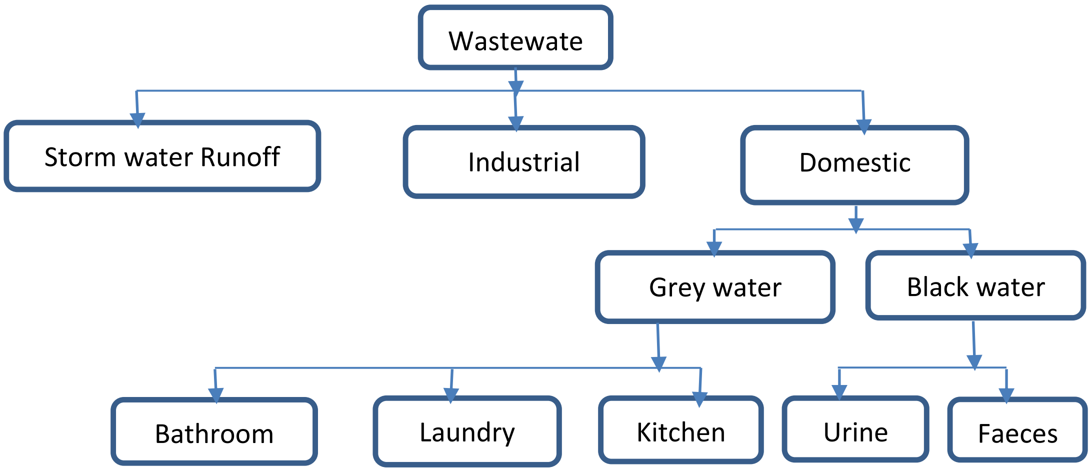

Figure 2.4: Classification of wastewater

Based on its origin wastewater can be classified as:

- Sanitary
- Commercial
- Industrial
- Agricultural
- Surface runoff

2.3 Characteristics of Wastewaters

Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. Table 2.4 shows the levels of the major constituents of strong, medium and weak domestic wastewaters.

Table 2.4: Major constituents of typical domestic wastewater

Constituent	**Concentration, mg/l**		
	Weak	**Medium**	**Strong**
Total solids	350	700	1200
Dissolved solids (TDS)	200	500	1000
Suspended solids	100	200	350
Nitrogen (as N)	20	40	80
Phosphorus (as P)	5	10	20
Chloride	30	50	100
Alkalinity (as $CaCO_3$)	50	100	200
Grease	50	100	150
BOD_5	100	200	300
COD	250	500	1000

(Source: Davis and Cornwell, 1998)

Municipal wastewater of Khulna city also contains a variety of inorganic substances from domestic and industrial sources (Table 2.5). Even if toxic materials are not present in concentrations likely to affect humans, they might well be at phytotoxic levels, which would limit their agricultural use. However, from the point of view of health, a very important consideration in agricultural use of wastewater, the contaminants of greatest concern are the pathogenic micro- and macro-organisms.

Table 2.5: Physico-chemical characteristics of wastewater of Khulna city

Sl. No.	Water Quality Parameter	Unit	Range
01.	DO	mg/l	0.3-1.4
02.	pH	-	6.61-6.74
03.	TDS	mg/l	908-1060
04.	Ca^{2+}	mg/l	21.03-23.6
05.	Mg^{2+}	mg/l	17.17-22.5
06.	Po_4^{3-}	mg/l	0.6-41
07.	No_3^-	mg/l	1.11-1.37
08.	So_4^{2-}	Mg/l	29-36
09.	Cl^-	mg/l	261-335
10.	Na	mg/l	21.36-21.54
11.	Electrical Conductivity (EC)	dS/m	1.62-1.76

(Source: Mridha, 2012)

Characterization of wastes is essential for an effective and economical waste management programme. It helps in the choice of treatment methods deciding the extent of treatment, assessing the beneficial uses of wastes and utilizing the waste purification capacity of natural bodies of water in a planned and controlled manner. While analysis of waste in each particular case is advisable and the data from other cities may be utilized during initial stage of planning.

Domestic sewage comprises spent water from kitchen, bathroom, lavatory, etc. The factors which contribute to variations in characteristics of the domestic sewage are daily per capita use of water, quality of water supply and the type, condition and extent of sewerage system, and habits of the people. Municipal sewage, which contains both domestic and industrial wastewater, may differ from place to place depending upon the type of industries and industrial establishment. The important characteristics of sewage are discussed here.

Pathogenic viruses, bacteria, protozoa and helminths may be present in raw municipal wastewater at the levels indicated in Table 2.6 and will survive in the environment for long periods. Pathogenic bacteria will be present in wastewater at much lower levels than the coliform group of bacteria, which are much easier to identify and enumerate (as total coliforms/100ml). *Escherichia coli* are the most widely adopted indicator of faecal pollution and they can also be isolated and identified fairly simply, with their numbers usually being given in the form of faecal coliforms (FC)/100 ml of wastewater.

Table 2.6: Possible levels of pathogens in wastewater

Type of pathogen		**Possible concentration per litre in municipal wastewater**
Viruses:	*Enteroviruses*	5000
Bacteria:	*Pathogenic E. coli*	-
	Salmonella spp.	7000
	Shigella spp.	7000
	Vibrio cholerae	1000
Protozoa:	*Entamoeba histolytica*	4500
Helminths:	*Ascaris Lumbricoides*	600
	Hookworms	32
	Schistosoma mansoni	1
	Taenia saginata	10
	Trichuris trichiura	120

(Source: Feachem *et al.*, 1983)

2.3.1 Temperature

The observations of temperature of sewage are useful in indicating solubility of oxygen, which affects transfer capacity of aeration equipment in aerobic systems, and rate of biological activity. Extremely low temperature affects adversely on the efficiency of biological treatment systems and on efficiency of sedimentation. In general, under Indian condition the temperature of the raw sewage was observed to be between 15 to 35^{0}C at various places in different seasons (Carley, 2003).

2.3.2 pH

The hydrogen ion concentration expressed as pH, is a valuable parameter in the operation of biological units. The pH of the fresh sewage is slightly more than the water supplied to the community. However, decomposition of organic matter may lower the pH, while the presence of industrial wastewater may produce extreme fluctuations. Generally the pH of raw sewage is in the range 5.5 to 8.0 for the existence of biological life is quite narrow (Akpor & Muchie, 2011).

2.3.3 Colour and Odor

Color in water is primarily due to the presence of colored organic substances (primarily humic substances), metals such as iron, manganese or highly colored industrial wastes (e.g., from pulp and paper and textile industries). Fresh domestic sewage has a slightly soapy and cloudy appearance depending upon its concentration. As time passes the sewage becomes stale, darkening in color with a pronounced smell due to microbial activity. Lastly, if the color is dark grey or black, the wastewater is typically septic, having undergone extensive bacterial decomposition under anaerobic conditions.

2.3.4 Solids

Though sewage contains only about 0.1 percent solids, the rest being water, still the nuisance caused by the solids cannot be overlooked, as these solids are highly putrescible and therefore need proper disposal. The sewage solids may be classified into dissolved solids, suspended solids and volatile suspended solids. Knowledge of the volatile or organic fraction of solid, which decomposes, becomes necessary, as this constitutes the load on biological treatment units or oxygen resources of a stream when sewage is disposed of by dilution. The estimation of suspended solids, both organic and inorganic, gives a general picture of the load on sedimentation and grit removal system during sewage treatment. Dissolved inorganic fraction is to be considered when sewage is used for land irrigation or any other reuse is planned. Usually, volatile solids are presumed to be organic matter, although some organic matter will not burn and some inorganic salts break down at high temperature.

2.3.5 Nitrogen and Phosphorus

The principal nitrogen compounds in domestic sewage are proteins, amines, amino acids, and urea. Ammonia nitrogen in sewage results from the bacterial decomposition of these organic constituents. Nitrogen being an essential component of biological protoplasm, its concentration is important for proper functioning of biological treatment systems and disposal on land. Generally, the domestic sewage contains sufficient nitrogen, to take care of the needs of the biological treatment. For industrial wastewater if sufficient nitrogen is not present it is required to be added externally. Generally nitrogen content in the untreated sewage is observed to be in the range of 20 to 50 mg/L (Akpor & Muchie, 2011). Phosphorus is contributing to domestic sewage from food residues containing phosphorus and their breakdown products. The use of increased quantities of synthetic detergents adds substantially to the phosphorus content of sewage. Phosphorus is also an essential nutrient for the biological processes. The concentration of phosphorus in domestic sewage is generally adequate to support aerobic biological wastewater treatment. However, it will be matter of concerned when the treated effluent is to be reused. The concentration of PO_4 in raw sewage is generally observed in the range of 5 to 10 mg/L but phosphate levels greater than 1.0 mg/l may interfere with coagulation in water treatment plants (Akpor & Muchie, 2011).

2.3.6 Chlorides

Concentration of chlorides in sewage is greater than the normal chloride content of water supply. The chloride concentration in excess than the water supplied can be used as an index of the strength of the sewage. It may have an impact on the final use of treated wastewater (Mahmoud, 2011). The daily contribution of chlorides averages to about 8 gm per person. Based on an average sewage flow of 150 LPCD, this would result in the chloride content of sewage being 50 mg/L higher than that of the water supplied. Any abnormal increase should indicate discharge of chloride bearing wastes or saline ground water infiltration, the latter adding to the sulfates, which may lead to excessive generation of hydrogen sulphide.

2.3.7 Organic Material

Organic compound present in sewage are of particular interest for sanitary engineering. A large variety of microorganisms (that may be present in the sewage or in the receiving water body) interact with the organic material by using it as an energy or material source. The utilization of the organic material by microorganisms is called metabolism. The conversion of organic material by microorganism to obtain energy is called catabolism and the incorporation of organic material in the cellular material is called anabolism.

To describe the metabolism of organic material, it is necessary to characterize quantitatively its concentration. In view of the enormous variety of organic compounds in sewage it is totally unpractical (if not possible) to determine these individually. Thus a parameter must be used that characterizes a property that all these have in common. In practice two properties of almost all organic compounds can be used: (1) organic compound can be oxidized; and (2) organic compounds contain organic carbon.

In sanitary engineering there are two standard tests based on the oxidation of organic material:

1) The Biochemical Oxygen Demand (BOD) and
2) The Chemical Oxygen Demand (COD) tests

In both tests, the organic material concentration is measured during the test. The essential differences between the COD and the BOD tests are in the oxidant utilized and the operational conditions imposed during the test such as biochemical oxidation and chemical oxidation. The other method for measuring organic material is the development of the Total Organic Carbon (TOC) test as an alternative to quantify the concentration of the organic material.

2.3.8 Biochemical Oxygen Demand (BOD)

The BOD of the sewage is the amount of oxygen required for the biochemical decomposition of biodegradable organic matter under aerobic conditions. The oxygen consumed in the process is related to the amount of decomposable organic matter. The general range of BOD observed for raw sewage is 100 to 400 mg/L.

2.3.9 Chemical Oxygen Demand (COD)

The COD gives the measure of the oxygen required for chemical oxidation. It does not differentiate between biological oxidisable and nonoxidisable material. However, the ratio of the COD to BOD does not change significantly for particular waste and hence this test could be used conveniently for interpreting performance efficiencies of the treatment units. In general, the COD of raw sewage at various places is reported to be in the range 200 to 700 mg/L.

In COD test, the oxidation of organic matter is essentially complete within two hours, whereas, biochemical oxidation of organic matter takes several weeks. In case of wastewaters with a large range of organic compounds, an extra difficulty in using BOD as a quantitative parameter is that the rate of oxidation of organic compounds depends on the nature and size of its molecules. Small molecules are readily available for use by bacteria, but large molecules, colloidal and suspended matter can only be metabolized after preparatory steps of hydrolysis. It is therefore not possible to establish a general relationship between the experimental five-day BOD and the ultimate BOD of a sample, i.e., the oxygen consumption after several weeks. For sewage (with k=0.23 d-1 at 20^{o} C) the BOD_5 is 0.68 times ultimate BOD, and ultimate BOD is 87% of the COD. Hence, the COD /BOD ratio for the sewage is around 1.7.

2.3.10 Toxic Metals and Compounds

Some heavy metals and compounds such as chromium, copper, cyanide, which are toxic may find their way into municipal sewage through industrial discharges. The concentration of these compounds is important if the sewage is to treat by biological treatment methods or disposed off in stream or on land. In general these compounds are within toxic limits in sanitary sewage however, with receipt of industrial discharges they may cross the limits in municipal wastewaters.

2.3.11 Agro-Pollutants

The two main agro-pollutants in agricultural drainage waters are nutrients and pesticides. As nutrients were covered above, this section focuses on pesticides. Once a pesticide enters the soil, its fate is largely dependent on sorption and persistence. Sorption is mainly related to the organic carbon content of soils while persistence is evaluated in terms of half-life (the time taken for 50 percent of the chemical to be degraded or transformed). Pesticides with a low sorption coefficient and high water solubility are likely to be leached while pesticides with a long half-life could be persistent.

Pesticides vary widely in their behavior. Pesticides that dissolve readily in water have a tendency to be leached into the groundwater and to be lost as surface runoff from irrigation and rainfall events. Pesticides with high vapor pressure are easily lost into the atmosphere during application. Pesticides that are strongly sorbed to soil particles are not readily leached but may be bound to sediments discharged from croplands. Pesticides may be chemically degraded through such processes as hydrolysis and photochemical degradation. Pesticides may be biologically degraded or transformed by soil microbes.

Therefore, many pesticides are mainly found in surface drainage water and not in subsurface drainage water as such, due to the filtering action of the soils. However, some pesticides have a tendency to be leached through soil profiles and accumulate in groundwater, such as organophosphates (e.g. DBCP and Atrazine).

2.3.12 Sediments

Sediment contamination is a main concern for surface drainage in hilly areas and in areas with high rainfall. Sediment production in arid zones occurs in improperly designed and managed surface irrigation systems, especially furrow irrigation.

Table 2.7: Physical and chemical characteristics of wastewater and sources

Characteristic	**Sources**
Physical properties:	
Color	Domestic and industrial waste water, natural decay of organic materials
Odor	Decomposing waste water, industrial waste water
Solids	Domestic water supply, domestic and industrial waste water, soil erosion, inflow/infiltration
Temperature	Domestic and industrial waste water
Chemical constituents:	
Organic:	
Carbohydrates, fats, oils and grease, proteins, surfactants, volatile organics	Domestic, commercial and industrial waste water
Pesticides	Agricultural waste water
Phenols	Industrial waste water
Others	Natural decay of organic materials
Inorganic:	
Alkalinity, chlorides	Domestic waste water, domestic water supply, groundwater infiltration
Heavy metals	Industrial waste water
Nitrogen	Domestic and agricultural waste water
pH	Domestic, commercial and industrial waste water
Phosphorus	Domestic, commercial and industrial waste water natural runoff
Gases:	
Hydrogen sulphides, methane,	Decomposition of urban waste water
oxygen	Domestic water supply, surface-water infiltration

Sediments are a direct threat to living aquatic resources and the aquatic environment in general. They also increase the cost of drinking water treatment and maintenance of open surface drainage networks from sediment deposition like in Pakistan and China. In addition, phosphate, organic nitrogen and pesticides bound to sediment particles are a source of pollution. Sediment production can be reduced by minimum tillage practices and limiting surface runoff through sound irrigation practices. Sediment settling ponds may be used to reduce the load of sediments in receiving waters. Polyacrylamides appear to serve as an excellent coagulant for sediments in farm drainage. Sediments are not normally found in subsurface drainage water. However, a drainage pipe filled with soil particles might cause sediment pollution in subsurface drainage water.

2.4 Parameters of Agricultural Significance

Agricultural water quality parameters mainly consist of certain physical and chemical characteristics of the water. The primary wastewater quality parameters of importance from an agricultural viewpoint are:

2.4.1 Total Salt Concentration

Total salt concentration (for all practical purposes, the total dissolved solids) is one of the important agricultural water quality parameters. This is because the salinity of the soil water is related to, and often determined by, the salinity of the irrigation water. Accordingly, plant growth, crop yield and quality of produce are affected by the total dissolved salts in the irrigation water. Equally, the rate of accumulation of salts in the soil, or soil salinization, is also directly affected by the salinity of the irrigation water. Total salt concentration is expressed in milligrams per litre (mg/l) or parts per million (ppm).

2.4.2 Electrical Conductivity (EC)

Electrical conductivity is widely used to indicate the total ionized constituents of water. It is directly related to the sum of the cations (or anions), as determined chemically and is closely correlated, in general, with the total salt concentration. Electrical conductivity is a rapid and reasonably precise determination and values are always expressed at a standard temperature of 25°C to enable comparison of readings taken under varying climatic conditions. It should be noted that the electrical conductivity of solutions increases approximately 2 percent per °C increase in temperature. In this publication, the symbol EC_w, is used to represent the electrical conductivity of irrigation water and the symbol EC_e is used to designate the electrical conductivity of the soil saturation extract. The unit of electrical conductivity is deci-Siemen per metre (dS/m).

2.4.3 Sodium Adsorption Ratio

Sodium is a unique cation because of its effect on soil. When present in the soil in exchangeable form, it causes adverse physico-chemical changes in the soil, particularly to soil structure. It has the ability to disperse soil, when present above a certain threshold value, relative to the concentration of total dissolved salts. Dispersion of soils results in reduced infiltration rates of water and air into the soil. When dried, dispersed soil forms crusts which are hard to till and interfere with germination and seedling emergence. Irrigation water could be a source of excess sodium in the soil solution and hence it should be evaluated for this hazard.

The most reliable index of the sodium hazard of irrigation water is the sodium adsorption ration, SAR. The sodium adsorption ratio is defined by the formula

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where the ionic concentrations are expressed in me/l.

A monogram for determining the SAR value of irrigation water is presented in Figure 2.5 (US Salinity Laboratory, 1954). An exchangeable sodium percentage (ESP) scale is included in the monogram to estimate the ESP value of the soil that is at equilibrium with the irrigation water. Using the monogram, it is possible to estimate the ESP value of a soil that is at equilibrium with irrigation water of a known SAR value. Under field conditions, the actual ESP may be slightly higher than the estimated equilibrium value because the total salt concentration of the soil solution is increased by evaporation and plant trans-piration, which results in a higher SAR and a correspondingly higher ESP value.

It should also be noted that the SAR from Equation 1 does not take into account changes in calcium ion concentration in the soil water due to changes in solubility of calcium resulting from precipitation or dissolution during or following irrigation. However, the SAR calculated according to Equation 1 is considered an acceptable evaluation procedure for most of the irrigation waters encountered in agriculture. If significant precipitation or dissolution of calcium due to the effect of carbon dioxide (CO_2), bicarbonate (HCO_3^-) and total salinity (EC_w) is suspected, an alternative procedure for calculating an Adjusted Sodium Adsorption Ratio, SAR_{adj}. can be used. The details of this procedure are reported by Ayers and Westcot (FAO, 1985).

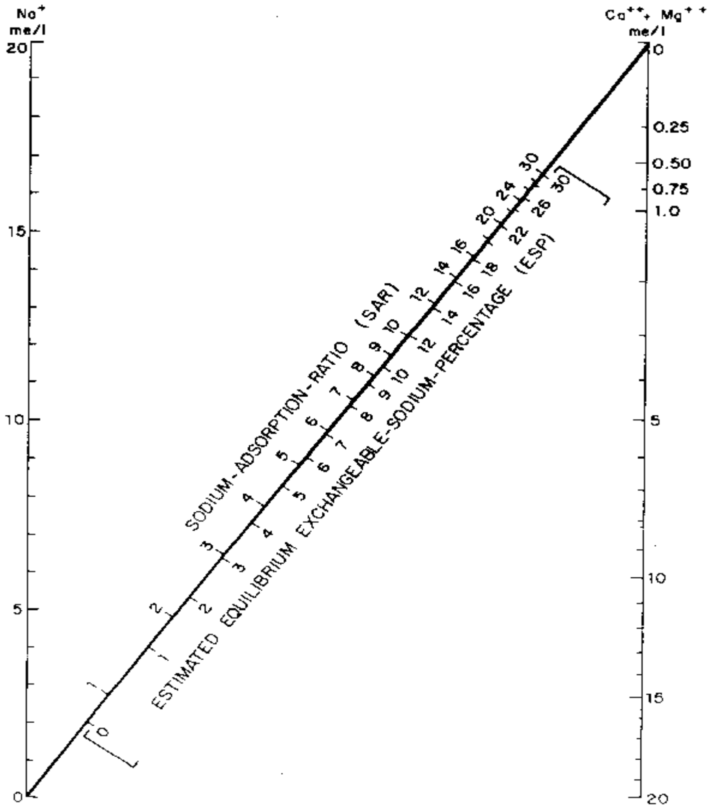

Figure 2.5: A nomogram for determining SAR (US Salinity Laboratory, 1954).

2.4.4 Toxic Ions

Irrigation water that contains certain ions at concentrations above threshold values can cause plant toxicity problems. Toxicity normally results in impaired growth, reduced yield, changes in the morphology of the plant and even its death. The degree of damage depends on the crop, its stage of growth, the concentration of the toxic ion, climate and soil conditions. The most common phytotoxic ions that may be present in municipal sewage and treated effluents in concentrations such as to cause toxicity are: boron (B), chloride (Cl) and sodium (Na). Hence, the concentration of these ions will have to be determined to assess the suitability of waste-water quality for use in agriculture.

2.4.5 Trace Elements and Heavy Metals

A number of elements are normally present in relatively low concentrations, usually less than a few mg/l, in conventional irrigation waters and are called trace elements. They are not normally included in routine analysis of regular irrigation water, but attention should be paid to them when using sewage effluents, particularly if contamination with industrial wastewater discharges is suspected. These include Aluminium (A1), Beryllium (Be), Cobalt

(Co), Fluoride (F), Iron (Fe), Lithium (Li), Manganese (Mn), Molybdenum (Mo), Selenium (Se), Tin (Sn), Titanium (Ti), Tungsten (W) and Vanadium (V). Heavy metals are a special group of trace elements which have been shown to create definite health hazards when taken up by plants. Under this group are included, Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg) and Zinc (Zn). These are called heavy metals because in their metallic form, their densities are greater than 4g/cc.

2.4.6 pH

pH is an indicator of the acidity or basicity of water but is seldom a problem by itself. The normal pH range for irrigation water is from 6.5 to 8.4; pH values outside this range are a good warning that the water is abnormal in quality. Normally, pH is a routine measurement in irrigation water quality assessment.

2.5 Factors Affecting Drainage Wastewater Quality

2.5.1 Geology and Hydrology

The geology of the region plays an important role in drainage water quality. Through weathering processes, the types of rocks (both primary and sedimentary) in the upper and lower strata define the types and quantities of soluble constituents found in the irrigated area. The oceans have submerged many parts of the continents during a period in their geological history. The uplift of these submerged geological formations and receding seas have left marine evaporates and sedimentary rocks behind, high in sea salts including sodium, chloride, magnesium, sulfate and boron. These geological formations exist in varying thicknesses, depths and extents on the continents. Through hydrological processes, solutes can enter the upper stratum by irrigation or floodwater, upward groundwater flow in seepage zones, with rising groundwater levels, or capillary rise. Once the solutes are in the upper strata, they influence the quality of agricultural drainage water through farmers' irrigation and drainage water management. The following example shows how the geology and hydrology of an area influence the quality of agricultural drainage water. It also illustrates the relationship between geomorphology, waterlogging and salinization.

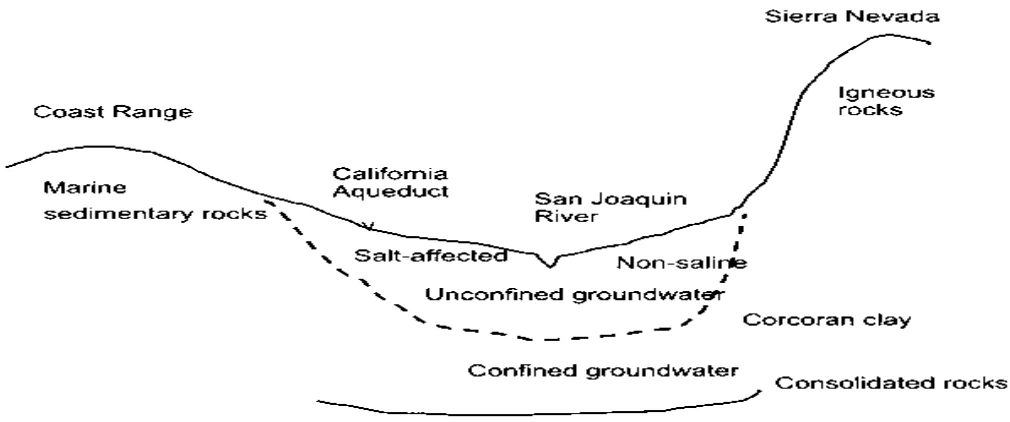

Figure 2.6: Cross-section of the San Joaquin Valley

Figure 2.3 shows a schematic cross-section of the San Joaquin Valley with the San Joaquin River as the principal drainage course for this river basin. The eastern side of the valley was formed from the alluvium of the Sierra Nevada, which consists mainly of granitic rocks. The soils derived from Sierran alluvium tend to be coarse textured and non-saline. The eastern ground waters are characterized as low-salt calcium-bicarbonate-type water with total dissolved solids (*TDS*) typically in the 200-500 mg/l range. In contrast, the soils on the western side were formed from alluvium of the Coast Range made up of uplifted marine sedimentary rocks. The soils on the western side tend to be finer textured and saline. The ground waters on the western side are characterized as moderately saline sodium-sulfate-type waters with *TDS* typically in the 1 000-10 000 mg/l range. The unconfined aquifer in both sides of the valley is gradually being filled up with decades of irrigation deep percolation. The soils in the valley and lowest part of the alluvial fans in the western side are waterlogged and salt affected. A nearly water-impermeable clay layer known as the Corcoran clay, about 200 m deep, serves as the boundary between the unconfined and confined aquifer. The ground waters in the confined aquifer contain from 500 to 1 000 mg/l *TDS*. During the geologic past, plate tectonics caused the horizontal-lying Corcoran clay in the shallow sea to tilt upwards forming the Coast Range.

Figure 2.7 is a free body diagram of the waterlogged irrigated lands on the western side showing the water flow pathways in the surface and subsurface. The applied irrigation water is about 450 mg/l calcium-bicarbonate-type imported water from the Sacramento River basin to the north. Much of the surface runoff is captured and reused on site. Much of the collected saline subsurface drainage water (4 000-10 000 mg/l *TDS*, sodium-sulfate type) is discharged into the San Joaquin River. Especially high concentrations of trace elements such as boron and selenium originating from the marine sedimentary rocks, found in the subsurface drainage waters, have given rise to environmental and health concerns. Discharges from these areas are now constrained by waste discharge requirements.

A second example comes from the Aral Sea Basin, where in total 137 million tonnes of salt are annually discharged, of which 81 million tonnes (59 percent) originate from the irrigation water and 56 million tonnes (41 percent) from the mobilization of salts from the subsoil. In the mid-stream areas, mobilization of subsoil salts is the most substantial. The annual discharge from the Karshi oblast (Uzbekistan) is 10.8 million tonnes of salts, which corresponds to about 34 tonnes per hectare. About 4.3 million tonnes (about 40 percent) originate from irrigation water and the remainder are mobilized salts from the subsoil through irrigation and drainage. Further, in Australia, large amounts of salts are added to the soil profile by atmospheric deposition of salts from upwind wind erosion of salt pans.

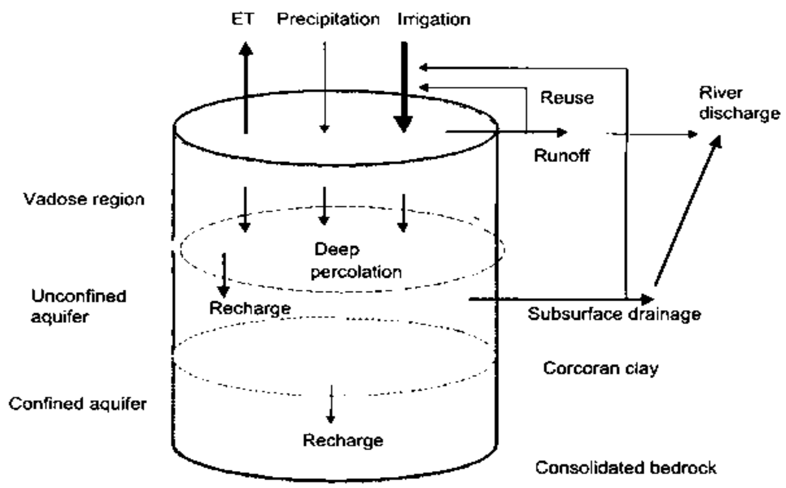

Figure 2.7: Free body diagram of water flows in the San Joaquin Valley

2.5.2 Soils

Figure 2.8 depicts the water movement over the soil surface and through the soil profile. Soils serve not only as a medium for plant growth but also store water and nutrients and serve as the porous transport media. The soil's eroding capacity and chemical weathering leads to the generation of water-borne suspended particles and solutes, ranging from nutrients to all kinds of contaminants. Therefore, to understand the role of soils on drainage water quality, it is necessary to understand water movement over and through the soil and the associated suspended and dissolved substances it carries. Of the water added to the soil, either in the form of rainfall or irrigation, part is lost through runoff and direct evaporation at the soil surface. Runoff water collects in natural and constructed surface drains from where it finds its way to the final disposal site (a river, evaporation pond or outfall drain to the ocean or saline lake). The other part infiltrates into the soil. This water fills up the soil pores and restores the soil moisture content up to field capacity under free drainage. The stored water is now available for plant root extraction to satisfy the water requirement of the crop. Any water in excess of field capacity percolates below the root zone to greater depth in the vadose zone. The deep percolation water may eventually serve as recharge to the groundwater or saturated zone. In irrigated areas with shallow groundwater Tables, the recharge is immediate and causes the water Table to rise. Where subsurface drainage is installed in waterlogged soils, the drainage system removes deep percolation and groundwater.

Where the soil moisture content in the root zone drops as a result of evapotranspiration and if there is no recharge from irrigation or rainfall, capillary rise into the root zone might occur, depending on the water Table depth, soil texture and structure, and seepage.

Runoff in irrigated agriculture is mainly related to the intensity of irrigation and rainfall events in comparison to the infiltration capacity of the soil. Where the infiltration rate is smaller than the irrigation or rainfall intensity, water will accumulate on the soil surface and run off under a minimum surface slope. Soil degradation, in terms of compaction and crust formation as well as cultivation on steep slopes, promotes surface runoff. Through the physical forces of the running water, soil particles become suspended in the water and are transported to open drains, ditches, streams, rivers and lakes. Deposition of suspended sediments may occur downstream when current velocities decrease. Suspended soil particles are harmful to aquatic life as they diminish light transmission, but also because chemical contaminants may be associated with suspended sediments. Degradation of drainage water quality as affected by runoff from agricultural land is especially important in hilly areas and in areas with excess rainfall.

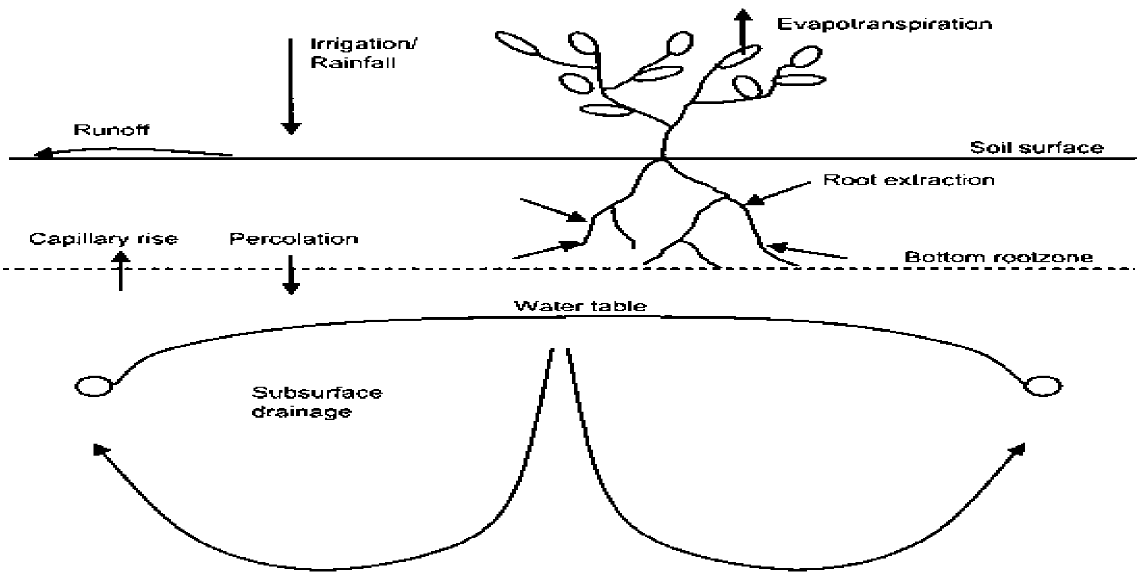

Figure 2.8: Water flow over and through the soil

In the more arid areas and in flat plains, water flowing through the soil profile and associated solute fluxes affected by mineral solubility and adsorption processes are of more importance for the final quality of the drainage effluent than surface runoff. In some places, weathering of soil particles might play a major role in the quality of drainage water (such as dissolution of gypsum). However, in general the soil's ability to adsorb and release through ion exchange and transform chemical elements through microbially-mediated redox reactions plays a more important role. In this context, soil characteristics such as water holding capacity, hydraulic conductivity, clay and organic matter content, soil minerals and soil microbes are important characteristics. Soil degradation in the form of erosion, compaction and loss of biological activity reduces the water and solute holding capacity of the soils. This increases the mobility of solutes through the soil and increases the risk that pollutants such as salts, nutrients and pesticides will be lost both to groundwater and through interception by subsurface drainage to surface water.

2.5.3 Climate

As the major transport of solutes through the soil is by the movement of water, climate plays a major role in determining drainage water quality. In humid tropics and temperate regions, the dominant movement of water through the soil is vertically downwards. Solutes, which are brought onto the soil by farmers or are naturally present in the upper soil layers, are leached into deeper soil layers and groundwater. Conversely, in arid climates where evaporation largely exceeds precipitation the dominant water movement through the soil is vertically upwards except during rainfall or irrigation events. Therefore, the chemical composition of deeper soil layers influences the quality of the shallow groundwater and the composition of the soil moisture in the root zone. Climate and temperature also play a role in the rate of weathering and chemical processes.

2.5.4 Cropping Patterns

Cropping patterns play an important role in the quality of drainage water in a number of respects. First, crops extract water from the root zone resulting in an evapo-concentration of salts and other solutes in the soil solution. Where the solubility product of minerals is exceeded through evapo-concentration, minerals precipitate out. This changes the composition of the soil solution and thus influences the chemical quality of subsurface drainage waters. Second, crop residues add organic matter to the soil profile. Organic matter in the soil increases the adsorptive capacity for metals and other solutes. Furthermore, organic matter enhances the soil structure, which increases the water holding capacity of the soil. The organic matter also serves as a carbon source for soil microbes involved in transformations such as de-nitrification, sulfate reduction and methane production in submerged soils. Third, plants extract nutrients through their rooting system and some plants have the capacity to accumulate large amounts of certain salts and toxic elements. Fourth, as not all crops have the same salt tolerance the type of crop largely determines the maximum salt concentration in the root zone and the amount of water needed to maintain a favorable salt balance in the root zone. Last, incorporation of nitrogen fixing crops such as legumes can help to reduce nitrogen leaching. Legumes in symbiosis with nitrogen fixing bacteria are both users and producers of nitrogen. They can substitute chemical nitrogen fertilizer in the crop rotation. Deep-rooted perennial crops such as alfalfa can also help to prevent nitrogen leaching by absorbing large amounts of nitrogen.

2.5.5 Use of Agricultural Inputs

Application of fertilizers, pesticides, soil and water amendments, and animal manures may influence the quality of drainage water to a great extent. The amounts and timing of application in relation to the growing stage of the crops, timing of irrigation, drainage practices and applied soil conservation measures largely define the influence of fertilizer, amendment and pesticide application on drainage water quality. Furthermore, the characteristics of the fertilizers themselves play a major role, also on the possible contamination of drainage water. Most nitrogen fertilizers are highly soluble and mobile in the soil, and nitrates readily enter drainage water through leaching processes. A portion of the nitrogen fertilizers made up of ammonium or anhydrous ammonia is initially adsorbed to the soil exchange complex but ammonium ions oxidize readily to nitrate. This is also true of urea containing nitrogen fertilizers that eventually oxidize to nitrates. Conversely, phosphorus fertilizers are less mobile in the soil because they have very low solubility, and phosphates are adsorbed on positive sites in soil organic matter and clay minerals (Westcot, 1997). The main route for phosphorous to drainage water is through runoff as sediment-bound inorganic and organic phosphate. Runoff waters may contain residues of anhydrous ammonia injected into irrigation water. Ammonia is highly toxic to fish. Runoff waters may also contain sediment-bound organic nitrogen. Excessive levels of nitrogen and phosphate in discharge waters may result in the eutrophication of water bodies.

Water and soil amendments such as gypsum may contribute significantly to salinity. Although gypsum is sparingly soluble, calcium contributed from gypsum may exchange with adsorbed sodium, and sodium sulfate is a highly soluble mineral. Acidic amendments react with soil calcium carbonates but do not contribute to salinity because the solubility of calcium carbonate is very low. Where animal manures are mineralized, nitrates and salts are produced. Some animal manure (e.g. poultry manure) contains appreciable amounts of salts.

2.5.6 Irrigation and Drainage Management

Irrigation and drainage management are the main factors influencing the flow of water over and through the soil in arid zone croplands. As solute transport takes place mainly through soil water fluxes, irrigation and drainage management determine to a great extent the solute fluxes through the soil. In irrigation management, timing in relation to crop water requirements and to fertilizer and pesticide application is key to controlling the amount of soluble elements that will leach below the root zone, from where they can be intercepted by subsurface drains. The timing of irrigation also affects capillary rise into the root zone, which might cause an accumulation of salts in the root zone but at the same time reduces the need for irrigation water. Of equal importance to the timing is the amount of irrigation water applied. Excess water, including infiltrated rainfall, leaches to deeper soil layers.

2.6 Water Quality Concerns for Uses

2.6.1 Crop Production

The total concentration of salts in drainage effluent is of major concern for irrigated agriculture. Salinity in the root zone increases the osmotic pressure in the soil solution. This causes plants to exert more energy to take up soil water to meet their evapotranspiration requirement. At a certain salt concentration, plant roots will not be able to generate enough forces to extract water from the soil profile. Water stress will occur, resulting in yield reduction. The extent to which the plants are able to tolerate salinity in the soil moisture differs between crop species and varieties.

For the stability of the soil structure, the composition of the soil solution is an important factor. In the solid phase, soils have a net negative surface charge. The magnitude of the cation exchange capacity (CEC) depends on the amount and type of clay and the organic matter content. Cations such as calcium, magnesium, sodium, potassium and hydrogen are adsorbed on the exchanger sites. Normally, a large fraction of the adsorbed cations is divalent calcium and magnesium. Divalent cations adsorbed to clay minerals provide structure and stability. Where monovalent cations dominate the exchangeable cations (sodium in particular), the soil structure loses its stability and structural degradation occurs easily. As cations are mutually replaceable, the composition of the exchangeable cations is related to the proportion of cations present in the soil solution. Therefore, where drainage water reuse for irrigation purposes is under consideration, not only the total salt concentration should be taken into account, but also the sodium to calcium and magnesium ratio, commonly expressed as the sodium adsorption ratio (*SAR*). High bicarbonate waters tend to precipitate out calcium carbonate. This may increase the SAR in the soil solution and increase the exchangeable sodium percentage (ESP) on the CEC.

The composition of the salts is also important for crop growth. Dominance of certain ions might cause an imbalance in ion uptake. This results in deficiencies of certain elements and depressed yields. The presence of high concentrations of sodium inhibits the uptake of calcium, causing nutritional disorders. Other ions can be toxic, causing characteristic injury symptoms as the ions accumulate in the plant. Toxic elements of major concern are chloride, sodium and boron.

The extent to which crops suffer from salinity stress depends on several factors. Although yield reductions are defined as a function of the average salt concentration in the root zone, interactions between soil, water and climatic conditions influence the relationship. Exceedingly high air temperatures may cause a reduced salt tolerance. Cultural practices also determine to a certain extent yield reduction resulting from salinity stress. Other plant characteristics (which differ between plant species, varieties of the same species and growth stages during which salinity stress occurs) determine their ability to cope with salinity stress.

The variations between crops in salt tolerance are attributable to the fact that certain crops can make the necessary osmotic adjustment to enable them to extract more water from saline soils. This adjustment involves two mechanisms: absorption of salts from the soil solution, and synthesis of organic solutes. Halophytes tend to absorb salts and impound them in the vacuoles, while organic solutes serve the function of osmotic adjustment in the cytoplasm. Normal plants tend to exclude sodium and chloride ions. For this reason, these plants need to rely more than halophytes on the synthesis of organic osmolytes. As a result, they are more salt sensitive than halophytes. Annex 1 presents data on crop tolerance to salinity and major ions.

Sensitivity to salts changes considerably during plant development. Most crops are sensitive to salinity during emergence and early development. Once established, most plants become increasingly tolerant during later stages of growth. There is general agreement that the earlier the plants are stressed, the greater the reduction in vegetative growth.

Not all trace elements are toxic and small quantities of many are essential for plant growth (e.g. iron, manganese, molybdenum and zinc). However, excessive quantities might accumulate in plant tissues and cause growth reductions. Crop tolerance to trace element concentrations varies widely. When accumulated in plant tissue, certain trace elements are also toxic to animals and humans upon eating, e.g. selenium, arsenic and cadmium. As plants do not absorb most of the trace elements that are present in the soil, the trace elements accumulate in the soils.

In 1985, FAO published general guidelines for evaluating water quality for irrigated crop production (FAO, 1985). These guidelines are general in nature and are based on numerous assumptions. Where the actual conditions differ substantially from those assumed, it might be necessary to prepare a modified set of guidelines. The case studies presented in Part II of this publication present several examples of guidelines developed for local conditions in the context of drainage water management. Scientists provide a list of recommended maximum concentrations of trace elements for long-term protection of plants and animals.

2.6.2 Living Aquatic Resources, Fisheries and Aquaculture

Aquatic organisms have different requirements with respect to the chemical and physical characteristics of a water body. Dissolved oxygen, adequate nutrient levels, and the absence of toxic concentrations of hazardous elements are essential factors for sustaining aquatic life. Drainage water disposal can disturb the chemical and physical characteristics of the aquatic habitat.

In natural water, the levels of trace elements are normally very low. Elevated concentration levels have a negative impact and harmful effects on aquatic life. Some trace elements such as mercury and selenium are of particular concern because of their bio-accumulative nature, even at very low concentrations (Westcot, 1997). For example, in the United States of America the regulatory maximum contaminant level for selenium for aquatic biota in freshwaters is 2 ppb and for drinking-waters for humans, 50 ppb. The former is lower due to the bioaccumulation of selenium through the aquatic food chain.

Pesticides may also cause toxicity problems in aquatic organisms in surface waters. While pesticide use is currently highest in North America and Europe, it is expected to increase at a faster rate in developing countries in the near future. Many of the synthetic organic compounds are persistent and bio-accumulate. They magnify up the food chain and are often absorbed in body fat, where they can persist for a long time. In the case of fish tissues and fishery products, some of these compounds may also reach consumers. As fish are an important source of protein, it is essential to prevent and avoid accumulation of contaminants in fish or shellfish.

All aquatic organisms including fish or other aquatic resources living in contaminated water bodies are being exposed daily to a multitude of synthetic chemical compounds that disrupt the development of the reproductive, immune, nervous and endocrine systems by mimicking hormones, blocking the action of hormones, or by other unknown interference with the endocrine system. Fish have different life stages: egg, larvae, fingerling and adult. Various pollutants may have different effects on their life cycle and on their functions and abilities (e.g. capacity to reproduce, nurse, feed and migrate).

The greatest threat to the sustainability of inland fishery resources is degradation of the environment. According to the GEO-I prepared by the UNEP, access to and pollution of freshwater are among the four key priority areas. Various guidelines have been proposed for water important for fisheries or protecting aquatic environmental quality in general. Water quality guidelines established for temperate regions should not be applied without caution to other climate conditions as toxicity, persistence and accumulation rates might differ substantially.

2.6.3 Livestock Production

Water for livestock watering should be of high quality to prevent livestock diseases, salt imbalance, or poisoning by toxic constituents. Many of the water quality variables for livestock are the same as for human drinking-water resources although the total permissible levels of total suspended solids and salinity may be higher. Appendix C presents water quality guidelines for livestock drinking-water quality. The guidelines consist of two parts. The first part consists of guidelines for the use of saline water for livestock and poultry. Unsafe levels of salinity and ions depend on the amount of water consumed each day, and on the type, weight, age and physical state of the animal. The second part contains maximum recommended limits of both chemical and microbiological variables. These limits are based on animal health, quality of the products and taste.

2.6.4 Concerns for Human Health

The quality of water has a major influence on public health. Poor microbiological quality is likely to lead to outbreaks of infectious water-borne diseases and may cause serious epidemics. Chemical water quality is generally of lower importance. The impact of chemicals on human health tends to be of a chronic long-term nature, and there is time available to take remedial action. However, acute effects may be encountered where major pollution events occur or where levels of certain chemicals (e.g. arsenic) are high from natural sources (WHO, 2000).

Increases in salinity, related to drainage water disposal on a shared water resource, may threaten its use for domestic and drinking-water supply. Although the WHO (1993) has not formulated any guidelines based on *TDS*, high salt concentrations can cause taste problems. Concentrations of less than 1 000 mg/liter (1.56 dS/m) are normally acceptable to consumers. For the majority of the major ions, no health guidelines have been derived. Present guidelines are based on taste and other side-effects of individual ions, such as staining of laundry by iron, or the rotten egg smell of sulphidic water. Most of the toxic trace elements are included in the health criteria for guidelines for the quality of drinking-water as some of them are carcinogenic. For example, arsenic contamination of drinking-water supplies is of major concern in Bangladesh. Expected concentrations in natural waters are generally well below 1 mg/liter. Where concentrations are exceeded, expensive treatment processes are required to make the water acceptable for human consumption. Some well-known chemical pollutants that affect health include nitrate, arsenic, mercury and fluoride. In addition, there is an increasing number of synthetic organic compounds released into the environment whose effect on human health is poorly understood, but appears to be carcinogenic (WHO, 2000).

Humans also use water resources for bathing and recreation. Such activities in contaminated waters pose a health risk due to: the possibility of ingesting small quantities; contact with the eye, nose and ear; and contact through open wounds. Health risks related to recreation are mainly related to pathogenic contamination. The potential risks from chemical contamination of recreational waters are usually small. Even repeated exposure is unlikely to result in ill effects at the concentrations of contamination found in waters and with the exposure patterns of recreational users. However, the aesthetic quality of recreational water is extremely important for the psychological wellbeing of users.

2.6.5 Effect of Industrial Wastes

Wastewaters from industries can form important component of sewage in both volume and composition. It is therefore necessary that details about nature of industries, the quantity and characteristics of the wastewater and their variations, which may affect the sewerage system and sewage treatment process, should be collected.

In case, where wastewaters high in suspended solids and BOD are to be accepted, provision should be made in the design of the treatment plant to handle such wastes. In certain instances, it is more economical to tackle the industrial waste at the source itself. Where, the wastewater has high or low pH corrective measures are necessary before admitting them to the sewers or the treatment plant. Toxic metals and chemicals having adverse effects on biological treatment processes, or upon fish life in a natural water course, or render the receiving water stream unfit as a source of water supply, should be brought down to acceptable limits at the source itself. Oil and grease in excessive amounts not only add considerably to the cost of treatment, but also pose a disposal problem. The industrial wastewaters may be discharged into public sewers if the effluents meet the tolerance limits prescribed by the authority. If the wastewaters are to be discharged into inland surface waters, tolerance limits set by the concerned authority should be satisfied.

2.6.6 Effluent Disposal and Utilization

The sewage after treatment may be disposed either into a water body such as lake, stream, river, estuary, and ocean or on to land. It may also be utilized for several purposes such as:

a) Industrial reuse or reclaimed sewage effluent cooling system, boiler feed, process water, etc.
b) Reuse in agriculture and horticulture, watering of lawns, golf courses and similar purpose, and
c) Ground water recharge for augmenting ground water resources for downstream users or for preventing saline water intrusion in coastal areas.

2.6.7 Microbial Diseases

Wastewater is generally divided into two categories: black water and gray water. Black water refers to toilet waste and gray water refers to the remaining wastewater from sinks, showers, laundry, etc. The septic tank provides primary treatment of both types of wastewater by settling out the solids and providing space for floating scum to be retained. Relatively clear, but not clean, water is discharged from the septic tank to the absorption field. The soil provides for further treatment when the waste water percolates through the soil profile.

Untreated or improperly treated wastewater contains biological contaminants known to cause disease. These contaminants are known as germs or pathogens. Pathogens fall into five main categories: bacteria, viruses, protozoans, fungi and worms. Most of these pathogens use the fecal/oral route to spread disease. Fecal material, including human waste, contains pathogens. The usual method of infection requires you to touch the fecal material with your hands and then transfer it to your mouth, either directly or through food. Pathogens can also contaminate water supplies when the wastewater is allowed to reach the water Table before adequate treatment occurs.

2.6.7.1 Bacteria

Bacteria are microscopic, single celled organisms that are typically round (Cocci), rod shaped (Bacillus), or spiral (Spirochetsia). Bacterial shapes come from three groups. Diplo means two bacteria attached together, Strepto means a twisted chain of bacteria, and Staphylo means a large clump of bacteria. You need a microscope to see bacteria, but not to see the damage they can do. Some diseases caused by bacteria are cholera, which causes vomiting, diarrhea, dehydration and even death; typhoid, which causes fever, chills, and sometimes death; salmonella, which causes fever, nausea, vomiting, bloody diarrhea, cramps and sometimes death; shigella, which causes fever, nausea, vomiting and diarrhea; and staphylococcus, which causes skin infections and mucus membrane infections.

2.6.7.2 Virus

Viruses use living cells to reproduce and cause infections. The virus penetrates the cell wall of the host, injects genetic material into it, and the host's infected cell makes more virus. Viruses are generally smaller than bacteria, but they can be more deadly. Diseases caused by viruses include hepatitis A, a viral infection of the liver which causes nausea, vomiting, diarrhea, skin and urine discoloration, weakness, and sometimes liver damage; gastroenteritis, a viral infection of the intestinal tract which causes fever, nausea, vomiting, diarrhea and pain; and polio, which causes inflammation of motor neurons of the spinal cord and brainstem, leading to paralysis, muscular atrophy and deformity, and sometimes death.

2.6.7.3 Fungi

WC-2 Fungi are non-photosynthetic living organisms such as yeast. They can be a single cell or a body mass of branched filaments. Diseases caused by fungi include candidiasis, which is transmitted by contact with feces or secretions from infected people. Although it usually causes mild infections, occasionally it may cause ulcers in the intestinal tract or lesions in the kidneys, brain or other organs.

2.6.7.4 Protozoans

Protozoans are large (compared to bacteria) single celled animals which have the ability to move. Diseases caused by bacteria include amoebiasis, which causes bloody diarrhea and sometimes death; and giardiasis, which causes diarrhea and severe gas. Perhaps the best known incidence of sickness caused by a protozoan is “Cryptosporidiosis”. Caused by Cryptosporidium, the infection in humans can be divided into two distinctly different diseases, depending on the patient’s immune status. Both forms have an incubation period of four to fourteen days. In the immune competent host, the onset is sudden. There is marked watery diarrhea, cramping, abdominal pain, and flatulence. Nausea, vomiting, fever, anorexia, weight loss, myalgia, and malaise may also be present. Symptoms usually begin to subside in five to ten days. In immune compromised patients (cancer, AIDS, elderly, previously diseased), the onset is more gradual, and the symptoms are more severe. Fluid losses may be excessive. Weight loss may exceed 10% of the patient’s original body weight. The duration of the illness may be indefinite. The deaths are usually in the immune competent host and are usually from loss of water to the system, loss of nutrition and no ability to fight the disease. There are few medications available to fight this disease.

2.6.7.5 Worms

This category includes hook, round, pin, tape and flatworms. In an ancylostomiasis infection, a hookworm penetrates the skin of the feet and travels to the gut. Ascariasis, a roundworm, lays eggs in sewage contaminated soil, which is ingested by an individual with dirty hands. The worms develop in the gut, attack the lungs, liver and other organs.

2.7 Conventional Wastewater Treatment Processes

Conventional wastewater treatment consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment. In some countries, disinfection to remove pathogens sometimes follows the last treatment step.

2.7.1 Preliminary Treatment

The objective of preliminary treatment is the removal of coarse solids and other large materials often found in raw wastewater. Removal of these materials is necessary to enhance the operation and maintenance of subsequent treatment units. Preliminary treatment operations typically include coarse screening, grit removal and, in some cases, commination of large objects. In grit chambers, the velocity of the water through the chamber is maintained sufficiently high, or air is used, so as to prevent the settling of most organic solids. Grit removal is not included as a preliminary treatment step in most small wastewater treatment plants. Comminatory are sometimes adopted to supplement coarse screening and serve to reduce the size of large particles so that they will be removed in the form of a sludge in subsequent treatment processes. Flow measurement devices, often standing-wave flumes, are always included at the preliminary treatment stage.

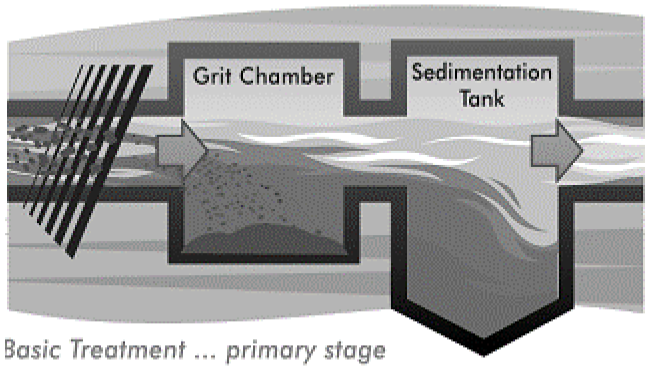

Figure 2.9: Basic primary treatment unit

2.7.2 Primary Sedimentation

In the primary sedimentation stage, sewage flows through large tanks, commonly called "pre-settling basins", "primary sedimentation tanks" or "primary clarifiers". The tanks are used to settle sludge while grease and oils rise to the surface and are skimmed off. Primary settling tanks are usually equipped with mechanically driven scrapers that continually drive the collected sludge towards a hopper in the base of the tank where it is pumped to sludge treatment facilities.

2.7.2.1 Plain Sedimentation

Wastewater, after preliminary treatment, undergoes sedimentation by gravity in a basin or tank sized to produce near quiescent conditions. In this facility, settle able solids and most suspended solids settle to the bottom of the basin. Mechanical collectors should be provided to continuously sweep the sludge to a sump where it is removed for further treatment and disposal.

2.7.2.2 Chemical Sedimentation

Sedimentation using chemical coagulation has been implied mainly to pretreatment of industrial or process wastewaters and removal of phosphorus from domestic wastewaters.

Chemical usage as a pretreatment step for industrial wastes and phosphorus removal is discussed later. The use of chemical coagulating agents to enhance the removal of BOD and suspended solids has not been used extensively on domestic wastewaters, since it is not usually economical or operationally desirable. However, special applications may exist at some installations.

Advantages of increased solids separation in primary sedimentation facilities are:

–A decrease in organic loading to secondary treatment process units.

–A decrease in quantity of secondary sludge produced.

–An increase in quantity of primary sludge produced which can be thickened and dewatered more readily than secondary sludge.

Chemicals commonly used, either singularly or in combination, are the salts of iron and aluminum, lime, and synthetic organic polyelectrolytes. It is desirable to run jar studies to determine the optimal chemicals and dosage levels. The use of a given chemical(s) and effluent quality must be carefully balanced against the amount of additional sludge produced in the sedimentation facility.

2.7.3 Secondary Treatment

The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids. In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolize the organic matter in the wastewater, thereby producing more microorganisms and inorganic end-products (principally CO_2, NH_3, and H_2O). Several aerobic biological processes are used for secondary treatment differing primarily in the manner in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolize the organic matter.

High-rate biological processes are characterized by relatively small reactor volumes and high concentrations of microorganisms compared with low rate processes. Consequently, the growth rate of new organisms is much greater in high-rate systems because of the well-controlled environment. The microorganisms must be separated from the treated wastewater by sedimentation to produce clarified secondary effluent. The sedimentation tanks used in secondary treatment, often referred to as secondary clarifiers, operate in the same basic manner as the primary clarifiers described previously. The biological solids removed during secondary sedimentation, called secondary or biological sludge, are normally combined with primary sludge for sludge processing.

Common high-rate processes include the activated sludge processes, trickling filters or bio filters, oxidation ditches, and rotating biological contactors. A combination of two of these processes in series (e.g., bio filter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources.

2.7.3.1 Activated Sludge

In the activated sludge process, the dispersed-growth reactor is an aeration tank or basin containing a suspension of the wastewater and microorganisms, the mixed liquor. The contents of the aeration tank are mixed vigorously by aeration devices which also supply oxygen to the biological suspension. Aeration devices commonly used include submerged diffusers that release compressed air and mechanical surface aerators that introduce air by agitating the liquid surface. Hydraulic retention time in the aeration tanks usually ranges from 3 to 8 hours but can be higher with high BOD_5 wastewaters. Following the aeration step, the microorganisms are separated from the liquid by sedimentation and the clarified liquid is secondary effluent. A portion of the biological sludge is recycled to the aeration basin to maintain a high mixed-liquor suspended solids (MLSS) level. The remainder is removed from the process and sent to sludge processing to maintain a relatively constant concentration of microorganisms in the system. Several variations of the basic activated sludge process, such as extended aeration and oxidation ditches, are in common use, but the principles are similar.

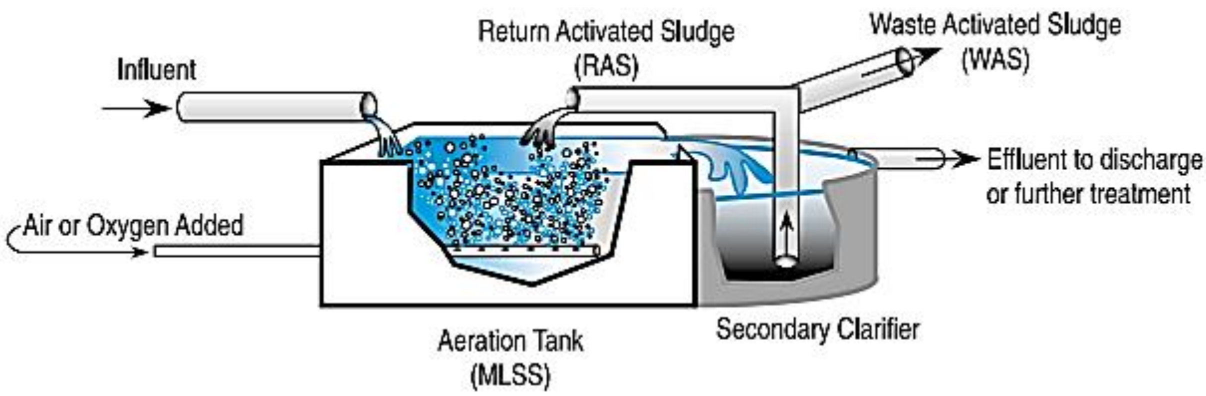

Figure 2.10: Basic schematic of the biological process in an activated sludge processing unit

A number of variations of the conventional activated sludge process were developed to achieve greater treatability y, to minimize capital and operating costs or to correct a problem.

The principal factors which control the design and operation of activated sludge processes are:

- **Mixed liquor suspended solids (MLSS):** In a well-operated plant, most of the bacterial biomass is associated with the activated sludge floc. By filtering and drying a sample of the suspended solids, and then weighing the dried residue, a measure of the biomass may be obtained. It is termed to as mixed liquor suspended solids or MLSS, and is expressed in mg/l.
- **Hydraulic retention time (HRT) or volumetric loading:** This is the average time spent by the influent sewage in the aeration tank. It is calculated as the tank volume (m^3) divided by the flow rate. Since flow rate Q is normally expressed in m^3/d and hydraulic retention time for the system is normally expressed in hours, the formula as follows:

$$\text{HRT}, \theta s = \frac{V}{Q} 24\ hours$$

Where, V= volume of reactor + volume of settling tank

The HRT for the reactor is:

$$\theta = \frac{Vr}{Q} 24hours$$

Where, V_r= volume of reactor

Clearly the higher the inflow rate Q, the sooner the sewage influent will reach the outlet and therefore the lower will be the residence time or hydraulic retention. The hydraulic retention time must be sufficiently long for removal of the requisite proportion of BOD_5 from the mixed liquor.

- **Food to microorganism (F/M) ratio:** The rate of biomass growth, and rate of respiration increase with increase in BOD loading. However, the rate of BOD_5 removal in the aeration tank is also related to sludge biomass. The higher biomass results in higher rate of BOD removal. It is calculated as the daily flow of BOD_5 divided by the total MLSS in the aeration tank. Thus:

$$\frac{f}{m} = \frac{BOD\ \left(\frac{mg}{l}\right) * flow\ \left(\frac{m3}{d}\right)}{MLVSS\ \left(\frac{mg}{l}\right) * tank\ volume(m3)} mg/(mg.d)$$

The value for f/m range from about 0.5 to 1.0. For conventional plants an f/m of between 0.2 and 0.5 is usually aimed for. At higher values, the rate of treatment increases, but at the cost of poor settle ability of the sludge.

- **Sludge age or solids retention time:** Sludge age is the mean residence time of the microorganisms in the system. It is calculated as the total amount of MLSS in the system divided by the MLSS that is lost in washing and in the effluent, each day i.e.

$$\theta c = \frac{VX}{QwXr + (Q - Qw)Xe}$$

Where, V= volume of aeration tank (m^3)

Q_w= wasting flow rate (m^3/s)

X_r= micro-organism concentration of the return sludge line (mg/l)= X_w

X_e= micro-organism concentration of secondary settling tank (mg/l)

The flow rate of sludge to be wasted is:

$$Qw = \frac{VX}{\theta cXr}$$

Where V=micro-organism concentration in aeration tank, MLVSS in mg/l

Return sludge flow rate is:

$$Qr = \frac{QX' - QwXr' - (Q - Qw)Xe}{Xr; -X'}$$

Where, X'= mixed liquor suspended solids, mg/l

X_r'= micro-organism concentration in return sludge line, mg/l

The net activated sludge produced each day is determined by:

$$Yobs = \frac{Y}{(1+Kd*\theta c)}$$

And

$$Px = \frac{YobsQ(So - S)}{1ooo}$$

Y_{obs} = observed yield, kg VSS/kg BOD_5 removed

P_x = Net waste activated sludge produced each day in terms of VSS, kg/d

- **Mass of Oxygen:** Mass of oxygen is used in the system to degrade the substrate to produce the high-energy compound for cell-synthesis and for respiration. The amount of oxygen required may be estimated as:

$$Mo2 = \frac{Q(So - S)}{f * 1000} - 1.42Px$$

Where, Q = wastewater flow rate into the aeration tank m^3/d

S_o = influent soluble BOD_5, mg/l

S = effluent soluble BOD_5, mg/l

f = conversion factor for converting BOD_5 to ultimate BOD_5

P_x = net waste activated sludge produced each day in terms of VSS, kg/d.

(Davies & Cornwell, 1998)

2.7.3.2 Trickling Filters

A trickling filter or bio filter consists of a basin or tower filled with support media such as stones, plastic shapes, or wooden slats. Wastewater is applied intermittently, or sometimes continuously, over the media. Microorganisms become attached to the media and form a biological layer or fixed film. Organic matter in the wastewater diffuses into the film, where it is metabolized. Oxygen is normally supplied to the film by the natural flow of air either up or down through the media, depending on the relative temperatures of the wastewater and ambient air. Forced air can also be supplied by blowers but this is rarely necessary. The thickness of the biofilm increases as new organisms grow. Periodically, portions of the film 'slough off the media. The sloughed material is separated from the liquid in a secondary clarifier and discharged to sludge processing. Clarified liquid from the secondary clarifier is the secondary effluent and a portion is often recycled to the bio filter to improve hydraulic distribution of the wastewater over the filter.

2.7.4 Tertiary and/or Advanced Treatment

Treatment unit operations further than secondary are called tertiary (advanced) treatment. This level of treatment is used before discharging of effluent and it aims to increase pollution removal efficiency of a WWTP and processes which use are dissimilar to primary and secondary ones. This process is performed by using different biological, chemical or physical treatment methods to boost the total removal of suspended and dissolved solids, organic matter, toxic substances and nutrients (Wang, *et al.*, 2006).

Tertiary and/or advanced wastewater treatment is employed when specific wastewater constituents which cannot be removed by secondary treatment must be removed. As shown in Figure 2.7, individual treatment processes are necessary to remove nitrogen, phosphorus, additional suspended solids, refractory organics, heavy metals and dissolved solids. Because advanced treatment usually follows high-rate secondary treatment, it is sometimes referred to as tertiary treatment. However, advanced treatment processes are sometimes combined with primary or secondary treatment (e.g., chemical addition to primary clarifiers or aeration basins to remove phosphorus) or used in place of secondary treatment (e.g., overland flow treatment of primary effluent).

2.7.4.1 Nitrogen Control

Ammonia in wastewater effluent can be toxic to aquatic life in certain instances. By providing additional biological treatment beyond the secondary stage, nitrifying bacteria present in wastewater can biologically convert ammonia to the non-toxic nitrate through a process known as nitrification. The nitrification process is normally sufficient to remove the toxicity associated with ammonia in the effluent. Since nitrate is a nutrient, excess amounts can contribute to eutrophication in the receiving waters. In situations where nitrogen must be completely removed from effluent, an additional biological process can be added to the system to convert the nitrate to nitrogen gas. The conversion of nitrate to nitrogen gas is accomplished by bacteria in a process known as de-nitrification. Effluent with nitrogen in the form of nitrate is placed into a tank devoid of oxygen, where carbon-containing chemicals, such as methanol, are added. In this oxygen-free environment, bacteria use the oxygen attached to the nitrogen in the nitrate form releasing nitrogen gas. Because nitrogen comprises almost 80% of the air in the earth's atmosphere, the release of nitrogen into the atmosphere does not cause any environmental harm.

2.7.4.2 Phosphorus Control

Like nitrogen, phosphorus is a necessary nutrient for the growth of algae. Phosphorus reduction is often needed to prevent eutrophication before discharging effluent into lakes, reservoirs, and estuaries. Phosphorus can be removed biologically in a process called enhanced biological phosphorus removal. In this process, specific bacteria, called polyphosphate accumulating organisms (PAOs), are selectively enriched and accumulate large quantities of phosphorus within their cells (up to 20% of their mass). When the biomass enriched in these bacteria is separated from the treated water, these bio-solids have a high fertilizer value.

Phosphorus removal can also be achieved by chemical precipitation, usually with salts or iron, alum, or lime. This may lead to excessive sludge productions as hydroxides precipitates and the added chemicals can be expensive.

2.7.4.3 Disinfection

Disinfection normally involves the injection of a chlorine solution at the head end of a chlorine contact basin. The chlorine dosage depends upon the strength of the wastewater and other factors, but dosages of 5 to 15 mg/l are common. Ozone and ultra violet (UV) irradiation can also be used for disinfection but these methods of disinfection are not in common use. Chlorine contact basins are usually rectangular channels, with baffles to prevent short-circuiting, designed to provide a contact time of about 30 minutes. However, to meet advanced wastewater treatment requirements, a chlorine contact time of as long as 120 minutes is sometimes required for specific irrigation uses of reclaimed wastewater. The bactericidal effects of chlorine and other disinfectants are dependent upon pH, contact time, organic content, and effluent temperature.

2.7.4.4 Chlorine

Chlorine kills microorganisms by destroying cellular material. This chemical can be applied to wastewater as a gas, a liquid or in a solid form similar to swimming pool disinfection chemicals. However, any free (uncombined) chlorine remaining in the water, even at low concentrations, is highly toxic to beneficial aquatic life. Therefore, removal of even trace amounts of free chlorine by de-chlorination is often needed to protect fish and aquatic life. Due to emergency response and potential safety concerns, chlorine gas is used less frequently now than in the past.

2.7.4.5 Ozone

Ozone is produced from oxygen exposed to a high voltage current. Ozone is very effective at destroying viruses and bacteria and decomposes back to oxygen rapidly without leaving harmful by products. Ozone is not very economical due to high energy costs.

2.7.4.6 Ultraviolet Radiation

Ultra violet (UV) disinfection occurs when electromagnetic energy in the form of light in the UV spectrum produced by mercury arc lamps penetrates the cell wall of exposed microorganisms. The UV radiation retards the ability of the microorganisms to survive by damaging their genetic material. UV disinfection is a physical treatment process that leaves no chemical traces. Organisms can sometimes repair and reverse the destructive effects of UV when applied at low doses.

2.7.5 Effluent Storage

Although not considered a step in the treatment process, a storage facility is, in most cases, a critical link between the wastewater treatment plant and the irrigation system. Storage is needed for the following reasons:

i. To equalize daily variations in flow from the treatment plant and to store excess when average wastewater flow exceeds irrigation demands; includes winter storage.
ii. To meet peak irrigation demands in excess of the average wastewater flow.
iii. To minimize the effects of disruptions in the operations of the treatment plant and irrigation system. Storage is used to provide insurance against the possibility of unsuiTable reclaimed wastewater entering the irrigation system and to provide additional time to resolve temporary water quality problems.

2.7.6 Sludge Treatment

The following are typical stages of the sludge treatment process.

2.7.6.1 Thickening

The sludge produced by primary and secondary treatment is approximately 99% water and must be concentrated to enable its further processing. Thickening tanks allow the sludge to collect, settle and separate from the water for up to 24 hours. The water is then sent back to the head of the plant or to the aeration tanks for additional treatment.

2.7.6.2 Digestion

After thickening, the sludge is further treated to make it safer for the environment. The sludge is placed in oxygen free tanks, called digesters, and heated to at least 95 degrees Fahrenheit for between 15 to 20 days. This stimulates the growth of anaerobic bacteria, which consume organic material in the sludge. Unlike the bacteria in the aeration tanks, these bacteria thrive in an oxygen-free or “anaerobic” environment. The digestion process stabilizes the thickened sludge by converting much of the material into water, carbon dioxide and methane gas. The black sludge that remains after has little odor. This is called digested sludge.

2.7.6.3 Sludge Dewatering

Dewatering reduces the liquid volume of sludge by about 90%. At these facilities, digested sludge is sent through large centrifuges that operate like the spin cycle of a washing machine. The force from the very fast spinning of the centrifuges separates most of the water from the solids in the sludge, creating a substance known as bio-solids. The water drawn from the spinning process is then returned to the head of the plant for reprocessing.

2.8 Classification and Application of Wastewater Treatment Methods

The degree of treatment required can be determined by comparing the influent wastewater characteristics to the required effluent characteristics, adhering to the regulations. Number of different treatment alternatives can be developed to achieve the treated wastewater quality.

2.8.1 Classification of Treatment Methods

The individual treatment methods are usually classified as:

- Physical unit operations
- Chemical unit processes
- Biological unit processes.

2.8.1.1 Physical Unit Operations

Treatment methods in which the application of physical forces predominates are known as physical unit operations. Most of these methods are based on physical forces, e.g. screening, mixing, flocculation, sedimentation, flotation, and filtration.

2.8.1.2Chemical Unit Processes

Treatment methods in which removal or conversion of contaminant is brought by addition of chemicals or by other chemical reaction are known as chemical unit processes, for example, precipitation, gas transfer, adsorption, and disinfection.

2.8.1.3 Biological Unit Processes

Treatment methods in which the removal of contaminants is brought about by biological activity are known as biological unit processes.

- This is primarily used to remove biodegradable organic substances from the wastewater, either in colloidal or dissolved form.
- In the biological unit process, organic matter is converted into gases that can escape to the atmosphere and into bacterial cells, which can be removed by settling.
- Biological treatment is also used for nitrogen removal and for phosphorous and sulfate removal from the wastewater.

2.8.2 Existing Wastewater Plant in Bangladesh

Domestic and industrial wastes of Dhaka City discharged into the river Buriganga by four main discharge pathways. Pagla Sewage Treatment Plant (PSTP) outfall is one of them, operated by Dhaka Water Supply and Sewerage Authority (DWASA). The plant treats wastes of about 7 million people at Dhaka city. The capacity of this treatment plant is only 0.12 million m3/day while the total sewage generated by the city as estimated by DWASA is about 1.3 million m3/day (Hasan *et al*. 2006). The treatment plant was consisted by different treatment units and shown in Figure

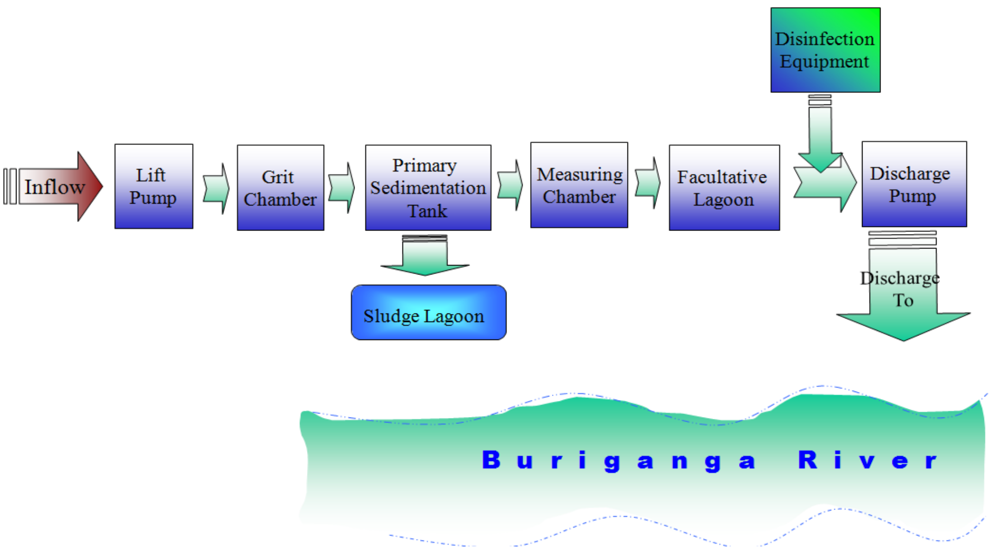

Figure 2.11: Sewage treatment plant at Pagla, Narayanganj

Chapter III

Research Methodology

This chapter covers the materials and methods involved in this study including research design, rational of the selection of study area, sources of wastewater sample collection, sampling size and sampling procedure, drainage wastewater treatment techniques and tools and data tabulation and analysis.

3.1 Research Design

The study is carried out on the basis of laboratory research design (Figure 3.1) because the study was focused on to investigate the drainage wastewater quality analysis and its treatment. Moreover the objective of the study was to develop a laboratory scale drainage wastewater treatment plant. A field survey was made in Khulna city to observe the negative impact of drainage wastewater. Firstly, a field visit was carried out in various drain outlet of KCC mainly Daulatpur to Gollamari bazar area. Then wastewater sample was collected to characterize wastewater quality by laboratory analysis and a laboratory scale wastewater treatment plant was developed. Finally, detailed performance study was carried out and treatment efficiency developed treatment plant was monitored.

3.2 Rational of the Selection of Study Area

The peri-urban residents of Khulna use the Mayur River for meeting the agricultural water demand, domestic water demand and water demand for pisciculture, an important livelihood. It also plays an important role in groundwater recharge. However, urban residents use this river as a dumping site for discharging wastewaters, domestic sewerage, solid waste dumping and other related uses. A number of hospitals, clinics, and automobile workshops are located within the catchment area of Mayur which also add to the pollutant load of the river. A large slaughter house is located on the banks of the Mayur at Gollamary bus station from where wastewater is directly discharged into the river without any treatment. Besides, a planned slaughter house is already under construction on the bank of Mayur. Thus anthropogenic activities have retarded the natural flow and degraded the water quality of Mayur. The river now completely looks like a wastewater channel at several points

(Rayermahal, Gallamary, Shashanghat, etc). About 30 years back, Mayur was a forceful river. Trawlers and gigantic country boats were used on this river for transportation of goods, services and people. Thus, the present situation is a large volume of wastewater generated in Khulna municipality area near bank of Mayur river and this generated wastewater discharged directly into river through the city corporation drainage network.

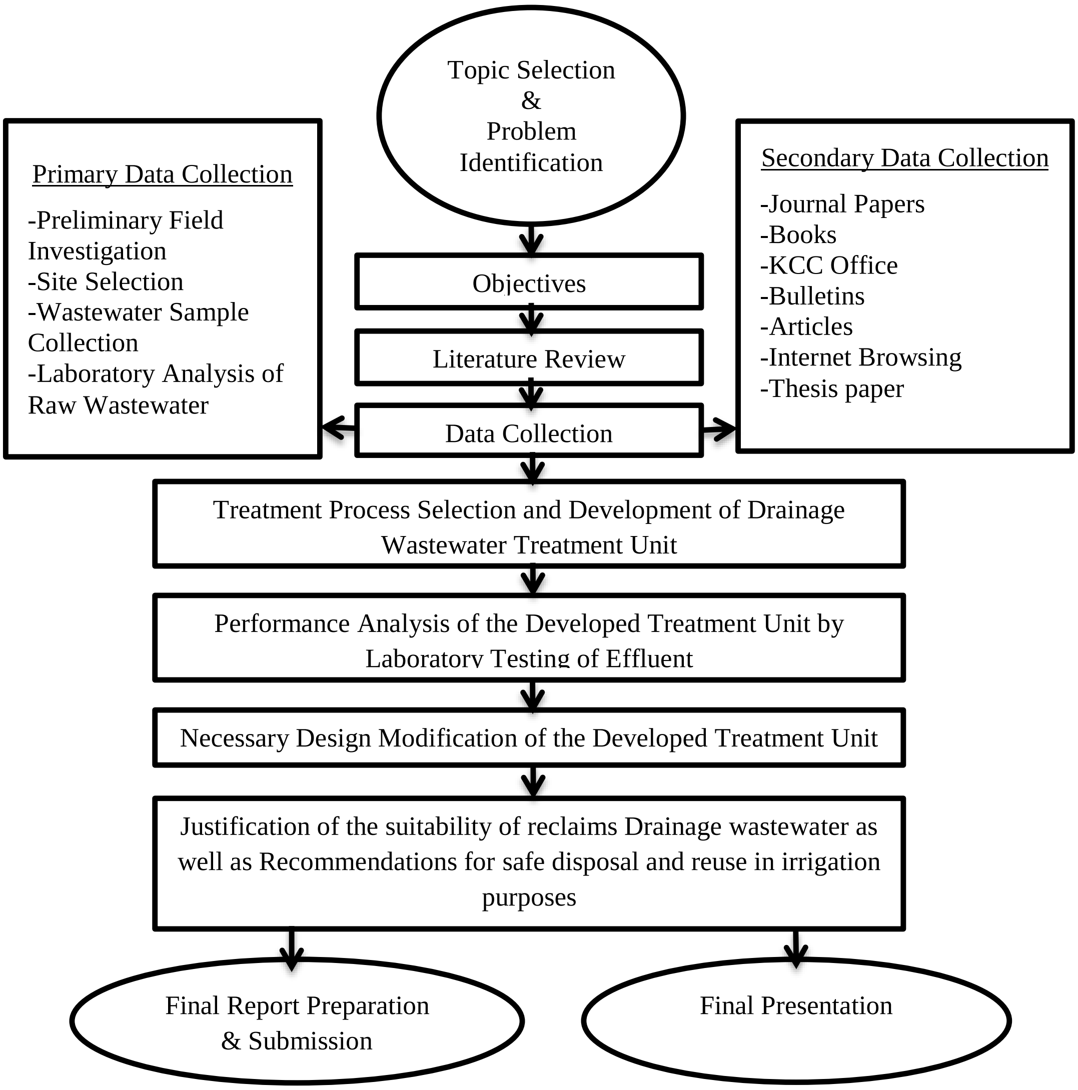

Figure 3.1: Flow diagram showing research design

Khulna, the third largest city in Bangladesh and the second largest in the coastal zone, is located on the banks of the Rupsha and Bhairab Rivers in Khulna District. It is the capital of Khulna Division and a major industrial and commercial center. Geographically, the city along with its surrounding lies between 22˚54’37” to 22˚45’58” N latitudes and 89˚29’22” to 89˚34’52” E longitudes. The whole city area is only about 2.5 meters above the mean sea level. As a deltaic plain the land is flat and poorly drained. The land-use pattern of this coastal city has been substantially influenced by Bhairab-Rupsha River system in the east and by the KhudiKhal-Mayur River system in the west.

3.3 Sources of Wastewater Sample Collection

When the wastewater is untreated, which have serious impacts on the quality of the environment and on the public health. The Mayur river gets almost total portion of the untreated drainage wastewater from the KCC drain outlets. The wastewater sample was collected from 50 to 100 feet ahead of drain outfall.

There are mainly ten outlets from which the wastewater releases into Mayur River. The outlets are shown in the Figure 3.5. The information regarding the drain outlets into the Mayur River are provided in Table 3.4. Sampling of wastewater was done from drain outlet 2 (Goalkhali, Bastuhara colony-Sample-1), 3 (Boyra Shahanghat bridge-Sample-2) and 7 (Gallamari, Gallamari bridge- Sample-3) for raw wastewater quality testing during December, January and April. It is noted that the period from December to May is the primary irrigation season when freshwater scarcity is a major concern in and around the city (Rahman et al. 2014).

Table 3.1: Details of the drain outlet (sampling station) location of Khulna city

Drain outlet*	Area, location	Latitude	Longitude	Elevation (m)
1	Daulatpur, Madhya Danga	22^{0}52’34.11”N	89^{0}30’33.72”E	4.6
2	Goalkhali, Bastuhara colony	22^{0}50’54.96”N	89^{0}30’47.37”E	3.0
3	Boyra Shahanghat bridge	22^{0}49’35.48”N	89^{0}31’46.76”E	4.6
4	Boyra, Nursing college	22^{0}49’26.91”N	89^{0}32’1.65”E	3.0
5	Sonadanga, Bus terminal	22^{0}49’1.89”N	89^{0}32’15.21”E	3.0
6	Sonadanga, Truck terminal	22^{0}48’33.63”N	89^{0}32’15.94”E	3.7
7	Gallamari, Gallamari bridge	22^{0}48’3.75”N	89^{0}32’25.62”E	4.0
8	Nirala area, Canal outlet	22^{0}47’50.74”N	89^{0}32’53.03”E	4.0
9	Bagmara, Bagmara bridge	22^{0}47’45.28”N	89^{0}33’28.09”E	4.0
10	Harintana, Harintana canal	22^{0}46’52.86”N	89^{0}34’15.90”E	3.7

*Sampling station (Source: Rahman et al. 2014)

The collected wastewater samples were analyzed individually. Drain outlet-2 and outlet-3 get water from almost domestic wastewater because this outlet passes through the residential area including huge slaughter houses. Moreover, in this area have some clinics and hospitals and plastic recycling factories. But drain outlet-7 carries wastewater coming from residential area, some factories and market as well. This wastewater is also directly dumped into open channels after generation. So, the wastewater passing through these three drainage network was highly polluted in comparison with other drains due to the characteristics of human settlement beside the drainage network. Because of these highly contaminated domestic wastewater, market wastewater and factory related wastewater these three drain outlet were considered as sampling points for this study.

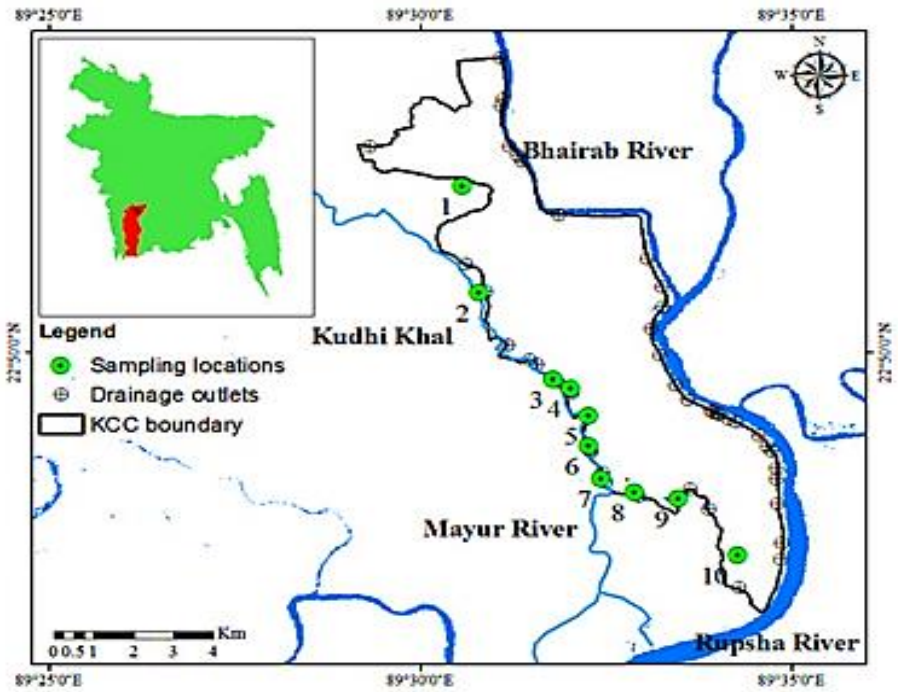

Figure 3.2: Sampling stations over Mayur river (Source: Rahman et al. 2014)

3.4 Sampling Size and Sampling Procedure

The KCC drain outlets were the potential sources of drainage wastewater sample collection of the study. Sampling size of the study was three. Three drain outlets no. 2, 3 and 7 were taken with random sampling from ten, mentioned in Table 3.4, as raw wastewater sampling station. From every sampling station three samples were collected with special care. Total nine wastewater samples, three from each spot in each month, were collected following standard guidelines. New plastic ‘Jerry Can’ of 20 litter capacity with hard plastic screw caps were used for wastewater sample collection. The Jerry Cans were properly cleaned before using and washed 2-3 times with the wastewater to be sampled before sampling. Wastewater samples were collected from the midpoint of the trunk drains by dipping each sample Jerry Can approximately 15-20 cm below the water surface, opening the Jerry Can and allowing it to fill in and closing with its cap under water. Wastewater sample was collected and transported to the laboratory on the same day. The samples were then preserved in a refrigerator at about 4°C until analysis. In all analyses samples were taken at dry weather conditions.

Figure 3.3: Wastewater sample collection container (Jerry Can)

3.5 Characterization of Drainage Wastewater

The physical, chemical and biological characteristics were determined in the laboratory to identify the extent of pollution. Some quality parameters of wastewater i.e. BOD_5, COD, pH, EC, DO, TDS, TSS, Cl-, NO^{3-}, SO_4^{2-} and PO_4^{3-} were selected based on the agriculture and health significances. All these parameters were measured, in a day so no further preservation was done, by following standard methods and instruments at Environmental Engineering laboratory, Khulna University of Engineering & Technology, Khulna, Bangladesh.

3.6 Drainage Wastewater Treatment Techniques and Tools

In this study, wastewater treatment consists of applying known technology to improve or upgrade the quality of a wastewater. Mainly wastewater treatment was done collecting the wastewater samples and subjecting the wastewater to various treatment processes are discussed below:

3.6.1 Development of Laboratory Scale Drainage Wastewater Treatment Plant

To identify the treatment units needed for the development of laboratory scale treatment plant, the physical, chemical and biological characteristics of wastewater were investigated in the laboratory. After the laboratory test to characterize wastewater quality of three samples and analyzing secondary data, the design criteria were set for the treatment units. Based on the developed criteria, a laboratory scale drainage wastewater treatment plant was constructed in the laboratory (Figure 3.6). The aeration method was adopted following filtration and chemical precipitation as this method is comparatively cheap and easy to operate for the treatment of wastewater. The wastewater treatment process used in this research can be classified under the following treatment methods-

3.6.1.1 Preliminary Treatment

In this research work, a bar screen was used which consists of 5mm x 5mm steel wire mess. The incoming wastewater was passed through the bars or screens and periodically the accumulated material was removed. The racks or screens were cleaned manually.

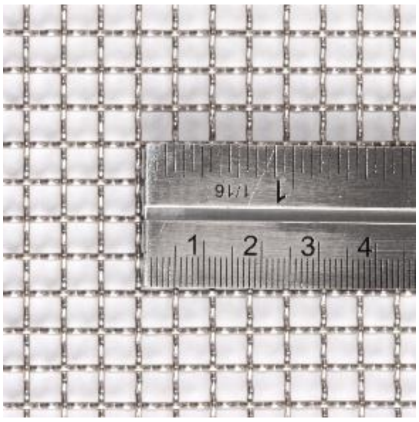

Figure 3.4: Bar screen of 5mm x 5mm in size steel wire mess

3.5.1.2 Primary Treatment

For laboratory scale, in this study a 45 litter capacity plastic rectangular container was used as primary clarifier. The size of the container was 20 inch in length, 15 inch in wide and 10 inch in height with 2 inch free board (Figure 3.5). The detention time was fixed to 2 hours for the sedimentation of settle able materials. In every batch of treatment 40 litter wastewater sample was entered into the chamber for 2 hours and from the bottom of the rectangular tank a path was made to remove sludge accumulated in this stage of treatment.

3.5.1.3 Secondary Treatment

In this study, 20"x15"x10" size plastic tank (Figure 3.6 and 3.7) was used as aeration chamber and a mechanical device was used to support continuous source of oxygen. The chamber also made with a 2 inch freeboard for preventing overflow. For the 1st sample aeration was done for 24 hours with 2h detention time in set of experiment. After the completion of aeration, optimum alum dose, 70 mg/L determined in laboratory, was added for chemical precipitation. Manual steering was done for complete mixing with a 30 minutes interval for 2 hours and finally kept the sample rest for another 2 hours for settling. Sludge was collected through the bottom of the chamber after the passing of water to roughing filter through the gate valve that was incorporated for regulation of flow. For the 2nd and 3rd sample same procedure was applied.

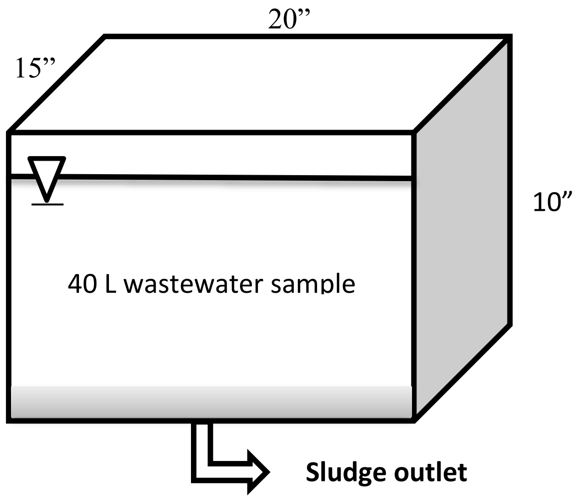

Figure 3.5: Plain sedimentation tank for primary treatment of wastewater

3.5.1.4. Tertiary Treatment

In this study, chemical precipitation and granular filtration were used for phosphorous and nutrient removal purpose. Up flow roughing filter was used for retaining floc generated from chemical precipitation. After roughing filtration the effluents passed through sand filter for nitrogen and pathogenic bacteria removal. Roughing filter and sand filter were made with 10"x15"x10" size (Figure 3.6 and 3.7) chamber full of brick khoa and Sylhet sand respectively. The brick khoa used for roughing filtration of 2mm to 40mm size. Similarly, the effective size of sand for sand filtration was 0.45mm to 1.5mm. The chambers also made with a 2 inch freeboard for preventing overflow.

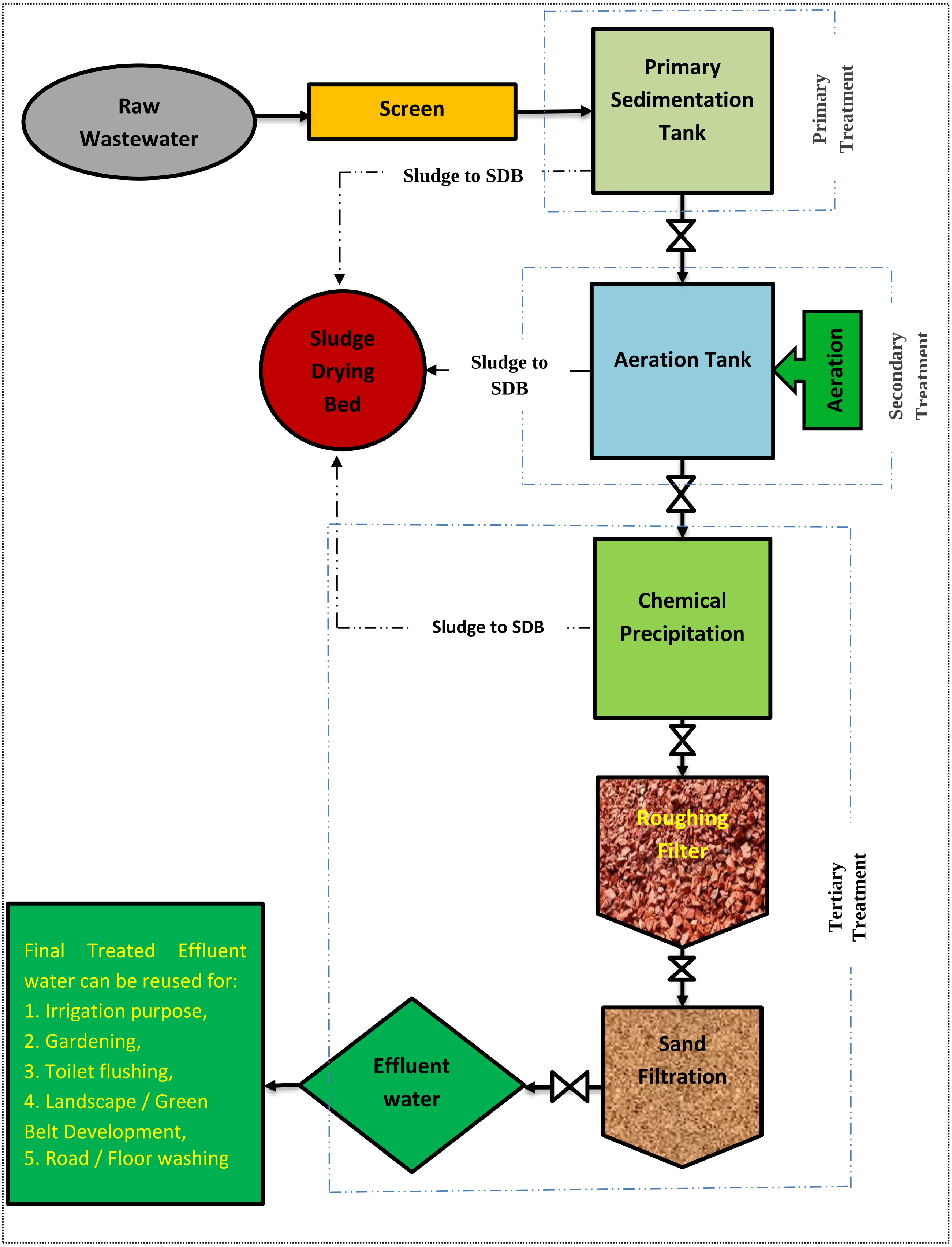

Figure 3.6: Flow diagram showing the proposed laboratory scale treatment units

3.5.2 Operation and Maintenance

The collected raw wastewater was poured into the sedimentation tank, which was passed through a connecting hose pipe into the aeration tank. The wastewater was aerated for preselected time before pouring the effluent into the filter so that oxygen can be mixed with wastewater properly. After aeration, in the same chamber to save another one, optimum alum does (70mg/l) was applied due the removal of phosphorous. Manual steering was done for complete mixing of chemicals with wastewater and then kept the wastewater for retention and construction of floc. Then water passed through the up flow roughing filter to catchup the floc generated in chemical precipitation. After that it was again transferred into the sand filtration unit for nitrogen and bacteriological removal. A probation for storage tank was made before discharging as treated effluent. No power was used for the flow generation. Gravity flow was used in the whole treatment system. The whole setup is presented in Figure 3.7.

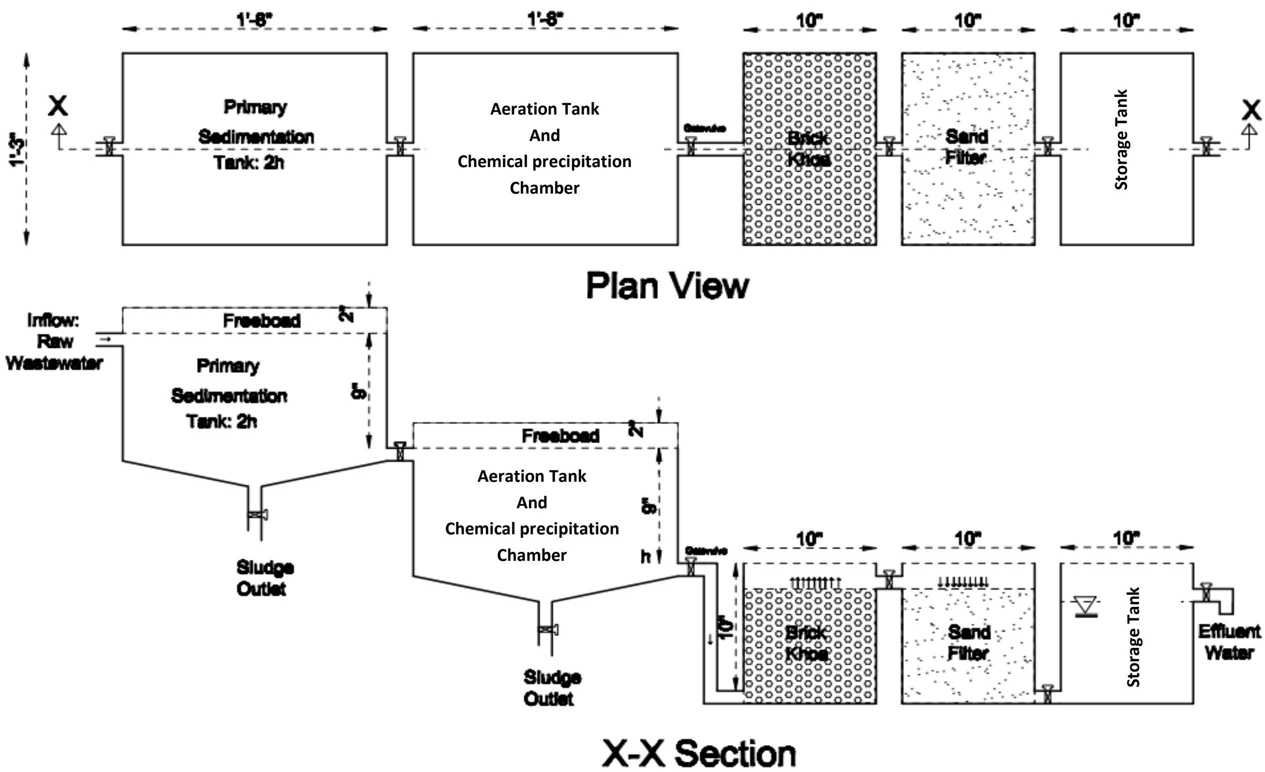

Figure 3.7: Instrumental setup and operation of developed treatment unit

The performance of the developed treatment unit was strictly maintained by avoiding the dropping of any type of additional waste materials. Before using the brick khoa and sand, they were cleaned properly by clear water. The filters need to be observed and maintained regularly because it can be clogged very fast and can hamper the whole system. After a certain time, the used brick khoa and sand must be changed for the continuity of the treatment system.

3.5.3 Laboratory Analysis

The raw wastewater and the effluents were taken to the laboratory for the analysis of different water quality parameter. The quality parameters tested in the laboratory were pH, turbidity, color, electrical conductivity, sulfate, chloride, nitrate, hardness, alkalinity, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total coliform and fecal coliform.

The methods outlined in the Standard Methods for the Examination of water and wastewater (APHA, 1992) was followed for the analyses of all the physical and chemical parameters.

- pH meter was used for determination of pH (HACH, sension2).
- Turbidity was measured with a Partech DRT 100B Turbidity meter.
- Colour was measured by the colour comparator.
- Conductivity meter was used for the determination of electrical conductivity.
- For the determination of sulphate, sulfa-Ver 4 reagent was used.
- Nitra-Ver 5 reagent was used for nitrate determination.
- EDTA was used in burette for titration in hardness test and Eri-chrom black T (EDT) was used as the reagent and titrated until the blue colour formed.
- TDS and TSS were determined by using filter paper and oven. After filtering the sample by the filter paper, it was placed into oven at 105^0C for 24 hours.
- DO bottle and DO meter (HACH, HQ 40d) were required for laboratory analysis of BOD_5 and 5 days were needed for the test.
- For determination of COD, $K_2Cr_2O_7$ was taken in the pipette and ferrion indicator was used as reagent and titrated until the radish colour formed.
- Total coliform and faecal coliform were measured by the membrane filtration technique by using XMG Agar reagent into a petri-dish.

3.6 Data Tabulation and Analysis

The collected raw water and treated water data were tabulated by the help of MS office program software widely used in research and data analysis through computer. All the necessary statistical tools like tables, graphs, means and medium were calculated from the program.

Chapter IV

Wastewater Characterization of Khulna Municipality

This chapter covers the general understanding of drainage wastewater quality in this study area for the development of a laboratory scale treatment plant and evaluation for irrigation uses with discharging into surface water bodies**.**

4.1 General

Investigating the initial raw water quality, the contamination rate of the wastewater was studied in the laboratory. The water quality parameters of the raw water were tested to study the treatment option and degree of treatment and to judge the suitability of the drainage wastewater for reuse. Laboratory experiments were carried out using the samples considering the requirements of resources and time related to the research. Physical, chemical and biological water quality parameters were obtained from the laboratory testing.

4.2 Physico-chemical Characteristics of Raw Drainage Wastewater

The composition of the wastewater samples in the study area shows a wide range. The results for the various physico-chemical parameters determined in the wastewater samples are presented in Tables 1 (Appendix A). The quality of wastewater is influenced by chemical, biological and environmental factors. Physico-chemical parameters for the drainage wastewater are discussed as below:

4.2.1 Hydrogen Ion Concentration (pH)

Figure 4.1 illustrates the variation the laboratory test results of pH of raw wastewater collected from the seven sampling station of Mayur river, which represents that the pH of the wastewater passing through the outlets, lies within the range of 7.27 to 7.49, representing the value of pH is within the standard value (6-9) for using in irrigation purpose. The results between monitoring times of each location are not much different, they were around ±0.22. This variation was normal because pH is very sensitive to temperature and the wastewater quality. The maximum value was recorded at sampling station (SS-3): Gollamari bridge area whereas the minimum was at (SS-1): Bastuhara colony, Goalkhali. It is also observed that there were insignificant variations in pH values between the sampling spots during the studied period. The nearly neutral to slight acidic pH values were found in all the observation spots during the study period.

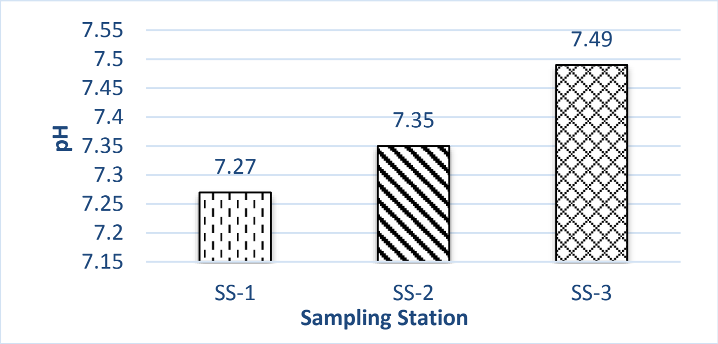

Figure 4.1: pH level at different sampling stations

4.2.2 Dissolved Oxygen (DO)

Normally, DO was measured immediately after samples taken in the lab. For all the sampling sites, DO values of the wastewater samples ranged from 0.69 to 0.79 mg/l (Figure 4.2). Every samples were found to have DO level lower than the standard limit (4.5-8 mg/l). The maximum DO was found to be in SS-2: Boyra Shahanghat bridge area in the month of December. However, the lowest concentration was found to be 0.69 mg/l at SS-3: Gallamari in the month of April, which was likely due to the higher temperatures in wastewater, intense algal growth and decay during this period. The significant decrease in DO during the warm period coincides chronologically with a great increase in algal blooms causing degradation of habitat for other life, and a change in the competitive balance between species leading to loss of biodiversity (Cooper et al., 2002). The decay of organic compounds consumes much oxygen and leads to the decrease in DO level. Low concentration of DO may impact adversely on all aquatic life.

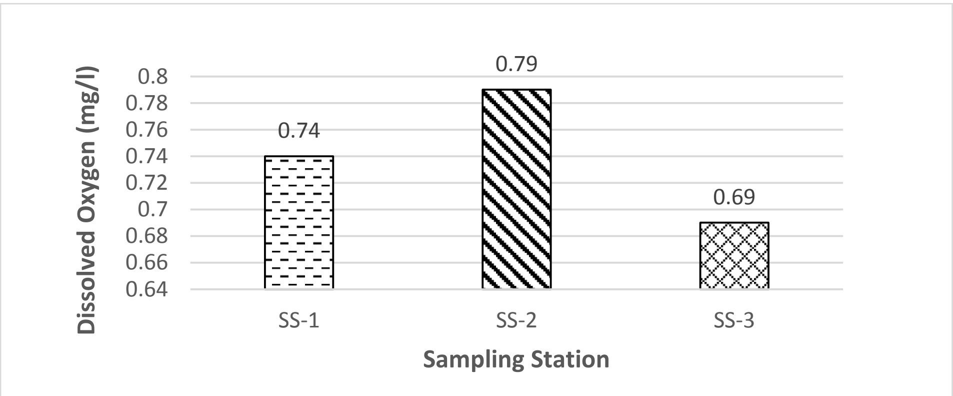

Figure 4.2: Dissolved oxygen level at different sampling stations

4.2.3 Biochemical Oxygen Demand (BOD_5)

Biodegradable organic materials present in the wastewater that can be oxidized by bacteria to form CO_2 and water, which are decomposed by absorbing large amount of dissolved oxygen (DO). Pollution increases with the amount of absorbed oxygen, which in terms reducing the amount of DO. If DO content in the water becomes low, it can threaten the survival of fish, plants and other aquatic life. It can be shown in Figure 4.3 that, the BOD of the wastewater disposed through drain outlet ranges from 58.76 mg/l to 226 mg/l (Figure 4.3). It can be treated by using trickling filter, roughing filter, aerobic granulation, activated sludge etc.

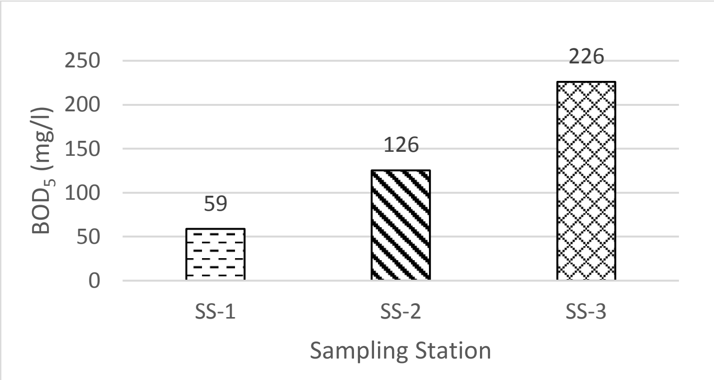

Figure 4.3: BOD_5 level at different sampling stations

4.2.4 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is a measure of the amount of non-biodegradable organic matters present in the water. Figure 4.4 shows that, all the outlets dispose water containing high concentration of non-biodegradable organic matters. High biochemical and chemical oxygen demand can affect soil and hydraulic properties. Adverse effect leading to reduce hydraulic conductivity and infiltration rates include physical blockage of pores by suspended material. SS-1, SS-2 and SS-3 dispose water with COD value 320mg/l, 420 mg/l and 435 mg/l. Figure 4.4 illustrates all the values except SS-1 exceeded the safe permissible limit for irrigation purpose (400mg/l).

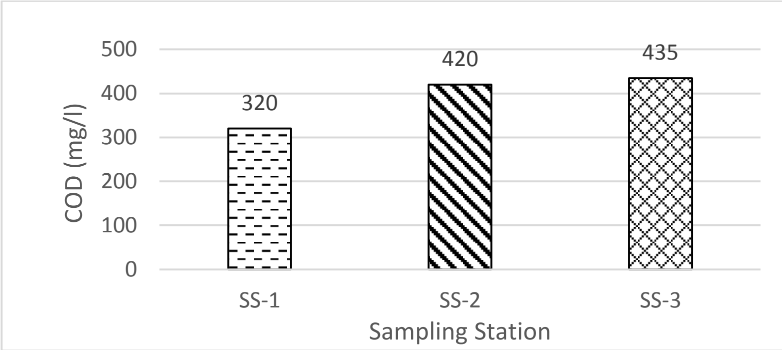

Figure 4.4: COD level at different sampling stations

The wastewater generated in the study area is considered to be easily treatable by biological means as the BOD_5/COD ration vary from 0.17 to 0.51 (Metcalf and Eddy, 2003).

4.2.5 Total Dissolved Solids (TDS)

Total dissolved solids comprise inorganic salts and small amount of organic matter of which dissolved inorganic substances may exert adverse effects on aquatic animals and plants and cause irrigation problems. Water disposing into the river contains high amount of dissolved solids. Figure 4.5 presents that, the water disposed into the river contains TDS ranging from 1800 mg/l at SS-1: Bastuhara Colony, Goalkhali to 2525 mg/l at SS-3: Gallamari, Gallamari Bridge, representing the requirement of treatment, to reduce the concentration below the safe limit (2100 mg/l) for irrigation purpose.

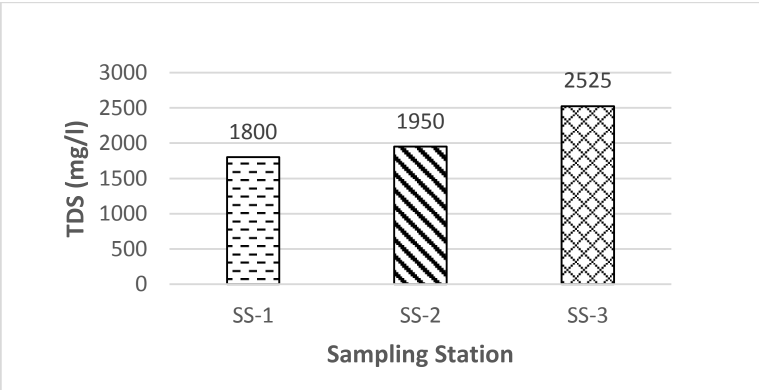

Figure 4.5: TDS concentration at various sampling stations

4.2.6 Total Suspended Solids (TSS)

On the other hand total suspended solids illustrated in Figure 4.6, present in the wastewater lies above the safe limit for irrigation purpose (100mg/l). In every sampling station dispose wastewater having TSS varied from 120 mg/l to 190 mg/l. Trickling filter, roughing filter, aerobic granulation, activated sludge etc. can be used to reduce the amount of dissolved and suspended solids to a safe limit for irrigation purpose.

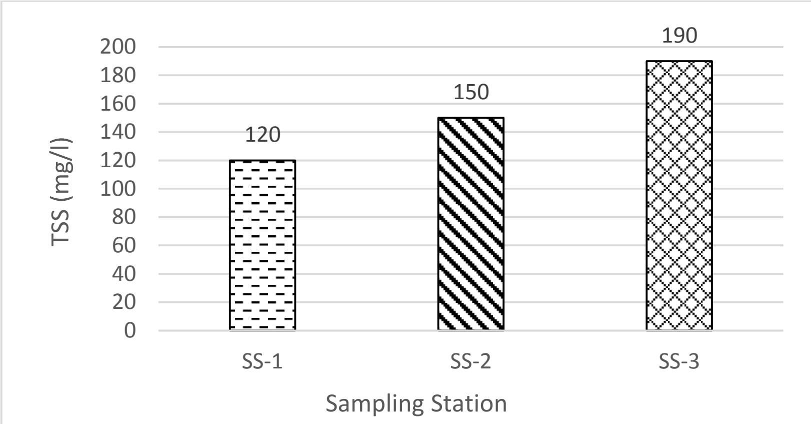

Figure 4.6: TSS concentration at various sampling stations

4.2.7 Hardness (as $CaCO_3$)

Hardness of water, which is defined as the presence of cations such as divalent calcium and magnesium, strontium, ferrous ions, manganous ions in water. The negative effect of hardness in water that, hard water consumes too much soap, and that it clogs skin, discolor porcelain, stains and shortens fabrics, and discolors vegetables and cooked foods. But it is a matter of hope that all the outlets dispose water with hardness below the safe limit for irrigation purpose and it ranges from 116 mg/l to 148 mg/l as $CaCO_3$ (Figure 4.7).

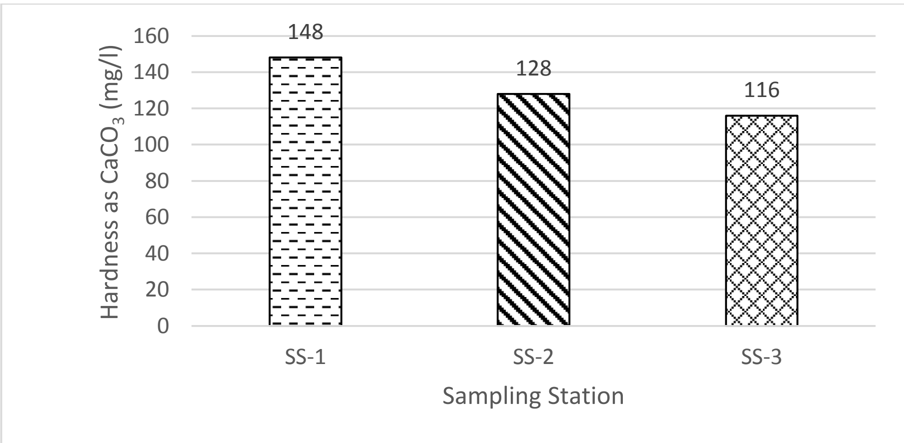

Figure 4.7: Hardness (as $CaCO_3$) level at different sampling stations

4.2.8 Alkalinity (as $CaCO_3$)

The alkalinity caused due to bicarbonates, carbonates and hydroxides present in wastewater. It causes nutritional disorders of plans, clog the nozzles of pesticide sprayers and drip tube irrigation system with obvious effects. Figure 4.8 illustrates the alkalinity of disposed water through the outlets and the Figure 4.9 shows that the concentrations of alkaline salts in the water is above the standard limit (200mg/l) for irrigation purpose. So, the wastewater generated from Khulna municipal area need to treatment before disposal.

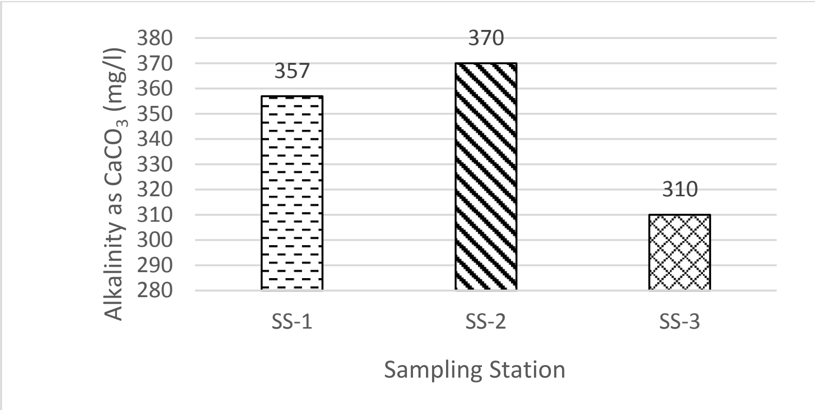

Figure 4.8: Alkalinity (as $CaCO_3$) level at different sampling stations

4.2.9 Chloride

Chloride, a hardness producing anion, occurs in water and wastewater in varying concentration. The concentration of chloride normally increases as the mineral content increase. Salts of chlorides are highly soluble in water and wastewater, which do not precipitate and cannot be removed by biological methods of wastewater treatment (Goel, 2006). It was also reported that domestic sewage and industrial effluents are significant sources of chloride in natural waters. A rise of chloride concentration in surface waters caused by the disposal of wastewater can be indicative of pollution. The most common toxicity in the irrigation water is from chloride (Ayers and Westcot, 1994).

The moderate concentrations of chloride were found in wastewater generated from the KCC area. The concentrations at all the sampling spots varied from 1250 mg/l to 1570 mg/l and the maximum value was found at SS-3: Gallamari bridge area. This variations could be attributed to input of highly variable soluble salts from the urban supplied water, liquid portion of septic tank, etc.

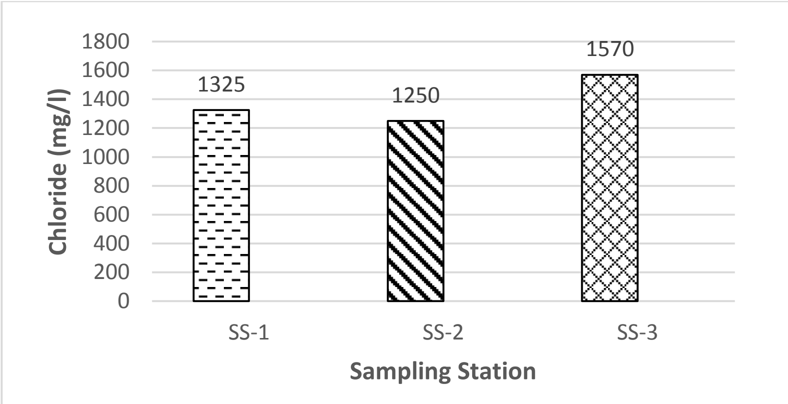

Figure 4.9: Chloride concentration at different sampling stations

4.2.10 Nitrate

Nitrate as nitrogen is a necessary primary macronutrient for plants that stimulates plant growth and is usually added as a fertilizer but can also be found in wastewater as nitrate, ammonia, organic nitrogen or nitrite (Pescod, 1992). The most important factor for plants is the total amount of nitrogen (N) regardless of whether it is in the form of nitrate-nitrogen (NO3-N), ammonium-nitrogen (NH4-N) or organic-nitrogen (Org-N). The concentration of nitrogen required varies according to the crop with more sensitive crops being affected by nitrogen concentrations above 5 mg/l, whilst most other crops are relatively unaffected until nitrogen exceeds 30 mg/l (Bai *et al.*, 2010).

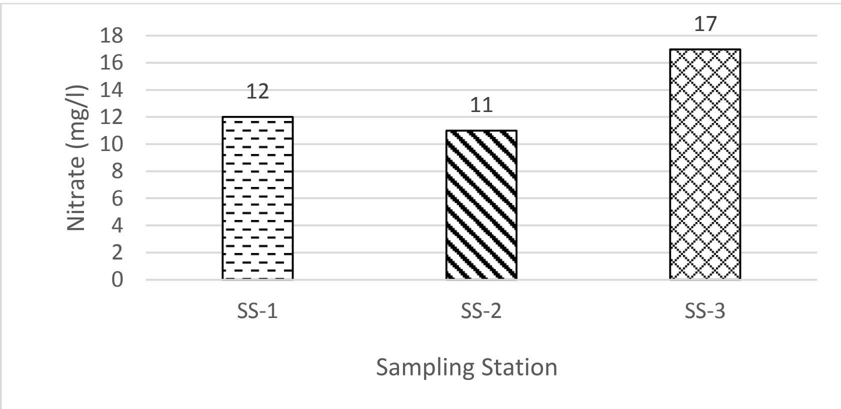

Figure 4.10: Nitrate concentration at different sampling stations

The results of NO_3^- in wastewater at all the observation stations ranged from 12 mg/l to 17mg/l. Figure 4.10 illustrates the variation of nitrates which are present into the water disposed through the main drain outlets of municipal sewage of Khulna city into Mayur river. It is also seen from the Figure 4.10 that, a significant amount of nitrates were present in the wastewater, which is below the safe permissible limit.

4.2.11 Phosphate

Phosphorus is also a primary macronutrient that is essential to the growth of plants and other biological organisms but quantities can be excessive and if the concentrations in water are too high noxious algal blooms can occur. Phosphates are classified as orthophosphates, polyphosphates and organic phosphates. Municipal wastewater may contain between 4 and 16 mg/l of phosphorus (Asano *et al.,* 2003). The phosphate contents in wastewater at all the stations ranged from 8.74 mg/l to 16.75 mg/l. The lowest concentrations were found in December at SS-1: Goalkhali, Bashtuhara colony whereas the highest was found to be in April at SS-3: Gallamari Bridge area.

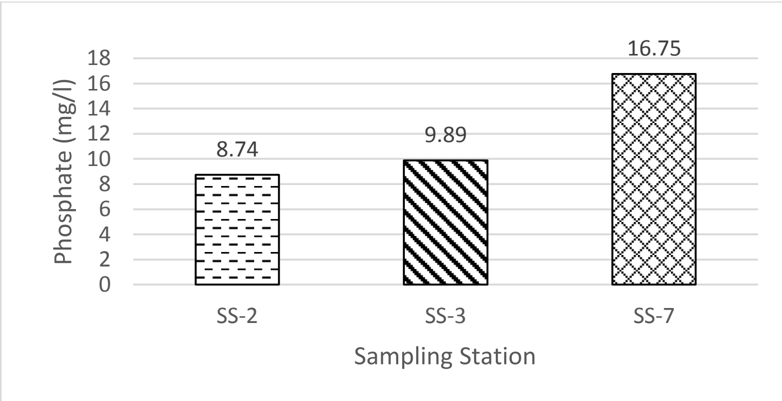

Figure 4.11: Phosphate concentration at various sampling stations

4.2.12 Sulfate

Sulfates occur in natural waters at concentration up to 50 mg/l. Concentration of 1000 mg/l can be found in wastewater having contact with certain geological formations e. g. gypsum reserves, water from pyrite quarries. Sulfur is required in the synthesis of proteins and is released in their degradation. Rain water has quite high concentration of sulfates particularly in areas with high atmospheric pollution. In humid region, sulfate is readily leached from the zone of weathering by infiltration-waters and surface run-off (Kotaiah and Swamy, 1994). The values of sulfate in wastewater varied from 154 mg/l to 180 mg/l. The highest value was found to be in April at SS-3: Gallamari bridge area whereas the lowest was in January at SS-2: Boyra Sashanghat bridge.

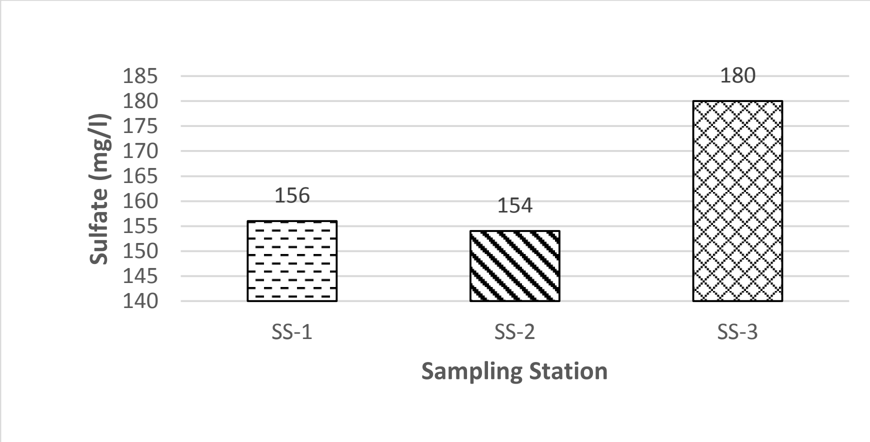

Figure 4.12: Sulfate concentration at various sampling stations

4.2.13 Iron

Excessive iron might injure carbon cycle and health of living creatures through it is essential for nitrogen binding and nitrate reduction in wastewater. Figure 4.13 shows the iron concentration present in the wastewater of Khulna Municipality. Significant amount of iron was observed in the wastewater under study. The iron concentration in the raw wastewater varied from 0.98 mg/l to 1.2 mg/l.

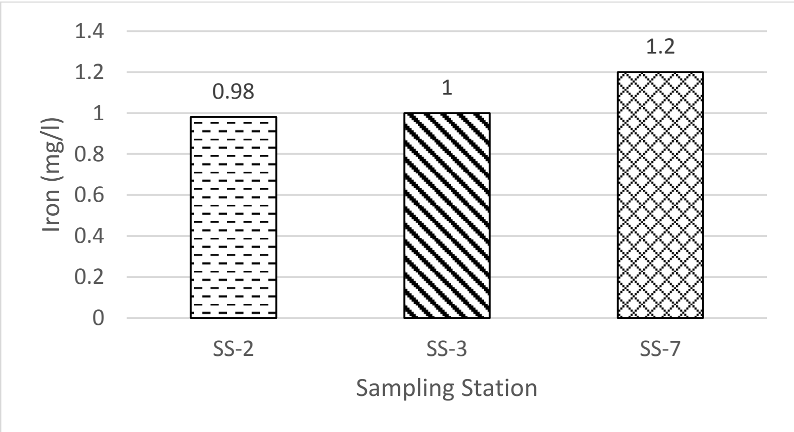

Figure 4.13: Iron concentration at different sampling stations

4.2.14 Electrical Conductivity (EC)

The EC is the capacity of water to conduct current, which is caused by the presence of salts, acids and bases, called electrolytes, capable of producing cations and anions (Goel, 2006). The conductivity increases with the increase of ions. It is also effectively a surrogate for total dissolved solids (TDS) and is important for irrigation because it is a measure of the salinity of the water. Salinity restricts the availability of water to plants by lowering the total water potential in the soil. Salinity also has an impact on crop physiology and yield with visible injury occurring at high salinity level.

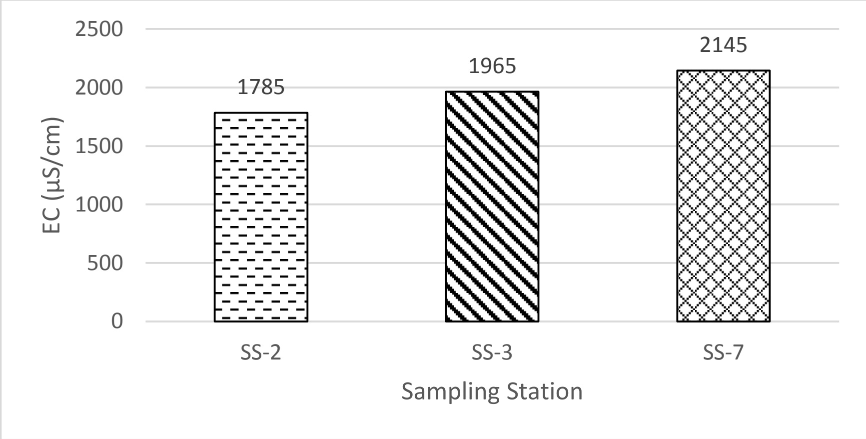

Figure 4.14: Electrical conductivity at different sampling stations

In the present study, the conductivity of wastewater samples varied from 1785 µS/cm to 2145 µS/cm in successive sampling station. The minimum value was observed SS-1: Goalkhali, Bashtuhara colony whereas the maximum value was found at SS-3: Gallamari area. It is clearly observed that the conductivity value increased first from upstream to downstream of Mayur river. This might be due to the variable mixing of ion producing electrolytes in wastewater from the background concentrations present in supplied salts dominated water in the Khulna City, the dilution caused by direct runoff (atmospheric precipitation) and by wastewaters from less solute laden drains, the higher evaporation in summer, etc. (Kazmi, 2000).

4.2.15 Total Coliform and E. coli

Mayur river is mostly polluted by faecal pollution, which may introduce a variety of intestinal pathogens, e.g. bacterial, viral or parasitic. It can be seen from the Figure 4.15 that, the water contains total coliform (TC) ranging from 65800 N/100ml to 98050 N/100ml which is approximately 12 to 98 times the safe permissible limit for irrigation purpose (1000 N/100ml), because it reduce the fertilization capacity of soil and cause various water diseases such as typhoid fever, bacillary dysentery and cholera.

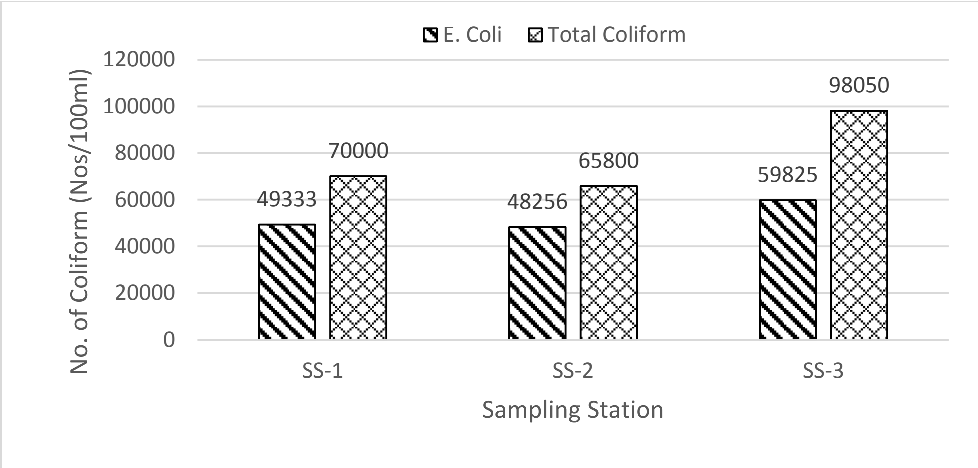

Figure 4.15: No. of Total coliform and E. coli at different sampling stations

Same conditions is seen for faecal coliform (E. coli), which is shown in Figure 4.15. Water disposed from all drain outlets contains E. coli ranges from 49333 No/100ml to 59825 N/100ml, whereas the permissible limit is only 200 N/100ml. So, the wastewater need to be treated before disposal.

4.3 Summary

The results of different drain outlet raw wastewater samples manifested the huge amount of polluting agents that are dumped every day in the water bodies without any treatments which was alarming for the ecology of inland surface water. The chloride is the most dominant anion in wastewater generated in Khulna city irrespective of sampling station. The least dominant one is iron in the study area. It is evident that the contribution of chloride, sulfate, nitrate and phosphate in wastewater composition in the study area from Goalkhali to Gallamari the downstream of Mayur River. The Physico-chemical analysis of raw drainage wastewater were presented in Table 1 (Appendix A), that shows a wide range of variation of drainage wastewater quality from different sampling station of drain outlets of Khulna city corporation under study for the development of a laboratory scale drainage wastewater treatment plant.

Chapter V

Performance study of Developed Laboratory Scale Wastewater Treatment Plant

This chapter covers the effluents quality analysis of developed laboratory scale treatment plant, modification of developed laboratory scale treatment plant, evaluation for irrigation uses, evaluation for discharging into surface water bodies and reliability on the developed wastewater treatment plant.

5.1 Treatment Efficiency of Developed Laboratory Scale Treatment Plant

With rapid development of cities and domestic water supply, quantity of drainage wastewater generation is increasing in the same proportion. Treatment of wastewater and its reuse is the need of the hour. One of the main reasons of pollution of surface water in our country is discharge of untreated wastewater. Thus, in this study, an attempt has been made to treat drainage wastewater and put it back for reuse. The wastewater has been treated by a treatment unit consists in combination with primary sedimentation tank, aeration tank and tertiary treatments. Three test were made in the month of December, January and April. The chemical and biological characteristics of drainage wastewater changed a lot after treatment in the developed laboratory scale treatment plant. Results from the three raw wastewater samples and effluents are illustrated in graphical representation in under mentioned paragraphs.

5.1.1 Hydrogen Ion Concentration (pH)

The standard value of pH for good environmental balance ranges from 6.0 to 9.0. The bioactivity in wastewater treatment processes trends to lower the the pH value. This happens because CO_2 is released in the decomposition process of organic matter that reacts with water to create carbonic acid. But, for sample 1 and sample 3 of drainage wastewater, the value of pH increased after the treatment and the values remain within the standard limit. Increase of pH after treatment may result of using alum for chemical precipitation and brick khoa &

sand in the filtration. The pH of effluents were found ranges from 7.37 to 7.99 shown in Figure 5.1.

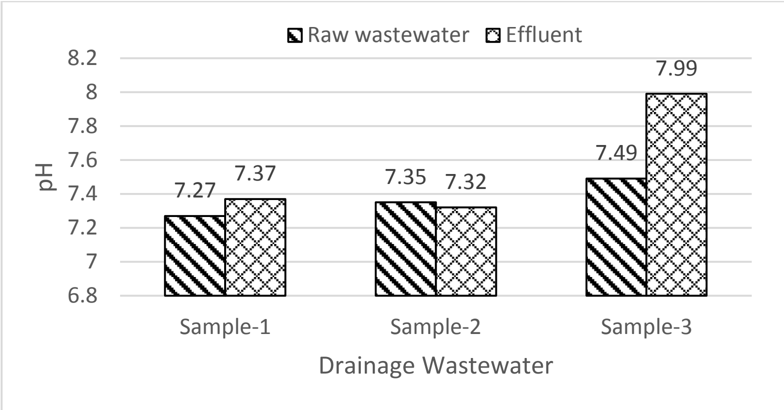

Figure 5.1: pH value of raw and treated wastewater

5.1.2 Dissolved Oxygen (DO)

Dissolved oxygen is one of the major quality parameter of wastewater for the existence of aquatic living species. After treatment of raw water samples it is shown that the DO value increase significantly. The raw water samples DO values varied from 0.69 mg/l to 0.79 mg/l. But after treatment DO rises up to 8.79 mg/l (Figure 5.2). The values of DO were increasing which indicate that the oxygen level was increased in treated wastewater samples. So the treated wastewater can be discharged into the natural water bodies or used for irrigation purposes.

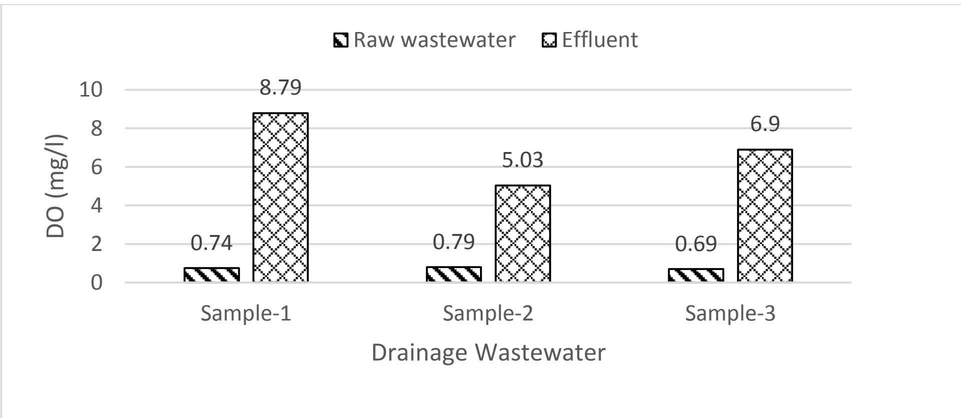

Figure 5.2: Dissolved oxygen concentration of raw and treated wastewater

5.1.3 Biochemical Oxygen Demand (BOD_5)

The most significant water quality parameter is BOD of wastewater when evaluating the effluent quality of wastewater treatment plant. Figure 5.3 illustrates after treatment of drainage wastewater the BOD of all samples has been decreased significantly. The effluent BOD values were recorded ranges from 40 to 115 mg/l whereas the standard limit of BOD_5 for disposal to inland water bodies is 50 mg/l (ECR, 1997). In case of sample-2 and sample-3 the BOD_5 values of effluent higher than the standard limit (Figure 5.3). Though the value of BOD_5 of treated wastewater was exceeded the standard limit but the removal efficiencies were 32%, 53% and 49% for sample-1, sample-2 and sample-respectively. For getting better effluent quality the raw wastewater might again run through another modified treatment unit or some additional treatment process might be adopted before disposal to inland water bodies.

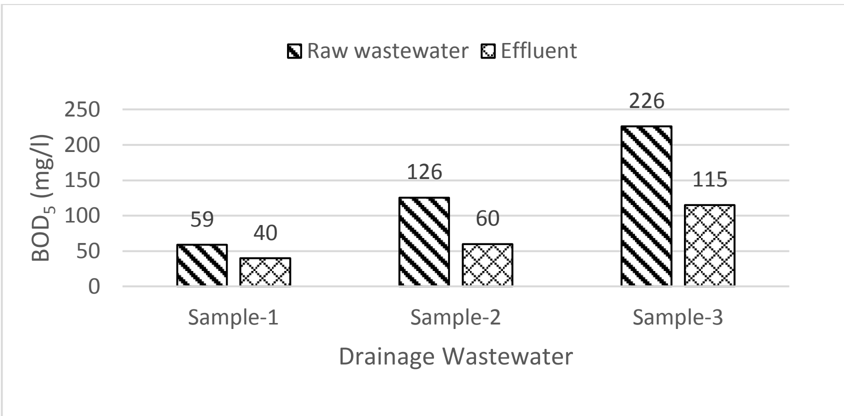

Figure 5.3: BOD level of raw and treated wastewater

5.1.4 Chemical Oxygen Demand (COD)

Figure 5.4 illustrates the variation of COD concentration of raw wastewater and effluents and shows a noticeable reduction of COD values. The range of treated wastewater COD is 160 to 256 mg/l whereas the raw water COD was 320 to 435 mg/l. The standard value of COD for industrial wastewater for disposal into surface water bodies is 200 mg/l (ECR, 1997) which was not satisfied by sample-3. So, the wastewater must need further treatment or the treatment system need to be modified for getting better COD removal. The mean removal efficiency of developed laboratory scale treatment plant was 48%.

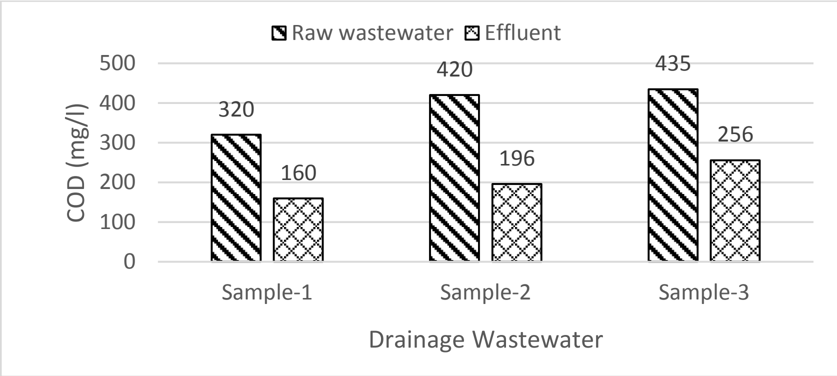

Figure 5.4: COD level of raw and treated wastewater

5.1.5 Total Dissolved Solids (TDS)

Figure 5.5 illustrates the variation of TDS of raw wastewater samples and treated water was high. After treatment, the dissolved solids content did not decrease much except sample-3. About 24 to 40% TDS reduction was obtained from the treatment. This is a clear indication for a medication of existing treatment units. The presence of TDS in effluents ranges from 1356 to 1500 mg/l which satisfy the FAO (1985) irrigation standard. So, the water can be used for irrigation purposes.

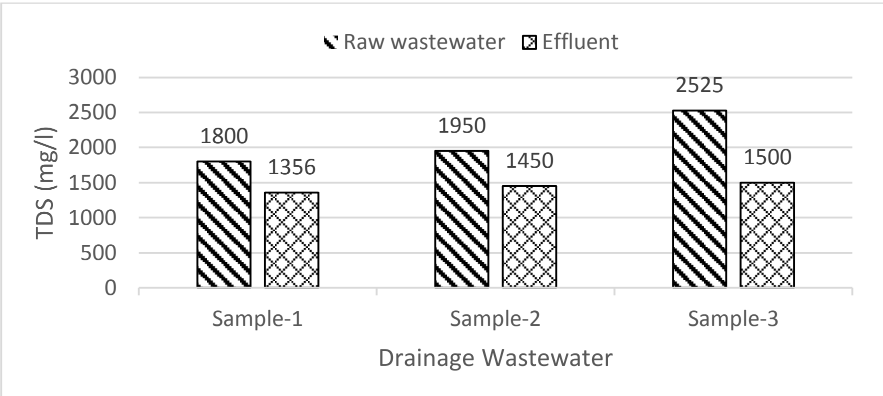

Figure 5.5: TDS concentration of raw and treated wastewater

5.1.6 Total Suspended Solids (TSS)

Suspended solids are also clogged into the pore spaces between the aggregates. It is seen from the Figure 5.6 that, there is about 60 to 63% removal of TSS due to the application of developed laboratory scale wastewater treatment plant. According to ECR (1997), the suspended solids should not exceed 150 mg/l. After treatment TSS values of all sample lies between 48 mg/l to 85 mg/l which fulfilled the ECR, 97 standard limit.

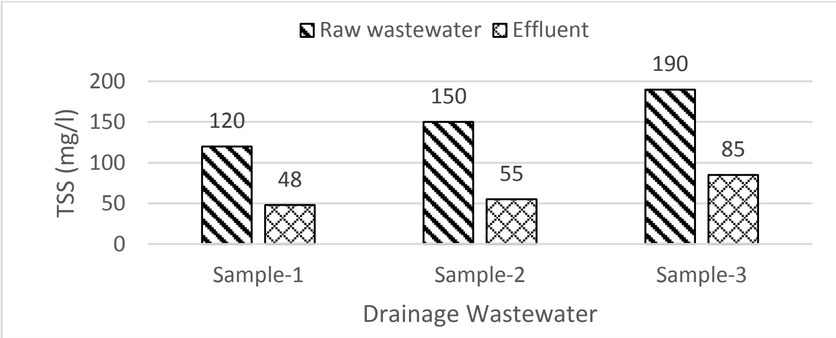

Figure 5.6: TSS concentration of raw and treated wastewater

According to Figure 5.5 and 5.6 the TDS and TSS reduction rate were calculated 24.7 % and 60% respectively. Thus, the TDS in treated water had the same pattern like total solids. The TSS decreased remarkably in case of sample 3 after treatment showing a reasonable sludge settlement.

5.1.7 Hardness (as $CaCO_3$)

Hardness is the representation of presence of Ca and Mg ion in wastewater. Raw wastewater and treated water hardness value lies between the safe limit of use in purposes. The treated water hardness value was reported from 76 mg/l to 134 mg/l as $CaCO_3$ (Figure 5.8). Very few percent removal efficiency was calculated and the reduction efficiencies varied from 5% to 35%. So, this is a clear indication that the treatment units need to be modified for better treatment.

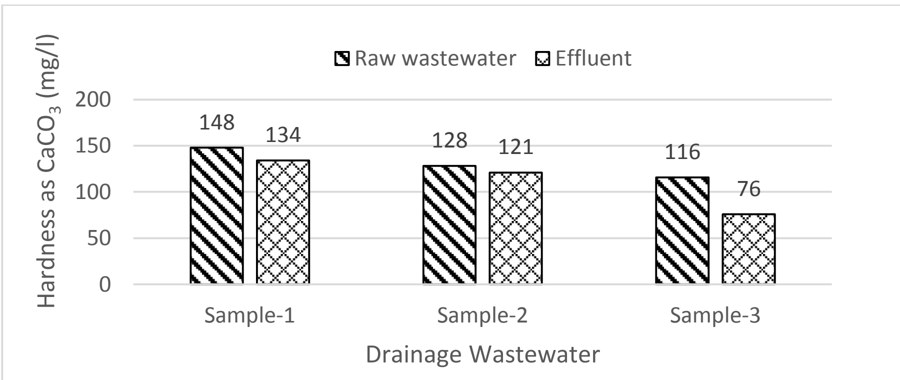

Figure 5.7: Hardness value of raw and treated wastewater

5.1.8 Alkalinity (as $CaCO_3$)

Alkalinity is the key to steady-state operations in biological treatment specially in activated sludge processing. Notification of the wastewater is the single largest factor which leads to the consumption of alkalinity, the pH of the system gets reduced. But, in drainage wastewater, the pH did not reduce rather in all cases it increased a little and remained steady at an alkaline level and the alkalinity reduction pattern was not similar for three samples. Figure 5.8 presents a small change in alkalinity. Maximum 40% alkalinity reduction was recorded for sample-3 but a few decrease was observed for sample-2. The alkalinity of treated water were found 185 to 353 mg/l as $CaCO_3$.

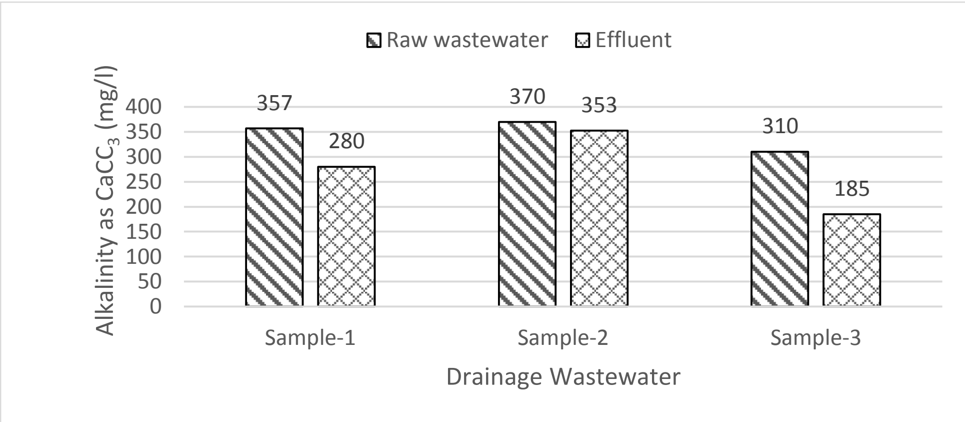

Figure 5.8: Alkalinity level of raw and treated wastewater

5.1.9 Chloride

The chloride is one of the most important and dominant water quality parameter for agricultural crop production. Figure 5.9 shows the raw wastewater chloride content ranges from 1250 mg/l to 1570 mg/l, on the other hand for effluents, the chloride content value lies between 390 to 600 mg/l. About 54% to 64% chloride reduction were calculated after treatment of wastewater samples. This indicates the decrease of chloride concentration due the filtration of granular filter media the end of treatment process.

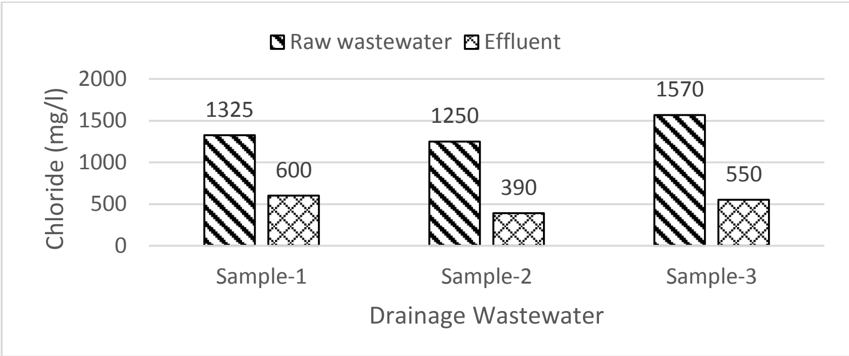

Figure 5.9: Chloride concentration of raw and treated wastewater

5.1.10 Nitrate

Nitrate as nutrient is an essential component for maximum crop yield. But in wastewater treatment process incorporated in this study decrease the nitrate concentration in effluents and it ranges from 0.2 to 1.1 mg/l (Figure 5.10) which satisfies the standard limit for nitrate for disposal surface water is 10 mg/l (ECR, 1997). For sample-2 maximum nitrate reduction was calculated and the value was about 98%. Discharging nitrogen to surface water bodies is undesirable for several reasons; it can lead to eutrophication, it can be toxic to fish and other aquatic life, nitrate and nitrite may reduce quality of drinking resources, and ammonia may deplete oxygen levels through nitrification (USEPA, 2000).

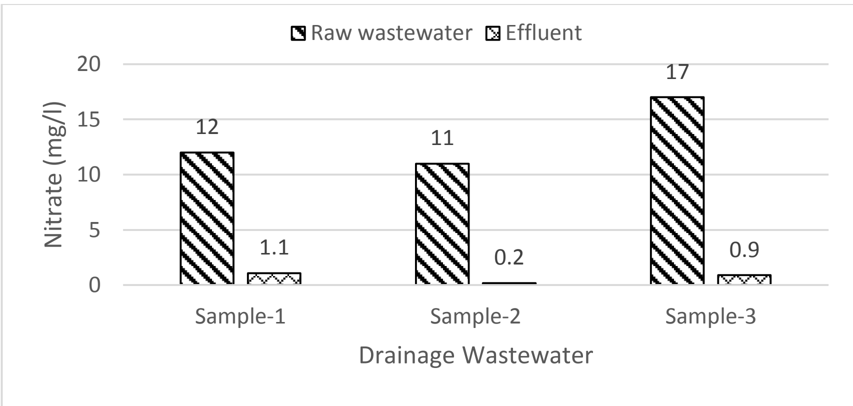

Figure 5.10: Nitrate concentration of raw and treated wastewater

5.1.11 Phosphate

Phosphate also an important for wastewater use in agricultural purposes. Phosphate is dropped significantly throughout the process as shown in Figure 5.11. The standard limiting value for phosphate for safe disposal as sewage into inland surface water bodies is 35 mg/l

(ECR, 1997). The effluents phosphate concentration were recorded from 0.47 to 5.26 mg/l. As phosphate decreases along with the reduction of nitrates in open water bodies, the growth of aquatic plants is not encouraged and algal blooms can occur which eventually will increase dissolved oxygen levels. In this study both nitrate and phosphate were decreased after treatment. About 86% and 97% removal of phosphate were recorded for sample-2 and sample-3. So, the developed treatment method alone is capable to meet the standard requirements for safe disposal of effluents into surface water bodies. In this treatment, phosphate is mainly removed by granular filtration. The media need to be selected specifically for phosphate removal in order to achieve high removal rate.

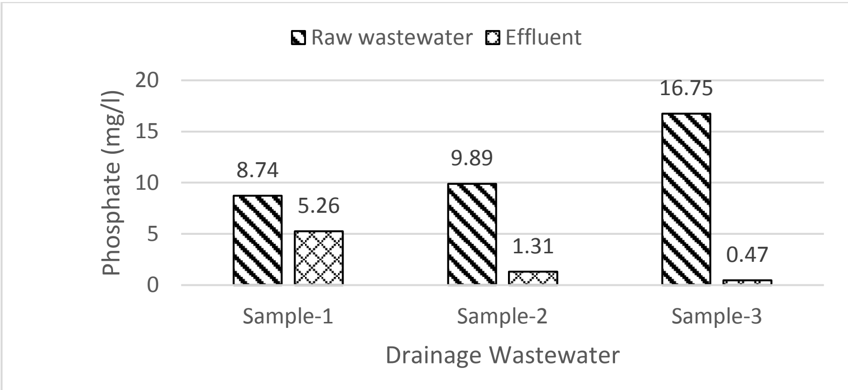

Figure 5.11: Phosphate concentration of raw and treated wastewater

5.1.12 Sulfate

Sulfate accumulation in the wastewater was occurred mainly from domestic and industrial water use. Figure 5.12 shows the variation of reduction of sulfate in treated water samples and it ranges from 9.3 to 11.8 mg/l whereas in raw wastewater high sulfate concentration were measured and it ranges from 154 mg/l to 180 mg/l. More than 92% sulfate reduction was obtained after treatment of drainage wastewater by the developed treatment plant.

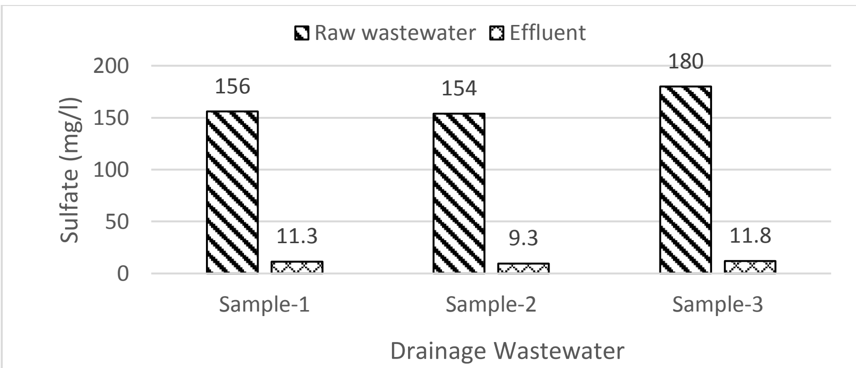

Figure 5.12: Sulfate concentration of raw and treated wastewater

5.1.13 Iron

Excessive iron might injure carbon cycle and health of living creatures though it is essential for nitrogen binding and nitrate reduction in wastewater. Analyzing the drainage wastewater samples, it was obvious that, all three samples contained small amount of iron as the wastewater generated from only residential area. According to ECR (1997), the iron content in wastewater effluent for disposal into open water bodies should not exceed 2 mg/l and all three sample fulfill the requirement. More than 98% iron removal was observed after the treatment of raw wastewater samples. Due to aeration iron transferred into its oxide and removed through filtration applied in this treatment plant.

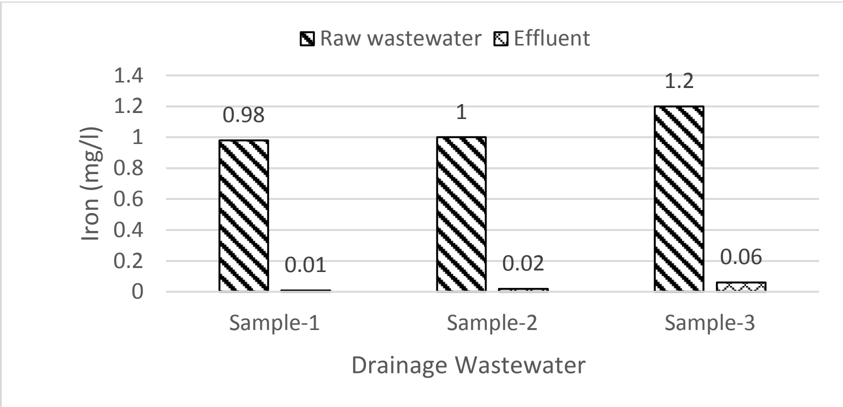

Figure 5.13: Iron concentration of raw and treated wastewater

5.1.14 Electrical Conductivity (EC)

Electrical conductivity is directly related to the total salt concentration. This parameter of wastewater is the representation of flow of current through water presence of inorganic or organic substance. So, the main process that reduces conductivity in wastewater treatment is biological nutrient removal. The raw wastewater samples have EC varied from 1833 µS/cm to 2145 µS/cm, whereas effluents water contains 785 µS/cm to 929 µS/cm. Figure 5.15 shows 57%, 52% and 59% of reduction of electronic conductivity were determined for sample-1, sample-2 and sample-3 respectively which means presence of some soluble matter in effluent water. So, the treatment system must need to update for reduction of electrical conductivity.

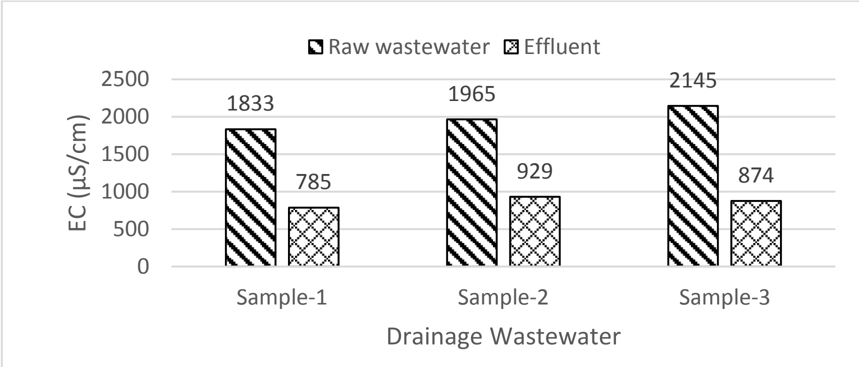

Figure 5.14: EC level of raw and treated wastewater

5.1.15 Total Coliform (TC) and E. coli

One of the most essential quality parameter of wastewater is the number of coliform present in it. Drainage wastewater of Khulna municipality was also contaminated with faeces. By the application of alum and filter media few numbers of coliform were found in the sample-1 but for the treatment of sample-2 and sample-3. Thus, the pathogen removal efficiency achieved after treatment from the developed treatment plant was varied from 88% to 96%. Figure 5.15 shows the variation total coliform before and after the treatment.

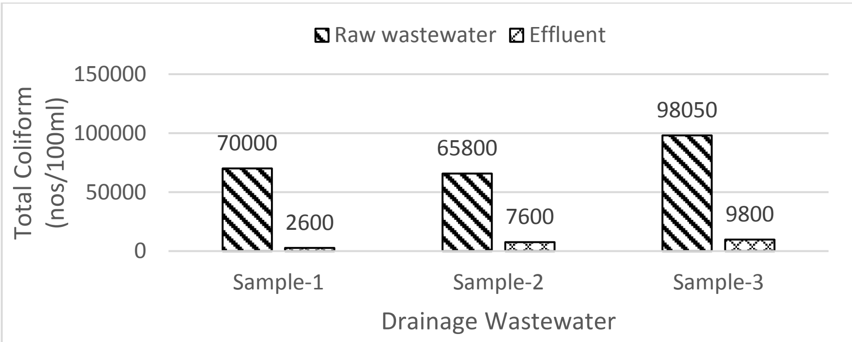

Figure 5.15: No. of total coliform of raw and treated wastewater

As a part of tertiary treatment, the biologically treated wastewater need further treated by chlorination. The average initial E-coliform count was reported as more than 59825 Nos/100 ml reduced to near about 2100 Nos/100 ml (Figure 5.16).

Harper and Sylvia (1924), has studied the Disinfecting Power of Sodium Hypochlorite. They have reported disinfecting coefficient of sodium hypochlorite as 99.2%. Berg *et al*. (1978), reported 99.9 % destroyed of indigenous fecal coliforms, total coliforms, and fecal streptococci in primary sewage effluent by combined chlorine in their paper “Validity of fecal coliforms, total coliforms, and fecal streptococci as indicators of viruses in chlorinated primary sewage effluents.

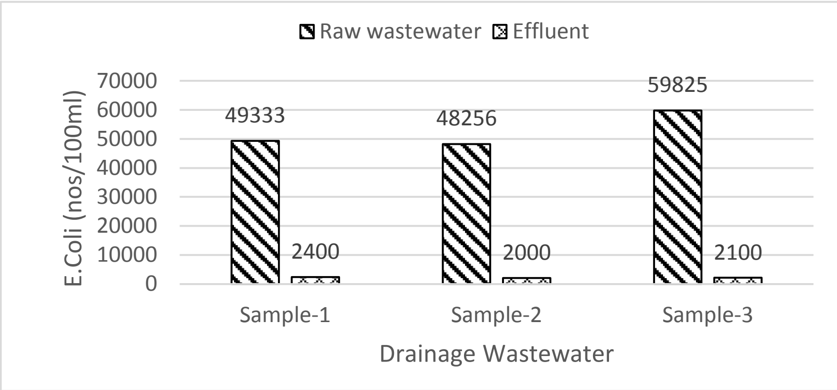

Figure 5.16: No. of E. coli of raw and treated wastewater

5.1.16 Summary

Performance of developed laboratory scale treatment plant varied depending on the parameters for which the plant was designed. Few of them improved and satisfied the standard limit whereas the others did not. The removal of BOD_5, COD and TDS were not quite good because only aeration alone is not sufficient for their reduction which leads to further modification of developed treatment plant. During aeration, flow of air with mechanical device were made through 24 hours. Maximum 53% COD and 52% BOD_5 reduction were obtained for 24 hours aeration. Similarly, 24.7% and 60.0% reduction were attained for TDS and TSS respectively from 24 hours of aeration process.

In this research work tertiary treatment was adopted to remove nutrients from wastewater effluents as well as for disinfection purposes. Granular filtration (Roughing and Sand) was applied to reduce nitrogen concentration and chemical precipitation was done by applying optimum alum dose for phosphorous removal. By the application of only alum and granular filter media for fecal coli-form and total coli-form 90% and 96 % of reduction were calculated respectively. Phosphate and nitrate reduction rate were found 97% and 98.0 % respectively after treatment with developed laboratory scale treatment plant.

From above discussion, it can be conclude that the developed laboratory-scale treatment plant need to be modified for getting good quality of BOD_5, COD and TDS reduction efficiency. Introducing a new modification unit may be the best accomplishment to elevate the quality of drainage wastewater.

5.2 Modification of Developed Laboratory Scale Treatment Plant

The developed laboratory scale treatment plant could not remove all harmful contaminants from the wastewater as per standard requirement of ECR (1997). Thus, an improved treatment method was required prior to disposal of the effluent. There are many different treatment process available and their suitability is a function of source water quality, level of operation skills and maintenance. Analyzing the results of treatment stated in previous paragraphs, addition of a biological removal treatment process would be the desired solution here which will lead to multiple barrier treatment system.

5.2.1 Introduction Modified Laboratory Scale Treatment Plant

Drainage wastewater treatment process included firstly the physical removal of contaminants through screening and settling followed by biological removal of microorganisms through activated sludge process. Due to poor quality of effluents, the developed treatment plant was modified by activated sludge processing following filtration. The activated sludge process unit consists of high quality plastic container as primary clarifier, the reactor for aeration chamber with an air blower, the secondary clarifier with a pump for returning sludge. Three, five and seven days mean cell residence time were considered to active the microorganism in activated sludge process unit. Then the effluents were passed through granular filter media made from stone chips and sand (Figure 5.17). The extended filter media was constructed with locally available stone chips bed at the bottom of the container along with a sand bed on its top. Both granular material were well cleaned before use and formed a uniform thick layer of 4 inch height each. At the bottom of filter chamber was kept blank of 2 inch for collection of sludge. The effluent from secondary clarifier first traveled through the stone chips bed followed by sand bed forming an up-flow of wastewater. The detail calculation for the activated sludge processing of this modified laboratory scale treatment plant is attached in ‘Appendix B’ at the end of the dissertation.

5.2.2 Treatment Mechanism through Modified Laboratory Scale Treatment Plant

The influent was passed through the screen (5mm x 5mm) to strain off any coarse solids into the primary clarifier, which was also worked as a grit removal chamber. Then it was discharged to reactor, the aeration chamber with a flow rate of 10 ml/min. The hydraulic retention time for this developed treatment unit was calculated as 4 hours in the aeration tank. The wastewater was then transferred to the secondary clarifier for bacterial floc formation and settlement as active sludge. From the secondary clarifier. A return sludge line was linked through a pump which returned 5 ml/min. of activated sludge to reactor. A balance was made in the wastewater flow rate between the reactor and secondary clarifier. Another sludge line was also formed in secondary clarifier to discard fixed amount of wastewater with flow rate 0.05 ml/min. to maintain the activated sludge process properly. After the continuation of all these steps, finally the treated wastewater was passed through filter media. Following activated sludge processing, in slow sand filter, the operating filtration rate is considered to be varied in the range of 0.1-0.3 $m^3/m^2/hr$. the top layer of the sand become biologically active by the establishment of a microbial community on the top layer of the sand substrate. After treatment with activated sludge process, the effluent is needed to pass slowly through the coarse stone media and sand filter to improve the water quality. Instead of following the traditional down-flow method, the flow path was made with up-ward through stone chips bed layer and then sand bed and finally the effluents were disposed off through an outlet arrangement. This approach is recommended for longer filter run with less operation and maintenance requirements (Zouboulisa et al., 2007).

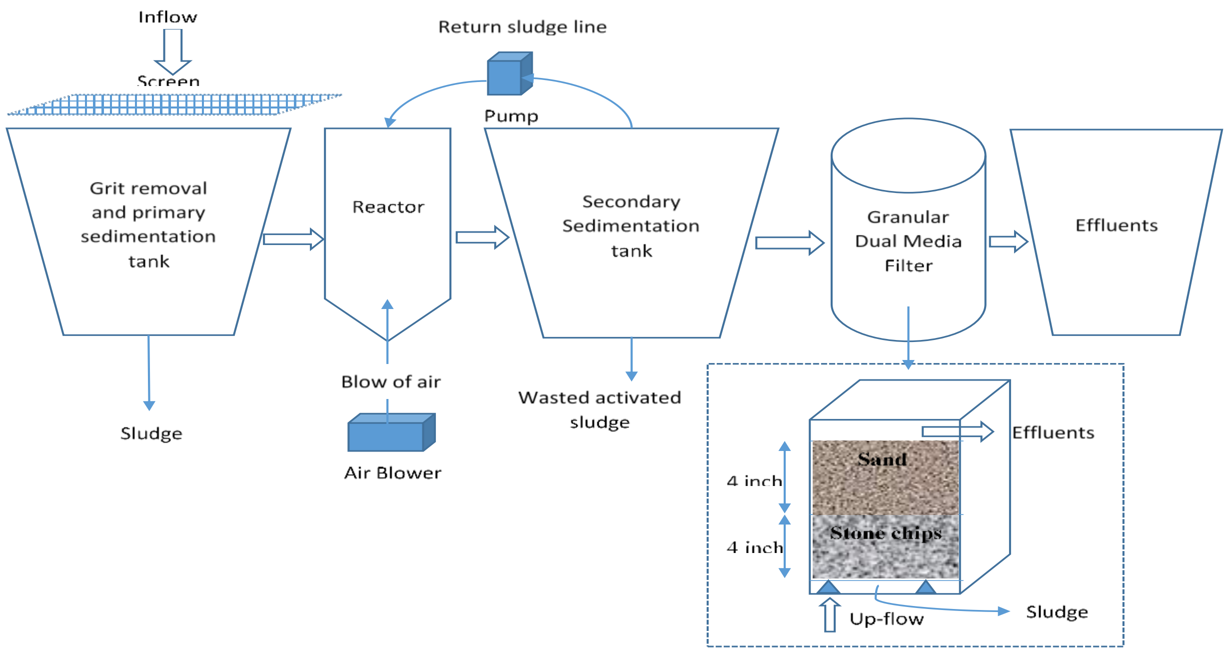

Figure 5.17 (a): Flow diagram of modified treatment plant

Figure 5.17 (b): Laboratory setup of modified treatment plant for municipal wastewater

5.2.3 Performance of Modified Laboratory Scale Treatment Plant

The performance of the modified treatment plant has been closely monitored to determine the treatment efficiency of this system. The evaluation of performance of activated sludge unit following filtration for wastewater treatment was done from the characteristics of wastewater flowing in and out of the developed treatment unit. Results from the raw water and treated water samples were illustrated in graphical representation. Table 3 (Appendix A) shows that the actual performance of biological treatment following filtration of municipal wastewater of Khulna municipality.

5.2.1.1 Hydrogen Ion Concentration (pH)

The standard value for good ecological balance was within 6.0 to 9.0. For both raw water and treated water samples the pH value varied from 7.49 to 8.12. When the pH drops below 6.0 or rises above 8.5, microorganism's activity decrease off dramatically. Bioactivity in wastewater treatment processes tends to lower the pH. This happens because of carbon dioxide that is released from the decomposition process reacts with water to create carbonic acid. But in all the cases of municipal wastewater treatment, the values of pH increased after treatment and this may due to application of filter media although the treated values remain within the standard limit. Figure 5.18 shows increase of mean cell residence tine the pH value also increase.

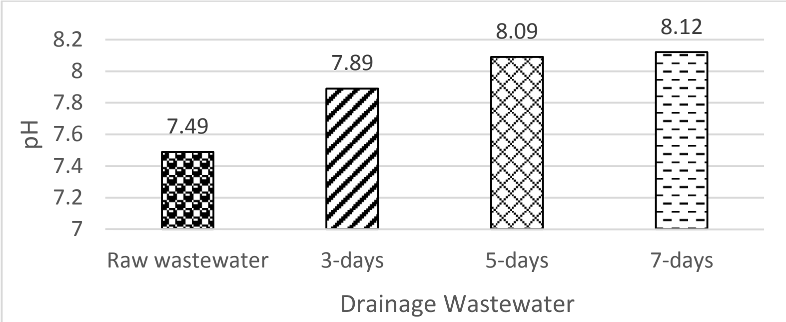

Figure 5.18: Variation of pH level of raw wastewater and effluents

5.2.1.2 Dissolved Oxygen (DO)

Dissolved oxygen is required for the respiration of aerobic microorganisms as well as all other aerobic life forms. The presence of DO in wastewater is desirable because it prevents the formation the formation of noxious odors (Metcalf and Eddy, 1995). The raw wastewater has dissolved oxygen value 0.58 mg/l and after treatment it rises to 7.1 mg/l. More than 91% of DO increases after the treatment of wastewater samples by 3 days activated sludge processing and the final DO value was recorded varied from 6.75 mg/l. Figure 5.19 also shows the variation of DO after treatment through modified treatment plant and for 5 days and 7 days treatment DO level increases 6.82 mg/l and 7.1 mg/l respectively. The values of DO were increasing which indicate that the oxygen level was increased in treated wastewater samples. So, the treated wastewater can be discharged into the natural water bodies or used for irrigation purposes.

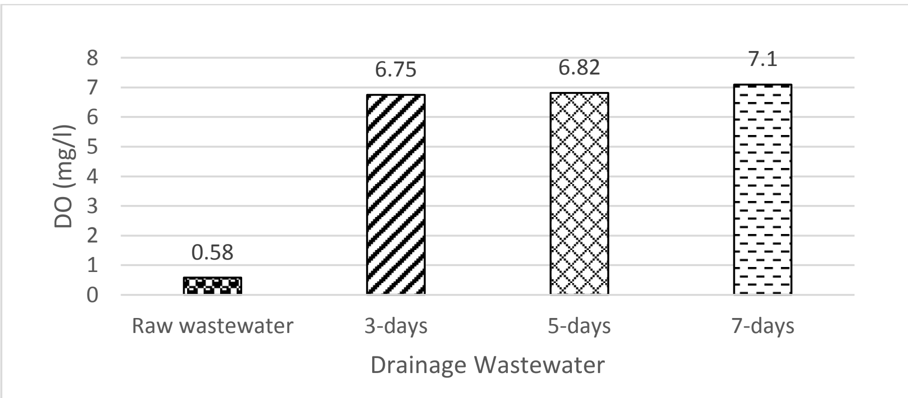

Figure 5.19: Variation of dissolved oxygen level of raw wastewater and effluents

5.2.1.3 Biochemical Oxygen Demand (BOD_5)

The most widely used parameter of organic pollution applied to both wastewater and surface water is the 5-day BOD. The raw wastewater sample has BOD_5 value 352 mg/l which represents some organic content present in the wastewater. After treatment of 3-days, 5-days and 7-days BOD_5 level decrease to 98 mg/l, 1.78 mg/l and 1,38 mg/l respectively which shows for 5 and 7 days BOD_5 values fulfill the ECR (1997) standard limit 50 mg/l but 3 days did not in the range. From the analysis of experimental result of 3-days it is found that moderate concentration of organic matter is skillfully decomposed when wastewater passed through the outlet of secondary settling tank.

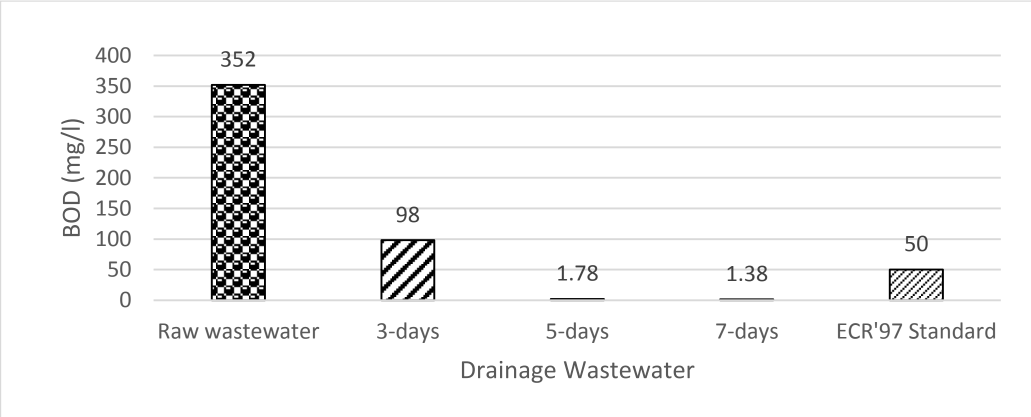

Figure 5.20: Variation of BOD_5 level of raw wastewater and effluents

5.2.1.4 Chemical Oxygen Demand (COD)

The COD test is used to measure the organic matter in industrial and municipal wastewater that contain compounds that are toxic to biological life. COD measurements can be used to good advantage for treatment-plant control and operation. The COD value of raw wastewater was 320 mg/l whereas after of 3-days, 5-days and 7-days the values were measured 192 mg/l, 96 mg/l and 32 mg/l respectively. The standard value of COD for industrial wastewater for disposal into surface water bodies is 200 mg/l (ECR, 97) which was fulfilled in all three cases. Figure 5.21 represents about 40%, 70% and 90% removal efficiency were found from biological treatment of 3-days, 5-days and 7-days respectively.

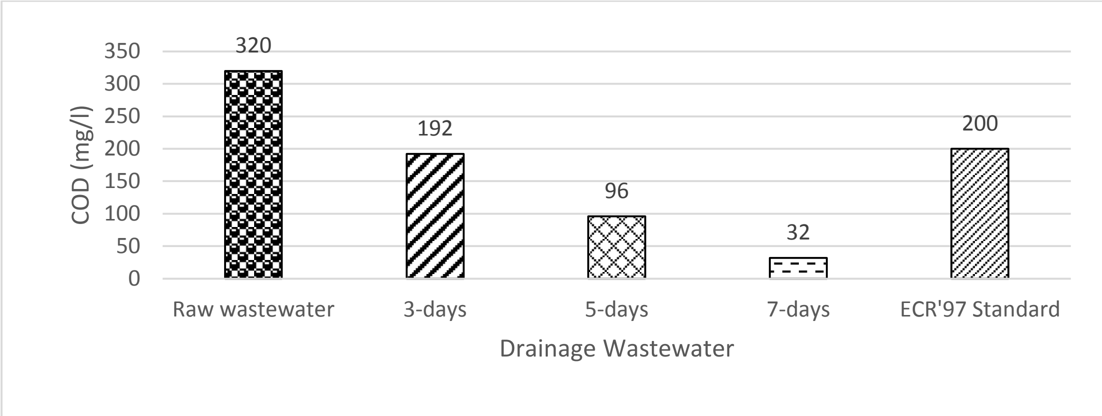

Figure 5.21: Variation of COD level of raw wastewater and effluents

In a similar study, Jungle *et al.* (2009), has studied the performance of activated sludge process in treating wastewater from food industry. In their paper, "aerobic treatment of wastewater generated from food industry by activated sludge process" they have reported COD reduction of 72%. Ghangrekar and Kahalekar (2003), has explained the suitability of Sand filter in removal of COD from anaerobically treated waste water. In his paper Performance and cost efficacy of Two stage Anaerobic Sewage treatment reported 60 -70 % of COD removal by sand filter.

5.2.1.5 Total Dissolved Solids (TDS)

TDS is important to be considered in thecalculation of irrigation water quality, because many of the toxic solid materials may be imbedded in the wastewater, which may cause harm to the plants (Matthess, 1982). Figure 5.22 illustrates the variation of removal efficiency of TDS before and after the treatment. During monitoring period, the final TDS values reported after the treatment were 1667 mg/l, 705 mg/l and 590 mg/l for 3-days, 5-days and 7-days respectively which shows a positive trend of treatment of wastewater by biological system, whereas for raw wastewater the value was 2920 mg/l. Thus, it can be seen that the average effluent concentrations were below the ECR (1997) standard limit (2100 mg/l).

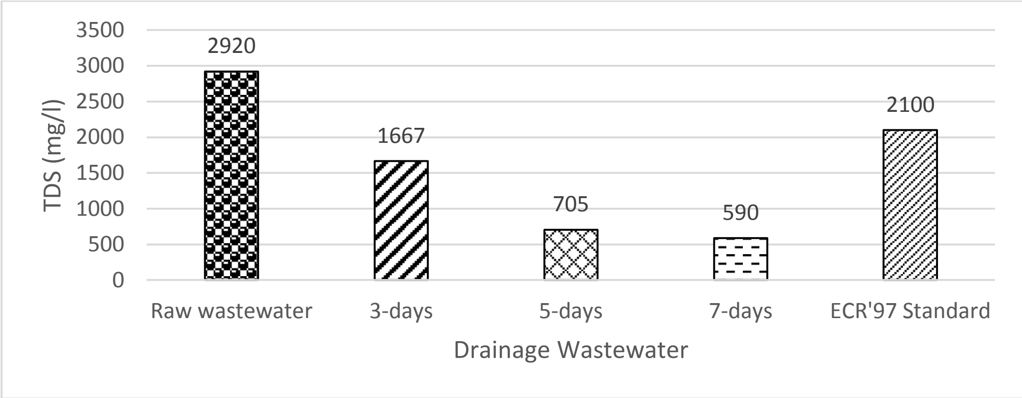

Figure 5.22: Variation of TDS concentration of raw wastewater and effluents

5.2.1.6 Total Suspended Solids (TSS)

Suspended solids refers to small solid particles which remain in suspension in water as a colloid or due to the motion of the water. It is used as one indicator of water quality. The raw wastewater sample has TSS concentration 320 mg/l. But, after treatment TSS level in the final effluents decreased to 95 mg/l, 45 mg/l and 35 mg/l for 3-days, 5-days and 7-days respectively. The standard limit of TSS concentration for disposal into inland water bodies is 150 mg/l (ECR, 1997). Thus, from figure 5.23 it shows that after treatment the TSS concentration of effluents lie in the range of standard limit.

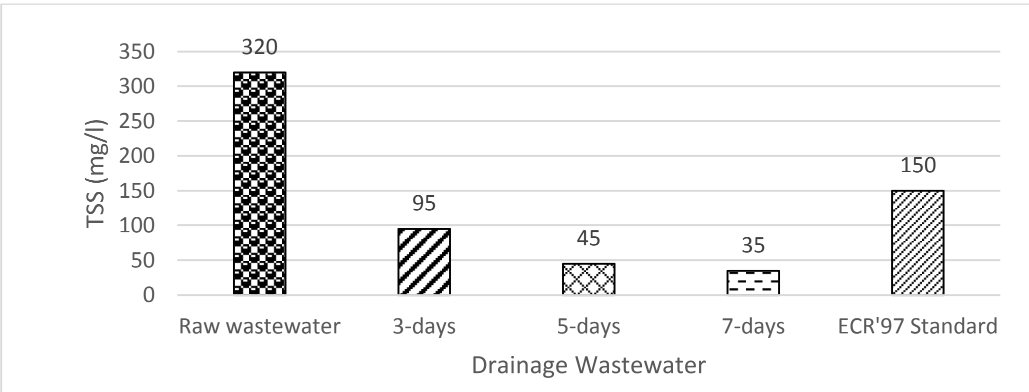

Figure 5.23: Variation of TSS concentration of raw wastewater and effluents

Saleem (2007), in his paper, Pharmaceutical Wastewater Treatment, has reported initial TSS concentration of Pharmaceutical wastewater as 880 mg/L. After coagulation and flocculation by alum, the TSS was reported as 185 mg/L. Finally, after activated carbon treatment, the TSS has been reported as low as 33 mg/L. Chatterjee *et al*. (2003), In the proceedings of 8th International conference on Water Conservation and Reuse of Wastewater held at Mumbai, in their paper Sewage Reuse – A Case Study has reported TSS removal from 150 mg/l to 10 mg/l by dual media filtration.

5.2.2 Summary

Along with solids removal, COD and BOD removal were also reported .The BOD and COD reduction were achieved by activated sludge processing and filtration more than 99% & 90% for 5-days and 7-days. This was mainly due to removal of TDS concentration which was otherwise contributing to total COD. From the above discussion, it can be concluded that with the increase of mean cell residence time the removal efficiency increase. The Table 3 (Appendix A) presenting the results of using modified treatment plant is indicating a positive trend and all the parameters are within standard limit. For using activated sludge process the amount of solids were reduced which served positively for the granular media filtration system longer run of operation and maintenance. The final parameters achieved after treatment shows that the effluent can be reused for cooling tower water make up, gardening, irrigation, toilet flushing, road washing, green belt /landscape development etc. Based on the finding of this research paper, commercial scale wastewater treatment plant can be installed as per treatment scheme shown in Figure 5.17 (a) and the treated wastewater can be put to reuse. This will not only reduce the pollution load on receiving water body but will also save a huge quantum of water , which will be a concrete step towards water conservation.

5.3 Comparison between Developed Treatment Plant and Modified Treatment Plant

Wastewater needs to treatment prior reuse or disposal. To achieve a better quality of effluents a laboratory scale treatment plant was developed. But, after performance study, it was showed that the developed treatment plant produce low quality of effluents. Considering this phenomenon, modification was done for the developed laboratory scale treatment plant. The results of removal efficiencies are tabulated in Table 5.1.

From the Table 5.1, it is seen that, 49% BOD reduction was observed for developed laboratory scale treatment plant but for modified treatment plant the reduction efficiencies were 72%, 99% and 99% for 3-days, 5-days and 7-days respectively which also satisfy the ECR (1997) standard limit. Similarly for COD and TDS the reduction efficiencies were calculated 53% and 40% for primarily developed laboratory scale treatment plant, respectively.

Table 5.1: Comparison of removal efficiency between developed and modified treatment plant

Water Quality Parameter	Developed Laboratory Scale Treatment Plant (% Reduction)	Modified Laboratory Scale Treatment Plant (% Reduction)		
		3-days	5-days	7-days
BOD_5	49	72	99	99
COD	53	40	70	90
TDS	40	43	76	80
TSS	60	70	86	89

On the other hand, 40%, 70% and 90% COD and 43%, 76% and 80% TDS reduction efficiencies were achieved from modified treatment plant for 3-days, 5-days and 7-days respectively. This shows a positive trend of treatment efficiency of the wastewater treatment by the modified laboratory scale treatment plant. A huge change was noticed is case of solids after treatment in modified treatment plant specially, in TSS removal. In case of developed treatment plant the TSS removal efficiency was 60% whereas for modified it rises to 89% for 7-days treatment. After treatment by modified unit, the value of pH increase but remain in the standard limit. DO level of the effluent also rises to 7.1 mg/l for modified treatment plant that shows a significant achievement of wastewater treatment for the existence of aquatic life. So, the modified laboratory scale treatment plant is more efficient than developed treatment plant.

5.5 Evaluation for Agricultural Use

Wastewater is gaining popularity as a source of irrigation water in different countries around the world. The treated wastewater quality has been studied by taking samples and analyzing them for their suitability to be used for irrigation. The quality parameters for these samples were tested and the results are shown in Table 5.2

Table 5.2: Comparison of effluents water quality with FAO (1985) irrigation standards

Sl. No.	Parameter	Unit	FAO (1985) Irrigation Standard	Effluent (7-days)
01.	pH	-	6.5-8.4	8.12
02.	BOD_5	mg/l	<100	1.38
03.	COD	mg/l	-	32
04.	TDS	mg/l	450-2000	590

(Source: Muthukumaran and Ambujam, 2003)

From the above Table 5.2, it could be observed that the pH in the treated effluent water is meeting the FAO irrigation water quality standards (6.5 – 8.4) and the TDS after the treatment is lying in slight to moderate limits (450 – 2000 mg/l). The BOD in the inlet is high as of the organic content in the city wastewater is usually high. After biological treatment for 7 days in the activated sludge processing unit following filtration, it is reduced drastically to 1.38 mg/l which satisfies FAO water quality standards that is highly suitable for irrigation. For coliform, the value obtained after treatment without chlorination does not satisfy the FAO irrigation water quality standards (less than 1000). If chlorination will incorporate with the treatment process, the quality parameter for coliform would be satisfy the FAO irrigation water quality standards.

Table 5.3: Water quality classes of drainage wastewater for irrigation

Sl. No.	Parameter	Rate of Hazard	Water Class	Effluent water
01.	pH	6.5-8.4	No problem	8.12
		5.1-6.4 and 8.5-9.5	Moderate	
		0-5.0 and 9.5+	Severe	
02.	Alkalinity (mg/l)	0-60	Very low	
		60-150	Moderately low	
		150-200	Moderately high	185
		200 to 240+	Very high	
03.	Hardness (mg/l) as $CaCO_3$	0-60	Soft	
		60-120	Moderately hard	76
		120-180	Hard	
		>180	Very hard	
04.	Nitrate (mg/l)	<5	No problem	0.2
		5-30	Moderate	
		>30	Severe	
05	TDS (mg/l)	<450	Good	
		450-2000	Permissible	590
		>2000	Unsuitable	
06.	EC (µS/cm)	<250	Excellent	
		250-750	Good	
		750-2250	Permissible	785
		>2250	Unsuitable	

(Source: Rahman et al. 2014)

Similar to other irrigation waters, drainage wastewater contains dissolved minerals. Most of these mineral salts are beneficial for plant growth but in some cases they may be harmful. Therefore, a wastewater quality analysis is essential to prevent irrigation-induced problems.

The treated wastewater pH in each sampling station is found to be the normal range (6.5 to 8.4) for irrigation (Table 5.3).

This indicates that the effluent water is safe for irrigation in western fringe of Khulna city. According to the Bangladesh Irrigation Water Quality Standards (BIWQS) (DoE, 1997), it is also found in the safe limit (6.5-8.5) for irrigation. The alkalinity of effluent water is found to be 'moderately high' which indicated that the wastewater is excess buffering and not suitable for irrigation (Table 5.3). The confusion between high pH and high alkalinity stems from the fact that water is called "alkaline" if its pH is greater than 7, and it is said to have "high alkalinity" if it has a high concentration of bases. High alkaline water usually causes calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution (Bauder et al., 2006). Therefore, effluent water of high alkalinity could intensify sodic soil conditions in rice growing season covering winter and pre-monsoon seasons.

According to the classification of irrigation water based on EC and TDS the effluent water quality of Khulna city fall in 'permissible' category indicating there is no salinity hazard for crop production. Comparing with BIWQS (DoE, 1997). The average effluent water EC in each treatment batch is within the tolerance limit (2250 µS/cm) for irrigation. Generally, the continuous irrigation with water or wastewater of excessive dissolve salts triggers the salinity built-up in the root zone that further increases the osmotic pressure in soil solution and causes a reduction in both rate of water and nutrient absorption by plants, and the soil-water availability (Ayers and Westcot, 1994). The waste water generated in Khulna city is good for irrigation as revealed from the classification based on nitrate (Table 5.3). It may increase in soil and plant productivity in the study area.

5.6 Evaluation for Discharging into Surface Water Bodies

Effluents (treated wastewater) from wastewater treatment plants (WWTP) are widely used in different industries e.g. agriculture, cooling towers and so on, or back directly to the ecosystem through discharging to surface or ground water (Iman, 2010). The discharge of waste water from municipal, industrial, and agricultural areas is an issue of serious concern as it affects river's ecology (Varol et al. 2013). These far and wide usages of treated wastewater compel legislators to set stringent rules and regulations with respect to WWTP effluents. This study reveals that the effluents quality stated in Table 5.4 for discharging into surface water bodies most of the cases satisfies the standards except total coliform. Due to huge pathogenic bacteria, high range of TC value was observed in effluents. To improve the effluents quality some chlorination could be introduce in combination with the designed modified laboratory scale drainage wastewater treatment plant for treating water before discharging into surface water bodies.

Table 5.4: Comparison of effluents water with surface water quality standards

Sl. No.	Parameter	Unit	Bangladesh standard limits for disposal in surface water bodies (ECR'97)	Effluent water
01.	pH	-	6.0-9.0	8.12
02.	BOD_5	mg/l	50	1.38
03.	COD	mg/l	200	32
04.	TDS	mg/l	2100	590
05.	Nitrate	mg/l	250	0.2
06.	Phosphate	mg/l	35	0.47
07.	Total Coliform	nos/100ml	<1000	2600

5.7 Reliability on the Modified Laboratory Scale Wastewater Treatment Plant

Wastewater reclamation and reuse systems should contain both design and operational requirements necessary to ensure reliability of treatment. Reliability features such as alarm systems, standby power supplies, treatment process duplications, emergency storage or disposal of inadequately treated wastewater, monitoring devices, and automatic controllers are important. From a public health standpoint, provisions for adequate and reliable disinfection are the most essential features of the developed wastewater treatment process. Where disinfection is required, several reliability features that were incorporated into the system to ensure uninterrupted chlorine feed. Thus, considering all aspect of wastewater reclamation and reuse, the modified treatment plant would be a reliable option for drainage wastewater treatment for Khulna municipality.

Chapter VI

Conclusions and Recommendations

The chapter covers the overall conclusions of the study and the recommendations for the developed treatment plant of drainage wastewater treatment and for future study.

6.1 General

The wastewater, generated in KCC area, is not totally safe for reuse in agriculture in terms of some physico-chemical characteristics during the dry season. This municipal effluent dominated wastewater flow through the numerous concrete and earthen drains which finally dispose of to the nearby water bodies, like the Mayur river without treatment. As the quality of wastewater is not fully satisfactory, there are occurring pollution problems in river waters, becoming alarming situation in health and sanitation sectors and deteriorating environmental conditions. However, the Mayur river, located at western part of Khulna City, have already become a dumping ground for untreated wastewater coming from municipal area of Khulna.

6.2 Conclusions

Concerning the first objectives, the wastewater characteristics of Khulna municipality were analysed and discussed. According to the concentration of BOD_{5}, COD, TDS and TSS concentration the KCC drainage wastewater was a strong wastewater which was found to be highly polluted with biodegradable organic matter. All above mentioned parameters of drainage wastewater do not satisfy the standards for disposal into inland water bodies according to ECR'97. The pH of the wastewater of Khulna municipality was varied from 7.27 to 7.49 with alkalinity 310 mg/l to 370mg/l. Considering the quality parameters, the wastewater should be treated before disposal.

To fulfil the second objective, a laboratory scale study was conducted to develop a drainage wastewater treatment plant. The treatment units were consisted with primary sedimentation followed by aeration, chemical precipitation and granular media filtration. The mean removal efficiency achieved 49%, 53%, 40%, 60%, 97%, 81.0% and 96% for BOD_5, COD, TDS, TSS, Phosphate, Nitrate and Coliform respectively. Thus, the performance of developed laboratory scale treatment plant was not satisfactory as BOD_5, COD and solids concentration level in the effluents could not meet the ECR'97 standards for safe disposal into surface water bodies.

To get better quality of effluents, modification of developed laboratory scale treatment plant was done by activated sludge process followed by granular media filtration. The effluent from modified treatment plant contains BOD_5 level 1.38-1.78 mg/l, COD 32-128 mg/l and TDS 590-795 mg/l. About 72-99% BOD_5, 40-90% COD and 43-80% TDS removal efficiency were recorded. The pH and DO of effluents were raised to 8.12 and 7.10 mg/l respectively. After modification of developed treatment plant the removal efficiency has been increased and satisfied all criteria for safe disposal into surface water bodies according to ECR'97 standards.

The effluents quality of modified developed laboratory scale treatment plant were also compared with the national and international water quality standards set for irrigation water supply, which reveals that the effluents quality were in the safe limit to use as irrigation purposes but only for dry season because the study was conducted during the month of December to April.

In conclusion, many specific lessons have been learned through the study and development of laboratory scale drainage wastewater treatment technologies. Relatively simple wastewater treatment plant were designed to provide low-cost sanitation and environmental protection while providing additional benefits from reusing water and safe disposal.

6.3 Recommendations

- Relatively simple wastewater treatment technologies can be designed to provide low-cost sanitation and environmental protection while providing additional benefits from the reuse of water.
- As Mayur river is vital part of Khulna city where the river water is mostly used for irrigation purposes and other household uses, steps should be taken to reduce the impurity level for the safety of human health and environmental aspect. Therefore, the developed low-cost treatment unit can be a worthy resolution for the treatment of the drain water thus it can be discharged safely into the river.
- Most of the quality parameters after reclamation was within the standard limit except COD value. Chlorination process was adopted after the filtration. However, the value

was relatively high respect to the permissible limit. Further studies need to be conducted with the help of other treatment processes for the purpose of the reduction of the COD value.

- The proposed treatment unit needs to be cleaned, operated and maintained regularly and carefully otherwise the unit will not work as expected. For the safety of Mayur River, the proposed unit would supposed to be a great help.
- Based on these result, it appears that proper management of wastewater for irrigation and periodic monitoring of quality parameters are required to successful, safe and long-term reuse of wastewater in irrigation.
- It is recommended as a matter of high priority that preliminary treatment of wastewater generated in Khulna city should be done before irrigation particularly during the winter and pre-monsoon seasons.
- The treated wastewater should be considered and made a reliable alternative source in water resources management as it can effectively contribute to fill the increasing gap between water demand and water availability.
- In future, further work will be needed to examine metallic constituents in wastewater.
- Municipal wastewater effluents may contain a number of toxic elements, including heavy metals, because under practical conditions wastes from many small and informal industrial sites are directly discharged into the common drainage system. These toxic elements are normally present in small amounts and, hence, they are called trace elements. Some of them may be removed during the treatment process but others will persist and could present phytotoxic problems. Thus, municipal wastewater effluents should be checked for trace element toxicity hazards, particularly when trace element contamination is suspected.

References

ADB (Asian Development Bank). (2009) Sector assistance program evaluation: Urban sector and water supply and sanitation in Bangladesh. Manila.

ADB (Asian Development Bank). (2010) Bangladesh: Strengthening the resilience of the water section in Khulna to climate change. Final report for local government division, Khulna City Corporation, Khulna Water Supply and Sewerage Authority, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

ADB (Asian Development Bank). (2011) Adapting to climate change: Strengthening the climate resilience of water sector infrastructure in Khulna, Bangladesh. ADB, Mandaluyong city, Philippines.

Akpor, O. B. and Muchi, M. (2011) Environmental and public health implications of wastewater quality. African Journal of Biotechnology, 10(13):2379-2387.

Allam, A., Tawfik, A., Negm, A., Yoshimura, C. and Fleifle, A. (2015) Treatment of drainage water containing pharmaceuticals using duckweed (Lemna gibba). International conference on technologies and materials for renewable energy, Environment and Sustainability, TMREES15, Energy Procedia 74 (15):973-980.

APHA. (1992) Standard methods for examination of water and wastewater. 18th Edition. American Public Health Association. Washington DC.

Asano, T., Burto, F. L., Leveren, H. L., Suchihashi, R. and Tchobanoglous, G. (2003) Wastewater engineering treatment and reuse. 4th Edition, McGraw Hill, New York.

Asano, T., Burton, F. L., Leverenz, H. L., Tsuchihashi, R. and Tchobanoglous, G. (2007) Water reuse: issues, technologies and applications. McGraw-Hill: New York, USA.

Ayers, R. S. and Westcot, D. W. (1994) Water quality for agriculture. FAO Irrigation and Drainage Paper 29 rev. 1, FAO, Rome, Italy.

Bai, S., Srikantaswamy, S. and Shivakumar, D. (2010) Urban wastewater characteristic and its management in urban areas-A case study of Mysore City, Karnataka, India. J. Water Resource and Protection, 2: 717-726.

Bauder, T. A., Waskom, R. M. and Davis, J. G. (2006) Irrigation water quality criteria. Available on: http://www.ext.colostate.edu/PUBS/crops/00506.

BARC (Bangladesh Agricultural Research Council). (2017) Climate management information system. Long Term Average Rainfall Data: Khulna District, Available on: http://climate.barcapps.gov.bd/index.php?p=rainfall. Accessed date: 12.04.2017.

BBS. (2007) Bangladesh population census-2001: Community series. Bangladesh Bureau of Statistics, Ministry of Planning, Government of Bangladesh, Dhaka.

Berg, G., Dahling, D. R., Brown, G. A. and Berman, D. (1978) Validity of faecal coliforms, total coliforms and fecal streptococci as indicators of viruses in chlorinated primary sewage effluent. Applied Environ. Microbiol. 36(6):880-884.

Birks, R. and Hills, S. (2007) Characterization of indicator organisms and pathogens in domestic drainage water for recycling. Environmental Monitoring Assessment, 129 (1-3):61-69.

Carley, J. M. (2003) The effect of temperature and solids retention time on activated sludge treatment performance. Master's Dissertation.

Chatterjee, K. M. and Bhagwat, R. C. (2003) Sewage reuse- A case study. 8th International conference on Water Conservation and Reuse of Waste Water.

Chong, S., Sen, T. K., Kayaalp, A. and Ang, H. M. (2012) The performance enhancements of up-flow anaerobic sludge blanket (UASB) reactors for domestic sludge treatment - A State-of-the-art review. Water Research, 46 (11):3434-3470

Cooper, D. M., House, W.A., May, L. and Gannon, B. (2002) The phosphorus budget of the Thame catchment, Oxfordshire, UK: 1. Mass Balance. Science of the Total Environment, 282/283:233–251.

Davies, M. L. and Cornwell, D. A. (1998) Introduction to environmental engineering. Third Edition, McGraw-Hill International Edition, New York.

DoE (Department of Environment). (1997) The environment conservation rules 1997. Bangladesh Gazette no. DA-1, Ministry of Environment and Forest, Dhaka, Bangladesh, pp1324-1327.

ECR. (1997) The Environment Conservation Rules. Ministry of Environment and Forest, Government of the People's Republic of Bangladesh, pp 205-207.

Ensink, J. H. J., Vander Hoek, W., Matsuno, Y., Munir, S. and Aslam, M. R. (2002) Use of untreated wastewater in peri-urban agriculture in Pakistan: risks and opportunities. Research Report 64: 22. IWMI, Colombo, Sri Lanka.

ESCAP (Economic and Social Commission for Asia and the Pacific). (2000) Wastewater management policies and practices in Asia and the Pacific. United Nations, New York.

FAO. (1985) Water quality for agriculture. R.S. Ayers and D.W. Westcot. Irrigation and Drainage Paper 29 Rev. 1. FAO, Rome. pp 174.

Feachem, R. G., Bradley, D. J., Garelick, H. and Mara, D. D. (1983) Sanitation and disease: Health aspects of excreta and wastewater management. John Wiley, Chichester.

Ghangrekar, M. M. and Kahalekar, U. J. (2003) Performance and cost efficacy of two-stage anaerobic sewage treatment. Journal of Industrial Engineering (India), Part EN, Environmental Engineering Division 84(1):16-22.

Goel, P. K. (2006) Water pollution: Causes, effects and control, 2nd Edition. New Age International Publisher, New Delhi.

Iman, B. (2010) Disc-filters for tertiary treatment of wastewater at the Rya wastewater treatment plant in Goteborg. Master of Science Thesis in the Master’s programme Geo and Water Engineering, Department of Civil and Environmental Engineering, Division of Water Environment Technology, Chalmers University of Technology, Goteborg, Sweden.

Harper, F. Z. and Sylvia, M. E. (1924) American Dairy Sci. Asso. Indian Journal of Dairy Science. 7(4):318-329.

Hasan, M. M., Ahmed, M.K., Hafiz, F., Hussain, A.M.I., Parveen, S and Tinni, S.R. (2006) Heterotrophic and nitrifying bacteria in the lagoon and the receiving river Buriganga, Bangladesh. Journal of Microbiology. 23: 93-97.

Huibers, F. P. and Van Lier, J. B. (2005) Use of wastewater in agriculture: the water chain approach. Irrigation and Drainage 54 (Suppl.1): S-3-S-9.

IWMI (International Water Management Institute). (2006) Recycling realities: Managing health risks to make wastewater an asset. Water Policy Briefing 17. IWMI, Colombo, Sri Lanka.

Jimenez, B. (2005) Acknowledge all approaches: the global outlook on re use. Water 21: 32-37.

Jungle, S. K., Chatterjee, K. M. and Narkehede, S. D. (2009) Treatment of industrial wastewater by activated sludge process, Proc. Nat. Conf. Recent Trends in Bioscience. Institute of Science, Nagpur, India, pp 47.

Kazmi, A. A. (2000) Water quality modelling of river Yamuna. Journal of the Institutions of Engineers, 81:17-22.

KCC (Khulna City Corporation). (2017) Basic statistics of KCC. Available on: http://www.khulnacity.org/Content/index.php?page=About_KCC&amg&pid=30. Accessed date: 10.08.2017.

KCC (Khulna City Corporation). (2012) Survey to mitigate water logging problem in Khulna City. Drainage master plan, Map-1, Volume-1, Khulna-9100.

Kotaiah, D. B. and Swamy, N. K. (1994) Environmental engineering laboratory manual. Charoter publishing House, India. pp. 1-29, 42-104.

Lazarova, V. and Bahri, A. (2005) Water reuse for irrigation: Agriculture, landscapes, and turf grass. CRC Press, Boca Raton, USA.

Mahmoud, N. (2011) Report on wastewater characteristics: Prepared for Ecological Sanitation Training Course. Dhaka, Bangladesh.

Matthess, G., (1982) The properties of groundwater, John Wiley and Sons, New York, USA, pp. 397.

Metcalf and Eddy, I. (2003) Wastewater engineering: Treatment and reuse. 4th edition, Tata McGraw-Hill Publishing Company Limited, New Delhi, India.

Mojid, M. A., Wyseure, G. C. L., Biswas, S. K. and Hossain, A. B. M. Z. (2010) Farmer's perception and knowledge in using wastewater for irrigation at twelve peri-urban areas and two sugar mill areas in Bangladesh. Agricultural water Management 98:79-86.

Muthukumaran, N. and Ambujam, N. K. (2003) Wastewater treatment and management in urban areas - A case study of Tiruchirappalli City, Tamil Nadu, India.

Mridha, U.K. (2012) Wastewater characteristics of Khulna municipal area in Bangladesh. Peri-Urban Project, Environmental Science Discipline, Khulna University, Khulna-9208, Bangladesh.

Pescod, M. B. (1992) Wastewater treatment and use in agriculture. Food and Agriculture Organization (FAO) Irrigation and Drainage Paper, p. 73.

Qadir, M., Sharma, B. R., Bruggeman, A., Choukr-Allah, R. and Karajeh, F. (2007) Non-conventional water resources and opportunities for water argument to achieve food security in water scarce countries. Agricultural Water Management 87:2-22.

Rahman, M., Mridha, U. K. and Hassan, N. (2014) Evaluation of urban-wastewater quality for irrigation: A case study of Khulna city, Bangladesh. South Asian Water Studies, 4(2).

Saleem, M. (2007) Pharmaceutical wastewater treatment: A physicochemical study. Bahauddin Zakariya University, Multan, Pakistan. Journal of Science. 18(2):125-134.

UNESCO (United Nations Educational, Scientific and cultural Organization). (2003) Water for people, water for life. United Nations/ world water Assessment Programme, UNESCO; Berghahn Books, Paris; New York.

United Nations Water. (2015) Wastewater management: A UN-Water Analytical Brief. New York.

US Salinity Laboratory. (1954) Diagnosis and improvement of saline and alkali soils. Handbook No. 60. US Salinity Laboratory, US Department of Agriculture, Washington DC. 160 pp.

USEPA. (2000) Manual: Constructed wetlands treatment of municipal wastewaters. Cincinnati: United States Environmental Protection Agency.

Van der Hoek, W., Ul-Hassan, M., Ensink, J. H. J., Feenstra, S., Rashid- Sally, M. S., Aslam, A. R., Ali, N., Hussain, R. and Matsuno, Y. (2002) Urban wastewater: A valuable resource for agriculture. In Research Report 63, IWMI, Sri Lanka.

Varol, M., Gokot, B., Bekleyen, A. and Sen, B. (2013) Geochemistry of the Tigris River basin, Turkey: spatial and seasonal variations of major ion compositions and their controlling factors. Quaternary International, 304:22–32.

Westcot, D. W. (1997) Quality control of wastewater for irrigated crop production. Water Report no. 10. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 86 pp.

WHO (World Health Organization). (2000) Turning the tide of malnutrition: Responding to the challenge of the 21st century. (WHO/NHD) World Health Organization, Geneva, Switzerland, 24 pp.

WHO (World Health Organization). (1993) Guidelines for drinking-water quality. Volume 1: Recommendations, 2nd edition. World Health Organization, Geneva, Switzerland, 188 pp.

Zouboulisa, A., Traskasa, G. and Samaras, P. (2007) Comparison of single and dual media filtration in a full scale drinking water treatment plant. Desalination, 213:334-342.

Appendices

Appendix A

Table 1: Physico-chemical characteristics of raw drainage wastewater

Water Quality Parameters	Unit	Sampling Station (SS)			Max.	Min.	Avg.	Stand. Dev.
		SS-1	SS-2	SS-3				
pH	-	7.27	7.35	7.49	7.49	7.27	7.37	0.09
DO	mg/l	0.74	0.79	0.69	0.79	0.69	0.74	0.04
BOD_5	mg/l	59	126	226	226	59	137.00	68.62
COD	mg/l	320	420	435	435	320	391.67	51.04
TDS	mg/l	1800	1950	2525	2525	1800	2091.67	312.47
TSS	mg/l	120	150	190	190	120	153.33	28.67
Hardness as $CaCO_3$	mg/l	148	128	116	148	116	130.67	13.20
Alkalinity as $CaCO_3$	mg/l	357	370	310	370	310	345.67	25.77
Chloride	mg/l	1325	1250	1570	1570	1250	1381.67	136.65
Nitrate	mg/l	12	11	17	17	11	13.33	2.62
Phosphate	mg/l	8.74	9.89	16.75	16.75	8.74	11.79	3.54
Sulfate	mg/l	156	154	180	180	154	163.33	11.81
Iron	mg/l	0.98	1	1.2	1.2	0.98	1.06	0.10
Electrical Conductivity	µS/cm	1785	1965	2145	2145	1785	1965.00	146.97
Color	Pt.Co	478	503	615	615	478	532.00	59.57
Turbidity	NTU	42	65	93	93	42	66.67	20.85
E. Coli	Nos/100ml	49333	48256	59825	59825	48256	52471.33	5218.38
Total Coliform	Nos/100ml	70000	65800	98050	98050	65800	77950.00	14315.90

Table 2: Effluents quality of the developed Laboratory-scale treatment plant

Water Quality Parameters	Unit	Treated Drainage Wastewater			*ECR'97 Discharge Standard
		Sample-1	Sample-2	Sample-3	
pH	-	7.37	7.32	7.99	6-9
DO	mg/l	8.79	5.03	6.90	-
BOD5	mg/l	40	60	115	50
COD	mg/l	160	196	256	200
TDS	mg/l	1356	1450	1500	2100
TSS	mg/l	48	55	85	150
Hardness as CaCO3	mg/l	134	121	76	-
Alkalinity as CaCO3	mg/l	280	353	185	-
Chloride	mg/l	600	393	550	-
Nitrate	mg/l	1.1	0.20	0.9	10
Phosphate	mg/l	5.26	1.31	0.47	35
Sulfate	mg/l	11.3	9.3	11.8	-
Iron	mg/l	0.01	0.02	0.06	2
Electrical Conductivity	µS/cm	1785	1929	1874	1200
Color	Pt.Co	136	132	18	-
Turbidity	NTU	13.9	8.04	2.18	-
E. Coli	Nos/100ml	2400	2000	2100	-
Total Coliform	Nos/100ml	2600	7600	9800	1000

*ECR'97: The Environmental Conservation Rules (1997)

Table 3: Performance activated sludge processing following filtration

Water Quality Parameter	Unit	Raw wastewater	Effluent			ECR’97 Discharge standard
			3-days	5-days	7-days	
pH	-	7.49	7.89	8.09	8.12	6.0-9.0
DO	mg/l	0.58	6.75	6.82	7.10	-
BOD_5	mg/l	352	98	1.78	1.38	50
COD	mg/l	320	192	96	32	200
TDS	mg/l	2920	1667	705	590	2100
TSS	mg/l	320	95	45	35	150
TS	mg/l	3240	1762	750	625	-

Appendix B

Necessary Calculation for Activated Sludge Processing

Data:

Expected Effluent BOD = 50 mg/l

Expected Effluent SS = 150 mg/l = 0.150 mg/ml

Flow of Wastewater, Q = $14.4*10^{-3}$ m^3/d = 10 ml/min

Influent BOD, S_o = 150 mg/l

Assume the following values for growth constant:

Ks = 100 mg/l BOD_5

μ_m = 2.5 per d

Kd = 0.05 per d

Y = 0.5 mg VSS/mg BOD_5 removed

S = 0.005 kg/m^3 = 5 mg/l

MLSS concentration, X = 3000 mg/l

Xu (under flow concentration) = 10,000 mg/l

Assume mean cell residence time, θ_c = 3 days

Step 1:

Retention time, θ = V/Q

Where, V= volume of reactor and Q = flow of wastewater

Now we know,

$\frac{1}{\theta c} = \frac{QY(So-S)}{VX} - Kd$………… (1)

So, V = 1 L

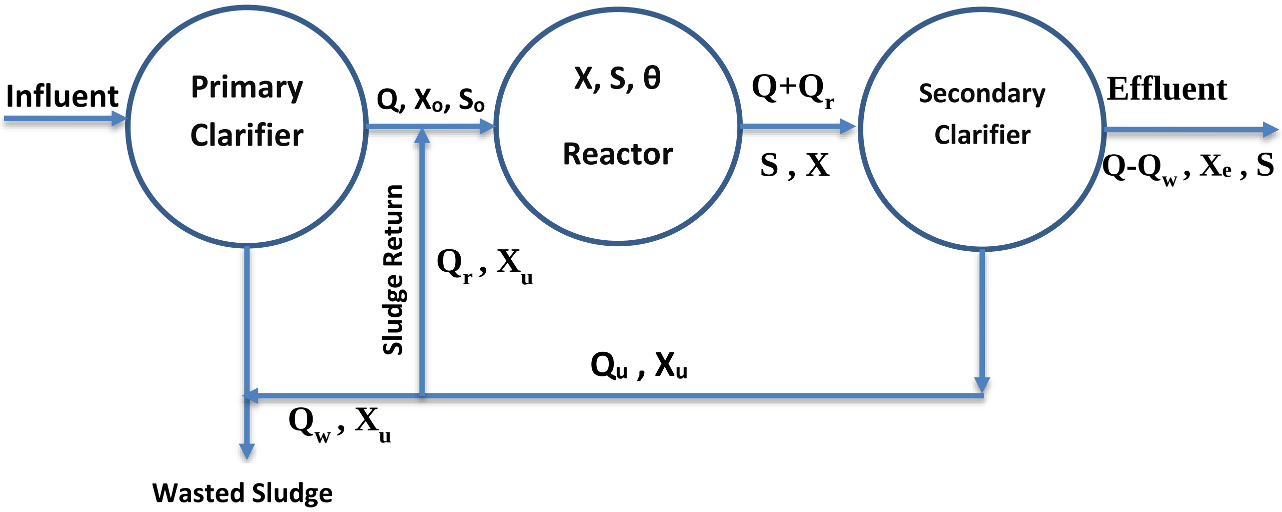

Figure 1: Process Flow diagram of activated sludge processing

Step 2:

The wasting flow rate of sludge

$$Qw = \frac{VX}{\theta c Xu} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

So, $Q_w = 10^{-4}\ m^3/d$ = 0.07 ml/min

Step 3:

The return sludge flow rate

$$Qr = \frac{QX - QwXu}{Xu - X} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

So, Q_r = 4.62 or 5.0 ml/min

Step 4:

Hydraulic detention time,

$$\theta = \frac{V}{Q} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

So, θ = 1.51 hour or 90 min

Step 5:

The F/M ratio = $\frac{QSo}{VX} = 0.5\ \frac{mg}{mg}.d$…………………(5)

Step 6:

The sludge production:

Yobs = observed yield, kg VSS/kg BOD removed

$Yobs = \frac{Y}{(1+Kd*\theta c)}$………………… (6)

So, Y_{obs} = 0.434 kg VSS/kg BOD removed

Step 7:

Px = Net waste activated sludge produced each day in terms of VSS, kg/d

$Px = \frac{YobsQ(So-S)}{1ooo}$……………… (7)

So, P_x= 0.047 kg/d of VSS

Step 8:

Increase in MLSS = 1.43*P_x = 1.43*0.047 = 0.07 kg/d

The mass of solids lost in effluent = (Q-Q_w)X_e = (10-0.07)*0.150 = 0.015 kg/d

The mas to be wasted = 0.07-0.015 = 0.055 kg/d

Step 9:

The required amount of oxygen, Moxy $= \frac{Q(So-S)}{f}$…………(8) where f = 0.68

So, Moxy = 0.00307 kg/d of oxygen

Air density = 1.185 kg/m^3

Oxygen content in air = 23.2% = 0.232

Efficiency = 10% = 0.1

The amount of air supplied at a 10% efficiency rate = $\frac{\mathrm{Moxy}}{\mathrm{Air\ density} * 0.232 * 0.1} = 0.157\ m^3/d$ = 156.8 L/d

Appendix C

Irrigation Water Quality Parameters

Table 1. Water classification on the basis of EC and SSP

Water class	Electrical Conductivity (μS cm-1)	% Sodium
Excellent	< 250	<20
Good	250-750	20-40
Permissible	750-2000	41-60
Doubtful	2000-3000	61-80
UnsuiTable	>3000	>80

Source: Wilcox, L.V. 1955. Classification and use of irrigation no. 969. Washington, USA. 19.

Table 2. Recommended maximum concentration of trace elements in irrigation water

Elements	Symbol	For water used continuously on all soil (mg/L)	For use up to 30 years on fine textured soils of pH 6.0-8.5 (mg/L)
Aluminum	Al	5.00	20.00
Arsenic	As	0.10	2.00
Beryllium	Be	0.10	0.50
Boron	B	<0.75	2.00
Cadmium	Cd	0.01	0.05
Chromium	Cr	0.01	1.00
Cobalt	Co	0.05	5.00
Copper	Cu	0.20	5.00
Fluoride	F	1.00	15.00
Iron	Fe	5.00	20.00
Lead	Pb	5.00	10.00
Lithium*	Li	2.50	2.50
Manganese	Mn	0.20	10.00
Nickel	Ni	0.20	2.00
Selenium	Se	0.20	0.02
Vanadium	V	0.10	1.00
Zinc	Zn	2.00	10.00
Molybdenum	Mo	0.01	0.05

* Recommended maximum concentration for irrigating citrus is 0.075 mg/L

Source: Ayers, R.S. and Westcot, D.W. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage paper. **29**(Rev. 1) 114.

Table 3. Water classification as per TDS

Water class	Total Dissolved Solids (mg/L)
Fresh water	0-1,000
Brackish water	1,000-10,000
Saline water	10,000-100,000
Brine water	>100,000

Source: Freeze, A.R. and Cherry, J.A. 1979. *Groundwater*. Prentice Hall Inc. Englewood Cliffs, New Jersey, USA. 84.

Table 4. Water class rating based on SAR

Water class	Sodium Adsorption Ratio (SAR)
Excellent	<10
Good	10-18
Fair	18-26
Poor	>26

Source: Todd, D.K. 1980. *Groundwater Hydrology*. 2^{nd} edition. John Wiley and Sons Inc., New York, USA. 304.

Table 5. Water classification according to RSC

Water Suitability	Residual Sodium Carbonate (me L^{-1})
SuiTable	<1.25
Marginal	1.25-2.50
UnsuiTable	>2.50

Source: Ghosh, A.B.; Bajaj, J.C.; Hasan, R. and Singh, D. 1983. *Soil and Water Testing Methods*. A Laboratory Manual, Division of Soil Science and Agricultural Chemistry, IARI, New Delhi, India.

Table 6. Classification of water on the basis of hardness (H_T)

Water class	Hardness (mg/L)
Soft	0-75
Moderately Hard	75-150
Hard	150-300
Very Hard	>300

Source: Sawyer, C.N. and McCarty, P.L. 1967. *Chemistry for Salinity Engineers*. 2^{nd} edition. McGraw Hill, New York, USA. 518.

Table 7. Classification of water on the basis of B concentration

Water class	Boron (mg/L)		
	Sensitive crops	Semi tolerant Crops	Tolerant crops
Excellent	<0.33	<0.67	<1.00
Good	0.33-0.67	0.67-1.33	1.00-2.00
Permissible	0.67-1.00	1.33-2.00	2.00-3.00
Doubtful	1.00-1.25	2.00-2.50	3.00-3.75
UnsuiTable	>1.25	>2.50	>3.75

Source: Wilcox, L.V. 1955. Classification and use of irrigation no. 969. Washington, USA. 19.

Appendix D

Photo Gallery

Photo 01: Nabinogor khal

Photo 02: Tamijuddin khal

Photo 03: Mandar khal

Photo 04: Gollamari north khal

Photo 05: Madhyadanga drain outlet into Mayur River, Daulatpur

Photo 06: Shahanghat bridge drain outlet into Mayur River, Boyra

Photo 07: Bastuhara colony drain outlet into Mayur River, Goalkhali

Photo 08: BOD_5 test samples

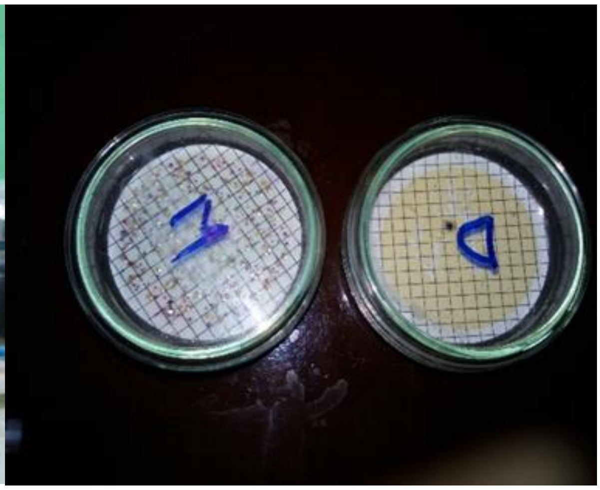

Photo 09: E-coli and total coliform test

Photo 10: EC, pH and turbidity test

Photo 11: TDS, TSS and TS test

Photo 12: COD test

Photo 13: Alkalinity test

Photo 14: Water Pump

Photo 15: Air Blower

Photo 16: Laboratory Set-up of Activated Sludge Processing Unit