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Presented by

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TITLE: PERFORMANCE EVALUATION AND OPTIMIZATION OF AN INDUSTRIAL WASTEWATER TREATMENT PLANT

(Case study: Bahir Dar textile factory, Ethiopia)

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DECLARATION

I, Yetagesu Talegeta Haile, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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ABBREVIATIONS

AS	Activated Sludge
BDT	Bahir Dar Textile
BOD_5	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DAP	Urea and Di-Ammonium Phosphate
DO	Dissolved Oxygen
EC	Electric Conductivity
EEPA	Ethiopian Environmental Protection Agency
EEPCO	Ethiopian Electric Power Corporation
ETP	Effluent Treatment Plant
IWTP	Industrial Wastewater Treatment Plant
MBR	Membrane Bioreactor
pH	Power of hydronium ion
RAS	Returned Activated Sludge
RBC	Rotating Biological Contactor
RO	Reverse Osmosis
SBR	Sequencing Batch Reactor
SRT	Solids Residence Time
TDS	Total Dissolved Solid
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus

TSS	Total Suspended Solids
UASB	Up-Flow Anaerobic Sludge Blanket
VFA	Volatile Fatty Acid
VSS	Volatile Suspended Solids
WAS	Wasted Activated Sludge
WHO	World Health Organization
WRRF	Water Resource Recovery Facility
WWTP	Wastewater Treatment Plant

ABSTRACT

Bahir Dar Textile Factory is one of the most important factories located at the edge of Blue Nile river. The factory generates a huge amount of wastewater after the manufacturing processes. The factory has an activated sludge wastewater treatment plant which treats a maximum of $1200m^3$ of wastewater in a single day.

The main goal of this research was to evaluate the efficiency of the treatment plant, assess the possible impacts on the quality of Blue Nile river, that is followed by an optimization of the plant for a better effluent quality. Laboratory analysis and historical data were used as a main source to examine the behaviour of the existing treatment plant. Then water quality of the river is assessed to inspect the impact of the effluent after disposal.

The wastewater treatment plant at the factory was found as efficient in terms of removing BOD_5, Nitrogen and Ammonia concentration from the influent. While, TSS, TP, TKN and COD concentration were beyond recommended limits. This will directly affect the quality of the river and the aquatic life, so that, optimization and upgrading is expected to improve the treatment performance. In order to optimize and upgrade the treatment plant, a computer software program named GPS-X was used. Sample results were used for model calibration then different scenarios were conducted.

The optimization of the treatment plant is addressed in two methods. The first one was to improve the effluent quality by adjusting some operational parameters within the existing plant, this shows a significant reduction of COD, TP, TKN and Ammonia. Secondly, three options are considered as an upgrading method so that, to improve the removal of TSS, a grit chamber and a sand filter were added to the treatment train as a result a substantial reduction of TSS is observed. The second option was addition of hybrid of anaerobic and anoxic tank before the activated sludge process, this shows a high decrease of COD and Phosphorus concentration. Lastly, Membrane Bioreactor replaced the activated sludge process and almost all of the physico-chemical parameters are reduced in substantial way. This was also beneficial in terms of operation, chemical cost and reduction of sludge.

Chapter 1:

INTRODUCTION

1.1 General Background

Textile industries are one of the major sources of pollutants because, they release highly polluted wastewater holding many chemicals and water intensive processes. Textile finishing industry consumes a huge amount of water, mainly because of dyeing and washing operations. Apparently, the wastewater effluent generated from these units contains considerable amounts of hazardous pollutants (Zhezhova, Risteski, and Saska 2014). The treated wastewater is considered as strong in colour, high pH variation, high COD and BOD_5 due to application of organic compounds, excess amount of nutrients which are rich in nitrogen and phosphorous in it (Mudassir, 2017).

Pollutants from textile manufacturing and wet processing activities depend on mainly on variety of chemicals use in these processes. When the wastewater is discharged, the water body receiving this wastewater changes its natural colour, become toxic and it became difficult to treat using conventional treatment methods(Chem et al. 2015).

In Ethiopia, it is stated that almost all of the textile industries have no suitable influent treatment systems. Even if they are few in number, their impact in terms of pollution is very significant as well as their old nature and process, the wastewater generating from this industry is very toxic and problematic to sort out since, they are discharged in the system in different forms (Solomon Chibssa, 2015). Majority of the industries are very old and use some outdated treatment technologies which are not considered as a system to remove the pollutants which present in the wastewater (EPA, 2003).

Bahir Dar textile factory is one of the factories operating in the vicinity of Blue Nile river, and it discharges in a range of 400-1200m^3 of wastewater in a single day into the Blue Nile river. The treatment plant is categorized as activated sludge system with the aim of reducing mainly BOD_5 and COD from the effluent. However, there is still reports of high concentration of pollutants in the effluent were discharged to the river even if they are beyond the guideline from WHO and national standards and this poses a question on the efficiency of the existing treatment system (Wosnie and Wondie 2014).

1.2 Research Objectives

The general objective of this research is to evaluate the treatment efficiency of the Bahir Dar Textile factory's wastewater treatment plant and identify possible treatment options to improve its performance.

Specific objectives:

- To evaluate physico-chemical characteristics of the treatment plant at the inlet and outlet of the treatment process.
- Investigation of the impacts of the textile factory's effluent on the downstream water quality of the Blue Nile river
- To optimize the treatment efficiency of the plant using a modeling program.
- To indicate possible improvements on water and energy usage

1.3 Statement of the Problem

Bahir Dar Textile factory has an activated sludge treatment plant with the aim of reducing organic and inorganic pollutants from the wastewater. However, this effluent is discharged to the nearby river Blue Nile without adequate treatment which results in nutrient enrichment, the accumulation of undesirable compounds and sediments around the river, this poses the river to be in risk of eutrophication and sediment deposits at the downstream.

1.4 Motivation

The Blue Nile river is used for so many purposes by the living community and it is the main source of Nile river. This study will assess the treatment efficiency of the Bahir Dar textile factory wastewater treatment plant before disposal to the river. Excess physico-chemical compositions of the effluent from the factory has long term and possible effects on the biota of Blue Nile river. This will be valuable information to indicate ways to improve and upgrade the system for safe surface disposal.

This kind of information is important in terms of applying appropriate water resource management practices and safeguarding the biodiversity.

1.5 Study Area

Bahir Dar city is the capital of Amhara region situated at south outlet of Tana lake. It is about 578km far from the capital city of Addis Ababa having an latitude of 11^{o}28'94'' to 11^{o}38'29''N and longitude of 37^{o}23'28'' to 37^{o}36'34''E with an altitude of 1820m a.s.l (Wondie 2009). The region shares its border with North Sudan at the west, Tigray region at the north, Oromia region at the south, Benishangul at the south-west and Afar region at the east. The population of Bahirdar city had been estimated to be more than 700,000 with covering area of 28km^2. Bahr Dar city is one of tourist destinations in the country, with diverse attractions around the nearby Lake Tana which has a surface area of 3150 km^2.

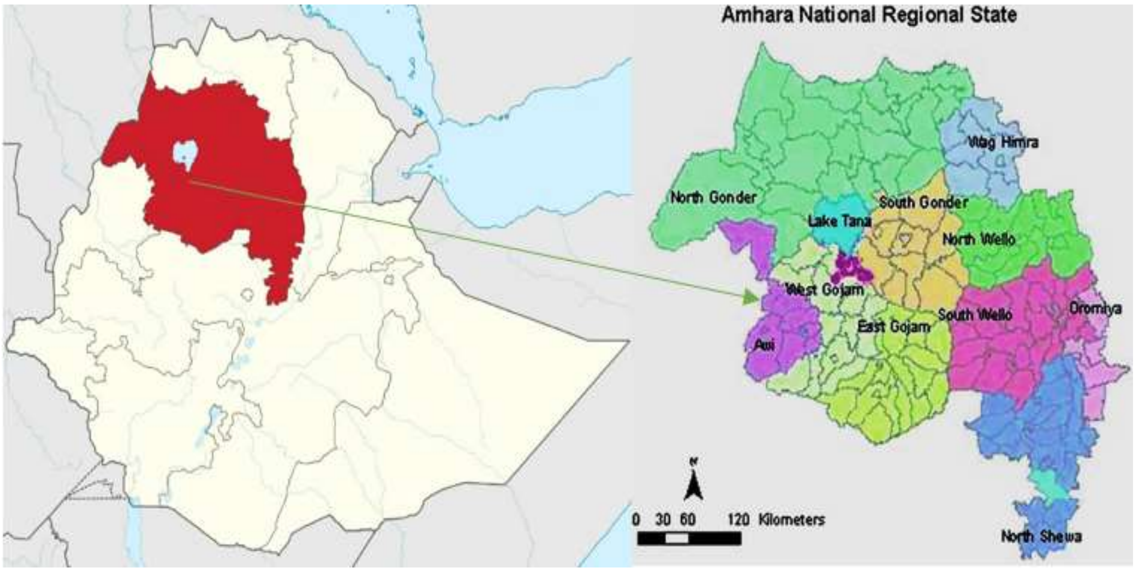


Figure 1.1 Location of the study area

1.6 Climate

The city is categorized as tropical climate, which is very close to subtropical plateau climate. The temperature at afternoon is very warm around the whole year and the temperature at morning relatively cool. Most of the temperature is highest on average in May, at reaches around 71.42^{o}C (Wondie 2009).

1.7 Temperature

The city of Bahir Dar has a warm season which lasts for consecutive months, from February to May, with mean daily temperature of 84°F. The hottest month of the year known is March, with 87°F and drops to 63°F sometimes. December in considered as the coldest month having a low temperature of 56°F (Wondie 2009)

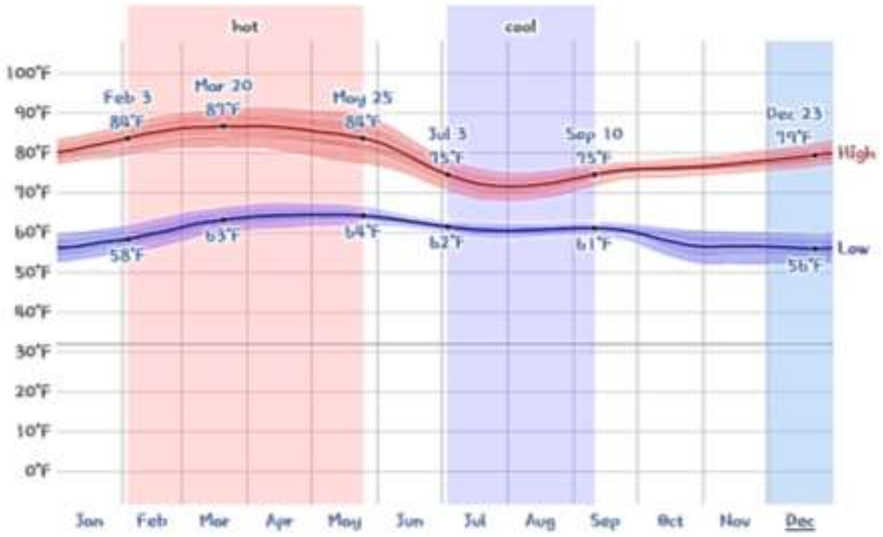


Figure 1.2 Daily average high and low temperature(Wondie 2009)

1.8 Rainfall

The wet season lasts for eight months starting from March to end of November and the remaining months stay without rain. The heaviest rain occurs around end of July, with total mean accumulation of 340.4 mm. The least rain falls in February, with an average of 8.7mm (Climate data.org).

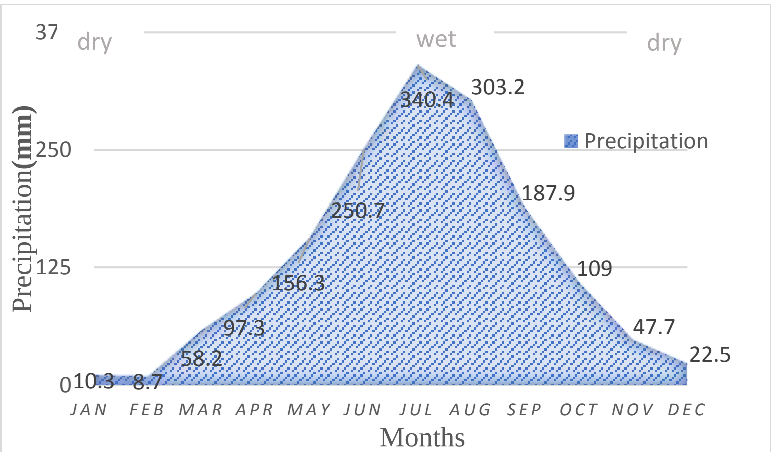


Figure 1.3 Annual precipitation of Bahir Dar city (Source: Climate data.org)

1.9 Outline of The Thesis

The thesis is organized in such a way that, the chapters keeps the flow from the evaluation of the treatment plant to the optimization stage.

The first chapter includes, general background, research objectives, problem statement and description of the study area.

Chapter two, presents the general literatures and further studies which are conducted on textile industries and effluent behaviour. Furthermore, concepts are also addressed about the process of textile manufacturing, origin and composition of effluents and the typical approach of treatment technologies.

In Chapter three, methodology of the whole research approach is discussed from data collection to the optimization stage. The software program which is used in optimizing the treatment system also discussed.

Chapter four, refers to results and interpretation about the data gathered in the process of laboratory analysis with meaningful discussions are provided within result generation. Additionally, sustainable improvement of Bahir Dar textile wastewater treatment plant is discussed in terms of hydraulic performance, cost and energy minimization.

Chapter five, addresses the conclusions part related to the results obtained along with Recommendation for future developments.

Chapter 2:

LITERATURE REVIEW

2.1 General Introduction

A fast growth of population, industrialization and an increasing trend of developments related to manufacturing, problems linked to the management of wastewater is becoming one of the issues in terms of assuring environmental sustainability nowadays. Municipal and industrial sewage contribute numerous quantity of nutrients and polluting constituents that have a number of antagonistic effects on the water bodies (Sorsa et al. 2015).

2.2 Industrial Activities and Water Pollution

Pollution related to industrialization is becoming one of the challenges in both developed and developing countries. Most of the factories are established very near to a natural water system, in order to dispose their sewage which is generated through the process of manufacturing. This leads to change in the quality of surface and ground water in a considerable way So, this is now becoming todays ecological concerns in terms of achieving ecological stability(Awasare, Bhosale, and Chavan 2015).

The utmost polluting factories are those which utilizes huge amount of water and chemically rich substances throughout their manufacturing processes. Disposal of those untreated wastewaters into the natural water has an adverse impact on the biota of the aquatic ecosystem, it also immensely affects the self-cleansing mechanism of the water system through different natural processes (Sorsa et al. 2015).

Incessant generation and discharge of this untreated effluent to the natural system have a huge impact on the accumulation of heavy metals in aquatic life then it affects the consumers around the lake system. So that, the biological system and other interactive natural system close to the river will fall in high risk of contamination from the untreated effluent.

Nearly, all of industries in developing countries discharge their wastewater directly to the nearby water systems because, majority of them are not equipped with modern or dependable wastewater treatment technology(Asmah 2016). Untreated wastewater from industries have great impact on the decline of water quality by changing the physico-chemical characteristics of the receiving body. This further results in massive degradation of the surface and ground water and make of inferior quality to use them other purposes(Pollut et al. 2017).

In Ethiopia, more than seventy two percent of the industries has not built any modern treatment technology for their wastewater treatment (Sorsa et al. 2015). Some factories has an old system of treating strong wastewater with a simple lagoon system, which are not capable of treating the pollutants in a desired level of quality(Tegegn 2012).

Bahir Dar Textile factory, one of the textile industries established in Ethiopia in the late 1961 with the help of Italian government as a war compensation. The factory is built at the edge of Blue Nile river where the downstream part of the river is used for domestic activities including drinking, irrigation, fishery and recreation. The textile factory has a treatment plant constructed in early 2012 after a pressure from the national environmental protection authorities since, the wastewater was affecting the river system in significant way. The plant is in use to treat major pollutants present in the wastewater which is generating continuously for the textile manufacturing processes (Wosnie and Wondie 2014).

Nevertheless, the treatment efficiency of the treatment plant is limited BOD_5 and Ammonia reduction. The concentration of most of the water quality parameters are quite passes the maximum permissible limits set by national and World Health organization standards.

2.3 Textile Manufacturing Processes

Textile manufacturing is one of the oldest and most important industries worldwide, where the process of production is based on conversion of fiber into yarn, then fabric then textiles as an end product. These productions involve the combination subsequent methods.

Spinning**:** It is a process of converting raw fiber to yarn or thread, in some cases the yarns will be dyed and finished as a final product. which is entirely a process without water use.

Knitting**:** Knitting is applied by meshing a series of yarn coils, usually using machinery which is sophisticated in some way.

Weaving**:** Which is one of the most important processes in textile production. In this process the threads are coated to improve their stretchable property and evenness.

Sizing**:** Sizing is the process of increasing the strength and smoothness of the yarn which help to reduce the breakage of the yarn. Waxes or lubricants are commonly used to process the system as well as a little amount of water is applied in the process of cleaning and tinning dyes.

Singeing**:** Singeing is categorized in a wet processing process, unlike other wet processing operations, it does not call for large quantities of water, except for slaking the material after singeing.

Desizing**:** The technique of desizing is the process of hydrolysing the starch available in the processed yarn after singeing. Gums and sticky substances are removed by a simple hot water with a slow process of washing. Due to this a high BOD_5 load added to the effluent which contribute up to 45% of the total pollution load of a wastewater generation.

Scouring**:** Scouring is the initial stage in the processing of woven fabrics and will remove the knitting oils which were applied to the yarn prior to knitting procedure. The scouring process is usually applied within a temperature of 100°C with addition of sodium hydroxide which yields strongly alkaline effluents having a pH ranges between 12-14 with high organic loads. This leads to the change the colour to dark and a high concentration of solids (TDS and TSS), oil and grease.

Bleaching**:** Removal of the natural coloured matter in a cotton material is referred to as bleaching. The process leads to high TDS levels and strong alkalinity ranging from a pH of 9-12 and the temperature near to boiling of water. A huge quantity of water is required to remove hydrogen components from fabrics.

Mercerization**:** This process made overall fabric to be stronger and easier to dye. Baths containing very concentrated solutions of sodium hydroxide (20-30%) are used to advance luster, strength and dye uptake and it also removes immature fibres. Adequate washing is required after this stage to eliminate any traces of caustic soda which leads massive amount of wastewater at the finish line of the process.

Dyeing**:** is a method of adding dyes to the textile material, and it is related to printing in their similarity in procedure. Dyes are deep in concentration of colours and are highly visible even in very low amount applied since the fabric is bleached to have a snowy appearance. The effluents from this process are heavy to treat because of high COD, BOD_5, suspended solids, and toxic constituents.

Printing**:** It is the procedure of spread over color to the cloth material in definite designs. It is related to dyeing process where a single color is covering the entire body of the garment. Whereas, in printing, various colours are used in sharply designated outlines. Significant quantity of water is used in this process since, the dyes are water soluble in most cases and this is considered as the main contributor for color destiny of the wastewater which is released after the processes.

Finishing**:** Finishing is another process happening at the end of all processes, which is changing the knitted cloth into a serviceable material by improving its performance and look. The water consumption in this process in not that much significant sine it is a dry process except a little spry for ironing purposes.

Table 2.1 Nature of effluent from different processes (Kanu and Achi 2011)

Process	**Compositions**	**Nature of effluent**
Sizing	Starch, waxes and wetting agents	High in BOD_5 and COD
Desizing	Starch, and tricky waxes	TSS, high BOD_5 and COD
Bleaching	Sodium hypochlorite, acids and sodium phosphates	High Alkalinity and High TSS
Mercerizing	Sodium Hydroxide, cotton waxes	High PH, low BOD_5 high TDS
Dyeing	Reducing agents, oxidizing agents, detergents and wetting agents	Strong colour, high BOD_5, DS, low SS and heavy metals
Printing	Pastes, urea, starches, reducing agents alkali	Highly coloured, high BOD_5, oily appearances, high TSS & BOD_5

Dyeing and printing processes in textile industry consume a lot of water that generates heavily polluted wastewater after each process. Those pollutants have varied depending on the chemicals used in the processes. This makes the wastewater from the textile to have an offensive smell and brackish. Dyes are so toxic highly stable this makes it difficult to use conventional treatment methods to treat the influent (Okoh et al. 2007).

2.4 Water Consumption in Textile Production

The quantity of water used in textile industries depends on type of process used, equipment and operations. The main water consuming processes in textile manufacturing industry are dyeing and printing. In a textile fabric preparation steps desizing, scouring, bleaching, and mercerizing use water as a medium of every process and this leads to the consumption of water in high quantity (Balachandran and Rudramoorthy 2009).

Table 2.2 Major uses of water in textile industries (Chougule, 2012)

Purpose	**Water use (%)**
Dyeing and bleaching processes	30
Cooling for tower	6.4
Demineralizing water for specific purpose	7.8
Domestic purposes drinking, gardening and sanitary uses	12.3
In a treatment plant, mainly, coagulation processes	16.0
Steam generation	5.2
Printing and Mercerizing processes	12.0
Miscellaneous use and fire fighting	10.3

2.5 Characteristics of Textile Influent

Textile manufacturing releases an enormous volume of wastewater composed of various chemicals used in dyeing, printing and finishing processes. Many textile effluent generated in different processes is highly polluted and dangerous where the effluent is characterized by strong colour, high Chemical Oxygen Demand (COD), BOD_5 (Biological Oxygen Demand) and a pH ranging from acidic to strong alkaline (Pe, Hlav, and Matys 2011).

Wet processing is one the most water intensive operation in textile processing such as scouring, bleaching, mercerizing and dyeing processes. From all these operations, dyeing and bleaching process normally uses large amount of water (Soliarceivala, 2011). These methods involve inorganic and organic chemicals, detergents, soaps and final compounds to assist for the dyeing process. There is a wide variety in specific water consumption in unit operations depending on the type of products (Balachandran and Rudramoorthy 2009).

2.6 Textile Wastewater Treatment Methods

Industrial effluent composition is unpredictable which changes as the developments of the production process are improving through time even though, to treat effluents from textile requires several treatment steps which can be applied with a combination of different treatment technologies to obtain an effluent which can meet the standards(Seif and Malak 2001). The selection of the treatment method depends on the composition of the target wastewater and on the intended use of the effluent and discharge requirements. Treatment method applied for both municipal and industrial wastewater treatment applications can be preliminary/primary, secondary and tertiary treatment which are discussed as follows.

2.6.1 Preliminary treatment

As the wastewater comes to the treatment system, it often undergoes to the preliminary treatment section. This treatment mainly includes screening to avoid large floating materials, such as rags, cans, bottles, wood and others to reduce the chance of clogging in the subsequent processes. Screens are generally placed in inclined manner to the opposite direction of the flow. Some plants uses different kind of devices which has a grinder attached with screening for shredding heavy objects (Okoh et al. 2007).

2.6.2 Primary treatment

Primary treatment is the second step in a wastewater treatment process which helps to separate suspended solids, grease and objects which leaves the preliminary treatment process. In some treatment plants, preliminary and primary stages may be combined into one basic operation (Okoh et al. 2007).

Equalization (Homogenization tank)

Most industrial wastewater treatment plants involve tanks to increase homogeneity of the influent coming from different direction of the factory. Mixing is mainly achieved by mechanical mixers or by natural or artificial aeration. It also helps to store and supply the influent continuously to a continuous flow to the treatment plant.

Some dissolution of oxygen would occur and this is useful if there is a concern that septic conditions may develop as biodegradable substances present in the wastewater degrade over the holding period.

Oil & Grease Removal

Excess amount of oil and grease affects the treatment process which can lead to the clogging of sewers and pumping plants and with the interference of biological treatment processes. The elimination of oil and grease load depends on the type of equipment used and purpose of the treatment plant.

pH Adjustment

Industrial wastewater has a varying pH from very basic to acidic behaviour. Most factories produce a number of chemicals which are the main factor for this variation. If the chemical consumption is reduced and reused in the process the Ph can be neutralized. An automatic pH adjustment is not easy task to achieve as needed Because of mixing a few chemicals with large quantity of wastewater.

This is made even more difficult if wastewater characteristics, like the discharge, changes rapidly.

As most of industrial wastewater treatment plants are small in size the preferred chemical for pH adjustment of acidic wastewaters is usually basic oxide (sodium hydroxide) and sulfuric acid or hydrochloric acid in some cases (H_2SO_4) instead of lime which is mainly used in municipal wastewater treatment as it needs storage and handling & some safety requirements A solution of sodium hydroxide would be prepared prior to its injection into the pH correction tank.

2.6.3 Secondary treatment methods

After the preliminary treatment of the influent coming from the industries biological treatment follows the next step. Some pollutants are expected to join the next treatment system since it is not possible to trap them in the primary treatment process. Which can be organic and biodegradable in nature so this can be treated by biological process. In the treatment, the bioprocesses can be used to provide partial and subsequently almost complete stabilization of substances which are biodegradable in nature.

The microbial activity in a biological treatment system can be fall in suspended or attached growth which is also known as biofilms. In some treatment plants the combination of the two ways of microbial degradation for better effluent quality from the biological reactors. In suspended growth method, the microorganisms are suspended in the reactor's mixed liquor in a mass. These flocs are kept in suspension with agitation by mechanical mixers or gas injection. The latter would typically be air in aerobic systems and biogas in anaerobic systems. The agitation facilitates intimate interaction between substrates and biomass.

Biological treatment methods are classified as Aerobic, Anaerobic and Anoxic which are discussed each of them as follows,

I. Aerobic Processes

Anaerobic process is referring the process of wastewater treatment with the application of oxygen which is very important for microorganisms to degrade the nutrients. In industrial wastewater treatment, this process can follow anaerobic processes to provide the additional treatment to improve the quality of the pre-treated effluents from the previous treatment units. Most of the aerobic systems used in Industrial Wastewater Treatment Plants are suspended growth systems. Rarely such aerobic systems may incorporate biofilms with suspended growth. Such reactors then provide both suspended and direct contact between the substrates and microbes. The nutrient load in industrial treatment plant is not as high as the wastewater coming from municipal sources so that, application of aerobic treatment is not applied more often. The following treatment methods are considered as types of an aerobic.

Activated sludge process

The organic compound also can be removed by an activated sludge process which is a biological process where the use of aeration tank followed by a secondary clarifier for settling. After a retention time of some hours, floating on the surface removed by an oil or grease skimmer. Then, the wastewater from the primary clarifier is delivered to aeration and the air is applied for survival of microorganisms. The returned activated sludge called RAS will enters the aeration tanks through sludge pumps and the wastewater are mixed. The remaining sludge called wasted activated sludge (WAS) from the clarifiers are pumped to the anaerobic digesters in order to produce biogas.

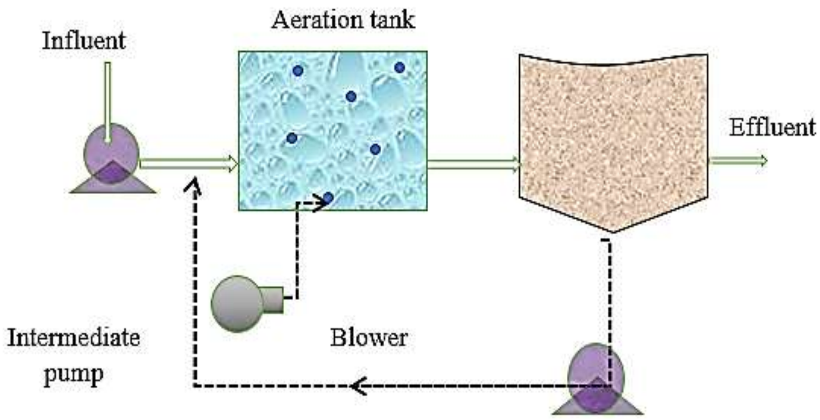


Figure 2.1 Flow diagram of the activated sludge (Libhaber and Libhaber 2009)

Trickling filter

This filter is classified as attached growth system of microorganisms treating the wastewater by consuming the coming substrate. It is a circular concrete structure the surface gives microorganisms an easy chance to grow. The trickling apparatus sprinkles the waste water over the course material. Aeration is applied to give the required oxygen for the bacteria to get the right living conditions. This easiest step of biological treatment is reducing the BOD_5 between 50 and 70%. Trickling filters are somehow common in such treatment plants which have been used to provide preliminary treatment of strongly organic wastewaters.

MBR (Membrane Bioreactors)

The removal efficiency of biological and chemical oxygen demand concentration using MBR technology is about 90% and 80% respectively The performance of the MBR unit was much superior to that of the functional ETP and the water treated by the MBR system can meet disposal standard (El-sheikh 2011). MBR system, combines the activated sludge process and the separation of biomass from treated water on porous membranes as shown on the figure below.

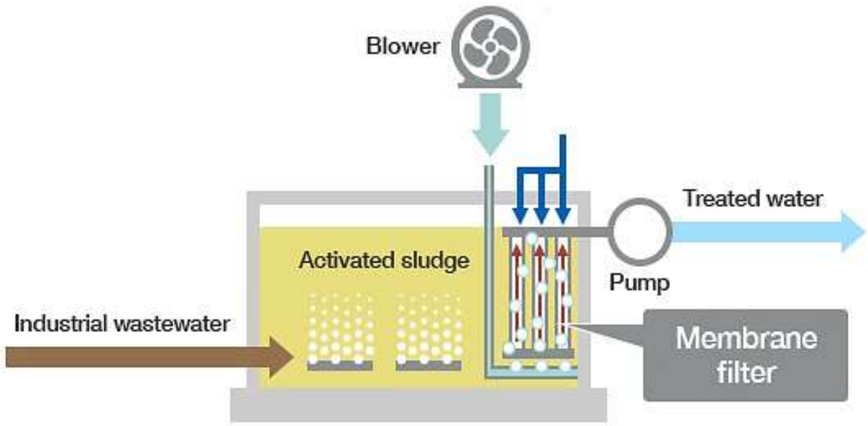


Figure 2.2 The Membrane Bioreactor treatment process (Source: Eco-MBR)

Sequencing batch reactor (SBR)

The composition of SBR treatment method is in happening in single reactor with batch and settling operations so that biological conversion takes place in the same tank in the system in back flow operation. It is preferred to treat wastewater compared to other technologies because of its efficiency and flexibility in resisting operating parameters (Jeppsson 1996). Oxygen is defused through the mixture of wastewater and activated sludge to reduce the organic matters like, BOD_5 and COD in a considerable way.

II. Anaerobic Processes

Anaerobic is process of biodegradation of matter without the application of oxygen in the system. Where complex organic compounds such as lipids, proteins, and carbohydrates are hydrolysed to simpler organic matter for further treatment.

The system has to be adequately mixed to avoid pH deteriorations which may adversely affect the process progress. The by-product of anaerobic reactions is commonly carbon dioxide and methane gases which will further used for electricity of other purposes as biogas.

The following treatment methods are considered as types of anaerobic treatment which can be applied in municipal and industrial treatment applications.

Anaerobic lagoon

Lagoons are classified as anaerobic treatment methods which are one of economical and effective ways of treating wastewater from small scale municipal and industrial discharges. As a result, many industries use a lagoon treatment to remove pollutants and heavy metals before immediate discharging to the receiving system. Lagoons require sufficient area and rarely used for industrial wastewater treatment in urban areas which are usually found away from urban areas and this means they are often associated with agricultural or agro-industrial wastewaters.

Septic Tank

The septic tank is a suitable and low-cost treatment technology and the easiest to use small scale anaerobic treatment method. It consists of anaerobic tank which is closed within a retaining time of 24 hours, sedimentation takes place and solids are retained at the bottom of the tank.

Sludge is digested in absence of oxygen in the tank which has a result in a reduced residual sludge. It has a removal efficiency of COD, BOD_5 and TSS reduction of 30%, 50% and 70% respectively.

Upflow anaerobic sludge blanket (UASB) reactor

UASB is a single chamber and a type of anaerobic wastewater treatment method it has high efficient in reduction of organic pollutants for municipal as well as industrial effluents. When the influent enters to the inlet point the flow directed to the suspended sludge blanket then filters and treats the wastewater as it flows in it. The microorganisms living in the residue consume the organic substrate by breaking it down anaerobically. The gas is separated at the upper section which can be methane, CO_2 or other gases.

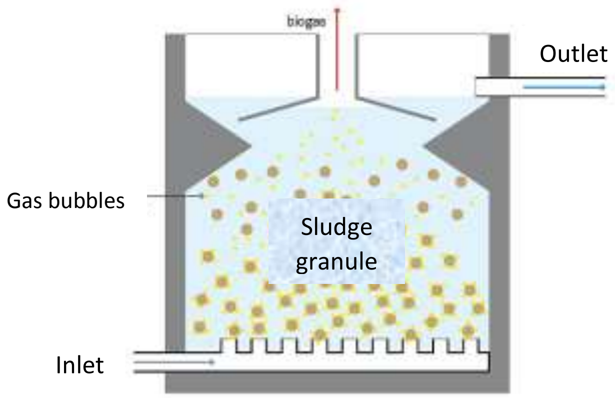


Figure 2.3 Principle of UASB reactor (Technologien and Wirtschaftsberatung 2001)

III. Anoxic systems

In wastewater treatment methods anoxic systems are used for the reduction of nitrogen compounds from a sewage. The process is called denitrification which needs the nitrogen to be first transformed to nitrate, which naturally occurs in absence of oxygen treatment such as aerated suspended growth processes the where water which is relatively treated is then open to an environment in the absence of oxygen for further digestion.

The main difference between anoxic and anaerobic tank is that, the first one is in total disappearance of free oxygen(O_2) and oxygen in a compound form like (NO_2, NO_3) and the previous one has deficiencies of free oxygen, but presence of oxygen in a compound form.

2.6.4 Tertiary treatment methods

An advanced sewage treatment method also called tertiary stage treatment is introduced in treatment sequence when it is necessary to obtain a water anticipated quality which is not likely happen by other biological treatment methods.

Some of examples of tertiary treatment methods are reverse osmosis, membrane treatment technologies, filtration and distillation where method selection is dependent upon the characteristics of effluent to be obtained after secondary treatment to decide for further use or disposal.

Filtration

Filtration in the water and wastewater define as a method where is it used to separate solids from suspension. The working principle of filtration is that, the mixture from the secondary treatment passes through a filter usually sand and gravel with mechanical separation processes.

In treatment process the particles which are considerably smaller than the bed void volume between the individual grains will retain between the sand materials which needs regular removal by backwashing. In case of backwashing, the filter process is reversed and the impurities of the filter are rinsed.

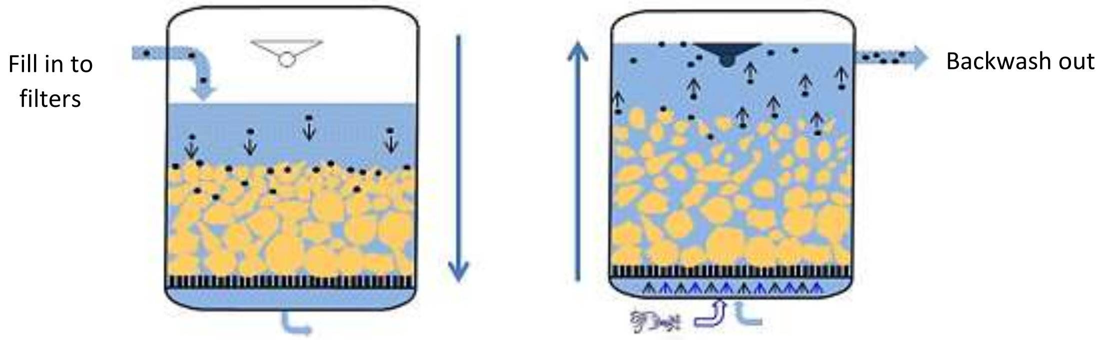


Figure 2.4 Filtration and the backwash process (Source: Chowdhury, Kumar, 2013)

Reverse Osmosis

Another commonly used membrane filtration technique in sewage treatment process is called reverse osmosis that eliminates many types of pollutants including ions and from effluents by application of external pressure to the sewage. It is also used to remove dissolved carbon-based constituents from wastewater which remain after advanced treatment process. RO system can function at 90 % efficiency or better with respect to dissolved solids reduction. It is also observed RO is effective in reduction of turbidity, bacteria and viruses.

Substance removal

Frequent removal of excess amount Phosphorus and Nitrogen content from the effluent reduces eutrophication and stagnation on natural water bodies. Phosphorous removal includes, filtration, chemical precipitation and biological assimilation. For nitrogen removal, biological nitrification and denitrification processes can be applied furthermore, coagulants can be used to eliminate the greyish colour of the textile effluent from dyeing process.

2.7 Sludge Management

Surplus amount of biomass in the reactor is not an appropriate condition since, it may exert an oxygen demand which is beyond the capacity of the installed aeration system. Excess biomass removal can be attained by desludging from the return sludge path coming from the secondary clarifier to the aeration section in continuous flow systems.

Sludge Thickening

Sludge thickening is manly used to make solids thick in density and decrease the volume with removing the moisture. Condensed sludge takes small space and chemical required to stabilize the sludge coming from settling treatment units.

Sludge Digestion

In industrial wastewater treatment anaerobic sludge digestion is rare because the content of organic matter is relatively low compared with municipal wastewaters whenever required the aerobic sludge digesters in industrial wastewater treatment plants can be designed as cyclic reactors. This can be a suitable mode of operation because excess sludge is unlikely to be wasted on a continuous source. Additionally, the recurring operations which allows the digester to stop aeration and settle the solids at the same place(Mogesse 2011).

Sludge Conditioning

When sludge conditioning is practiced in sludge treatment process inorganic chemicals such as iron containing salts and lime can be used in a ranged from 1–5%. To stabilize sludges lime can be added to reduce smell formation and putrefaction. Suitable dosages and adequate mixing are necessary to attain the desired sludge conditioning at the treatment plant. The risk of prolonged mixing can avoid deterioration of filterability of the sludge moisture.

Sludge Dewatering

Drying beds and filter press are the two more frequently used sludge dewatering devices at small scale wastewater treatment plants. The drying beds contain a layer of sand usually medium in size which is laid on a coating of gravel. On the other hand, the filter press is laid over drains or perforated pipes placed on the concrete floor serving as the underdrains which collect the filtrate draining from the beds.

The final water sludge is stored and disposed of at a landfill periodically. Sludge from industrial wastewater are not used as natural fertilizer or other, because of concerns over contaminants such as metals and excess nutrient content. If the dewatered sludge has not been stabilized, it has to be disposed of quickly and not stored for more than 2–3 days.

2.8 Sample Collection

In order to obtain an accurate representation of the wastewater sample, the collection, storage and analysis of the sample should follow the standard methods.
In wastewater quality analysis there are two types of sampling methods which are,

- Grab sampling
- Composite sampling

2. Wastewater Quality Analysis

The analysis of the samples is conducted in two ways, direct filed measurement and laboratory analyses with the help of chemicals and reagents. The filed measurement is very important to obtain physical wastewater parameters with a better accuracy because this are measured in-situ at the source. On the other hand, the laboratory analysis is important for the rest of physico-chemical analysis.

2.10 Optimized Treatment System

Wastewater treatment plants which are serving for decades, their efficiency reduces through time so that, it will not easy to achieve a required effluent quality to protect the safety of the human health and the environment. Therefore, upgrading and optimization outdated wastewater treatment plants is essential to meet the guideline limits within an economically responsible and environmentally sustainable way (Mahmoud A. El-Sheikh, 2011).

Reasons for optimization of a treatment plant can be,

- For persistent pollution control
- Based on the need for reuse of the effluent for other purposes;
- The increase of flow to the existing WWTPs due to increasing of service area.

Optimization of wastewater treatment plants have several benefits including:

- Allowing additional capacity in individual unit processes
- Reduction the energy use and costs associated
- Improving the ease and stability of plant operations; and result in an overall improvement in effluent quality

The effluent from the plant after proper treatment should meet the national and global quality standards whether for surface or land disposal.

An optimized wastewater treatment system also defined as a system which achieves a balance of the three segments, improved effluent quality before discharged to the receiving environment, improvement in hydraulic performance and efficient use of energy for operating units. The spot at their intersection can be referred to as optimized system.

Figure 2.5 Optimization of a system in wastewater treatment(Engineering 2015)

2.10.1 Effluent quality

Improvement in the quality of wastewater effluent is main target for successful process of a certain wastewater treatment plants in order to meet regulatory standards (Gillot et al. 1999). Identifying potential water quality problems such as high oxygen consuming pollutants, alkalinity, excess solids and undesirable substances which can affect the receiving water bodies will help to protect the habitat and the ecosystem in a significant way.

In order to optimize a given system of wastewater treatment plant it is very critical to know the performance of the whole system in terms of effluent quality. In order to do that the measured data from laboratory investigations and historical data from the plant can be used to know how much substance is removed in percentage.

2.10.2 Hydraulic performance

Hydraulic improvement of a wastewater treatment plants can lead to increase the treatment capacity as well as reduces the head losses in treatment plants. To improve the performance of a wastewater treatment system various method can be applied. The most common way to improve hydraulic efficiency of the plant is fixing some physical and operational parameters of the entire system for a better performance and minimized cost in terms of maintenance and operation.

2.10.3 Energy efficiency

For a wastewater treatment plant to be efficient and reliable it is not only the effluent quality that matters also the cost and need of energy required to operate the system. The improvement in energy efficiency can lower the energy utilization corresponding to effluent quality. Most treatment plants consume a huge amount of energy in different sections of the treatment processes. Aeration and pumping units are the main units takes more than 50% of the total energy supplied for the operation (Nolasco,2014).

2.11 Software Selection

Mathematical models contribute a lot in developing and understanding the behaviour of a system and operating approaches. A proposed system can be evaluated without building it. A costly or unsafe system can be experimented with by using a model rather than disturbing the real system (GPS-X Technical Reference).

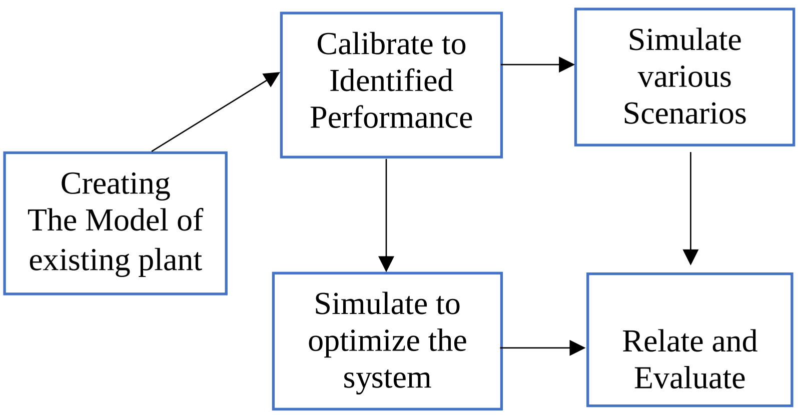


Figure 2.6 The flow of modelling using a software program (GPS-X tutorials)

GPS-X is a best, multi-functioning modelling program for municipal and industrial sewage treatment plants. It gives feature like addition of any new calculations and variables to model layout (GPS-X User Guide). No other software for modelling and simulation of wastewater treatment processes provides the power and flexibility available with GPS-X. It is state-of-the-art technology, using the most recent advances in process modelling, simulation technology, graphics and a host of productivity tools that simplify model(Jeppsson 1996).

GPS-X software v.7, was used to simulate the steady state and the dynamic behaviour of the treatment plant under the study. After constructing the layout of the plant, models, physical and operational data were introduced into the program then control and display variables were specified.

Differences between predicted and observed values were calculated after adjusting stoichiometric, kinetic and other parameters related to biochemical processes, like COD fractions. It was found that for model evaluation the characterization of the influent was the most important step, followed by knowledge of the effluent concentrations. The validated model will allow to undertake and optimization approach of the exploitation of the treatment plant under the study.

2.12 Steady State Versus Dynamic Modeling

Modelling is one of a tool which is used to understand the reality of a given system and predict its behaviour under different conditions. The main purpose of modeling is to simulate a system in order to investigate proposed development(Asmah 2016).

Static or steady state modelling in the design condition of an industrial treatment plant is used to represent average conditions over a relatively long period of time where the model variables reaches equilibrium state independent of time. Steady state models are based on the process type which could be fast such as chemical reactions and slow like microbial growth (Asmah 2016).

On the other hand, Dynamic simulation used to predict plant response through time varying and constant inputs. It is useful for diurnal or daily variations and prediction of the behaviour of biological systems under wet weather conditions (Pereira 2014). The dynamic simulation was performed with the same calibrated parameters from the steady state simulation using the same data input, except the flow rate.

2.13 Sources of Uncertainty

Uncertainty is happening about nearly every stage of laboratory analysis, data collection and the model itself which used for simulation. To reduce the uncertainty from field and laboratory activities, the instruments need to be calibrated for accurate measurement as well as various sampling techniques can be used to obtain the average values which can assure in reducing a wide variation of results because of external factors (Konikow and Glynn 2013).

Chapter 3:

RESEARCH METHODOLOGY

3.1 Introduction

The research methodology is the most important part of a research which describes the overall procedure in the process of achieving the objectives which are mentioned at the introduction section of research. The contents on this section are related directly related to the methods applied in determination of the wastewater quality from the treatment plant under study and looking the trends on the quality of wastewater compared to the receiving river. Further explanation is made about the software program used for optimization process for sustainable improvement.

3.2 Description of The Study Area

The city of Bahir Dar is found Ethiopia, in Amhara region which is located on the southern shore of Lake Tana. Several industries are established in the city, manufacturing different products for internal use and export purposes. Most of the factories are located at the edge of rivers for easy disposal of their waste discharge. Bahir Dar textile and two tannery industries are located at the edge of the Blue Nile river which is one of the contributing river to Nile river (Wondie 2009).

Bahir Dar textile factory is found at the head of Blue Nile river produces more than 17 tonnes of yarns and fabrics and has a manufacturing capacity of 100% cotton products which includes yarns and fabrics. For more than forty years, the textile factory discharges its effluent to the river with a certain treatment process.

However, after few years of disposal of raw effluent the factory owners planned to build a treatment plant which will treat the wastewater generating from the manufacturing process before reaching the river. The factory has an activated treatment system to treat some pollutants before discharging to the river Blue Nile.

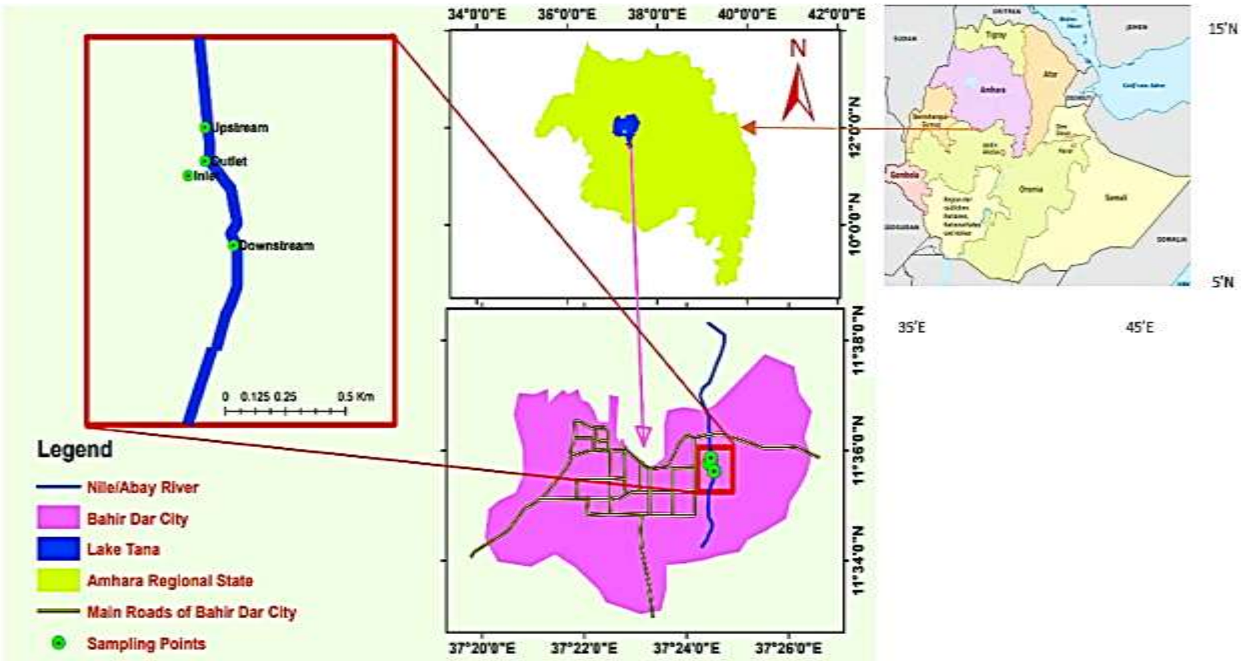


Figure 3.2 Location of Blue Nile river

3.3 Research Framework

The research methodology is the most important part of a research which describes the overall procedure in the process of achieving the objectives.

The following diagram shows the research framework applied in this study.

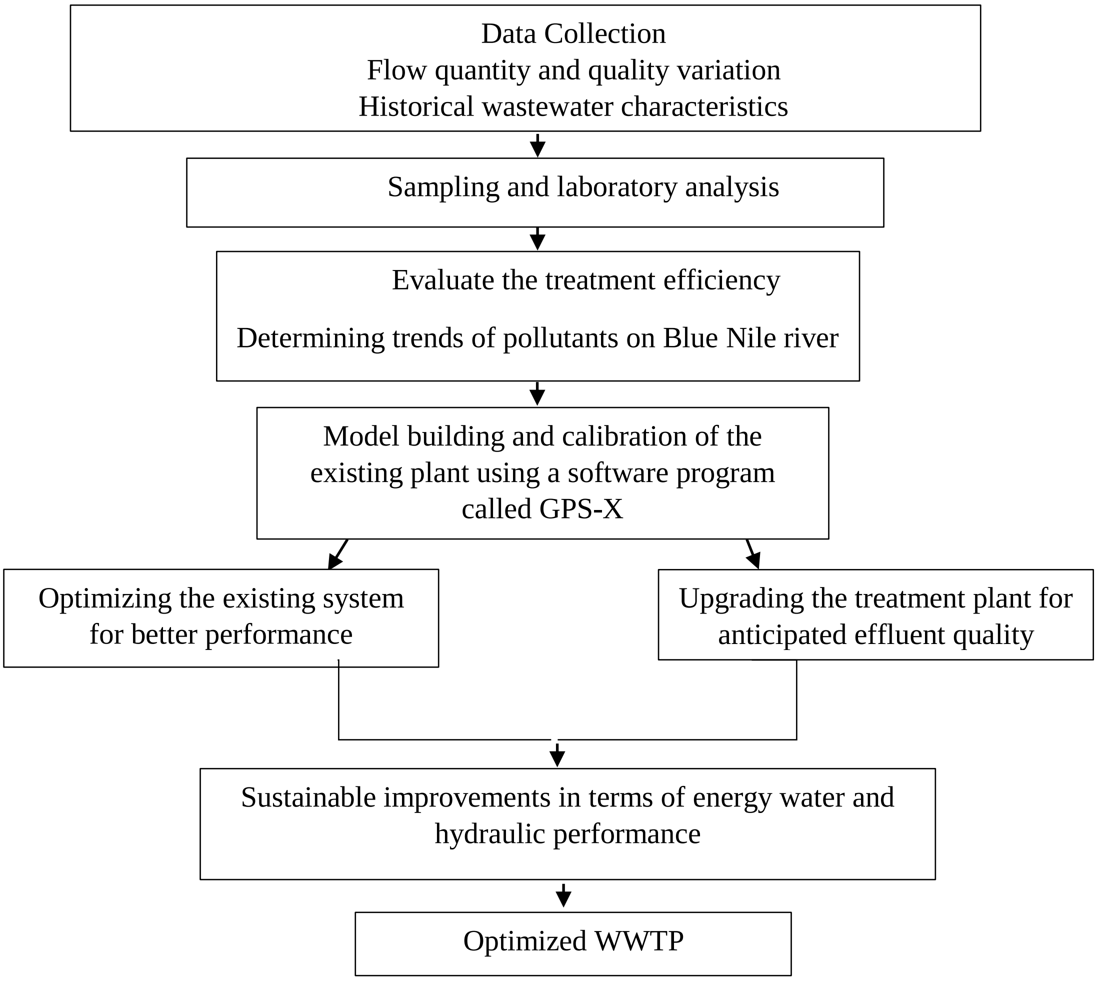


Figure 3.1 Research framework

3.4 Data Collection

The physical process data of the treatment plant, wastewater quality information and operational parameters were accessed in order to gather information about the influent and effluent characteristics which are important in the modelling process.

The physical input parameters were collected from the data sources from the factory respective offices. Parameters included in the data collection were the volume entering the treatment plant, water depth and normal depth, diameters of circular clarifiers, surface area and thereto. The operational parameters which are gathered from the site includes flow properties, pump properties and flow controlling devices.

The parameters analyzed in the laboratory include volatile suspended solids (VSS), total suspended solids (TSS), DO, COD and BOD_5, nutrients such as TKN (Total Kjeldahl Nitrogen) and TP (Total Phosphorus), Alkalinity and pH. The flow measurement was collected from the discharge measuring devices at different sections of the treatment plant.

3.4.1 Wastewater Sampling

In order to obtain an accurate representation of the wastewater sample, the collection, storage and analysis of the sample should follow a standard method. In this research Standard Methods for the Examination of Water and Wastewater is used as a reference for all procedures of wastewater collection and analysis (Federation 1999)

In wastewater quality analysis there are two types of sample collection procedures this are,

- Grab sampling
- Composite sampling

Grab sampling: Grab samples were collected once in a week from wastewater treatment plant at the sampling points.

Composite sampling: samples are collected based on time or flow and can be divided into three.

Time Sampling*:* This method is appropriate when the flow of the sampled stream is constant

Proportional Sampling: Collects a continuous sample in a desired volume at different time intervals proportional to flow stream.

Sequential Sampling: In this method samples are collected every 15 minutes, composited into separate containers each hour.

Continuous Sampling: Collect this sample continuously from the waste stream for analysis which give an accurate value compared to the above once.

3.5 Wastewater Quality Analysis

3.5.1 Sample site selection

The first sample was taken at the inlet of the treatment plant (influent) using a grab sampling technique immediately after the wastewater is entering the screening bars and mixing is applied. The next sample was taken at the outlet point of the treatment plant (effluent) to determine the treating efficiency of the plant samples were taken after treatment before reaching the river.

Figure 3.2 Sampling points along the river Blue Nile

From the figure above, the two sampling points (form the inlet and outlet) are used to determine the efficiency of the treatment plant of and this will lead to optimize the system. Additionally, two other sample sites were investigated in order to determine the pollution impact of industrial effluents to the receiving river.

The first one was at downstream of the river which is important to look for the impact of this discharges to the river water quality then at the far upstream point of the river where the textile effluents are not mixed.

For water quality analysis, more than two laboratories are involved because of the accessibility of equipments and chemicals in different places. Bahir Dar University

Institute of Technology Water Quality Laboratory is the main laboratory which helped to analyze main wastewater quality parameters pH, Temperature, Dissolved oxygen (DO), Total Nitrogen (TN) and Total Phosphorous (TP). Amhara design and supervision enterprise laboratory to determine chemical analysis of Ammonia Nitrogen, Total Kjeldahl Nitrogen (TKN) and Volatile Suspended Solids. The existing wastewater quality laboratory of the textile factory supported in assessing the historical data and determining COD, BOD_5, Total Suspended Solids (TSS) and Total Alkalinity.

To determine the quality of the Blue Nile river some data is collected and gathered from Abay Tefases office to compare the laboratory results and to ensure their proximity. The downstream quality of the river is affected by other factories including tannery, car washing and other small-scale enterprises. The national and WHO standards are used for a comparison for suitability of the effluents for disposal which is attached at the Annex of the paper.

The water samples were collected in a polythene-bottles having a volume of one litre. and prior to sampling each bottle was washed with diluted acid and distilled water and before actual sampling. The samples were labelled carefully and then placed in a temperature of 4^oC.

3.5.2 Field measurements

Measurements which are directly applied at the source of the sampling points are consider as field measurements. A mobile instrument is used measure wastewater quality parameters especially physical parameters like temperature, pH, TDS and biological once like dissolved oxygen.

Temperature

For determination of temperature a Multiprobe is used where it was inserted into the wastewater sample, upon the stabilization the temperature was recorded from the small digital screen in degree centigrade. Temperature also can be detected using a probe which can detect pH and electrical conductivity simultaneo1usly. To have a confidence on measurement device, the probe calibrated.

Dissolved oxygen

Winkler Method was used to determine dissolved oxygen in the wastewater sample where the sample was filled water and a series of reagents are added for titration then a color change is observed in the sample so that the of volume for titrant is measured for DO determination.

pH

In this research a digital pH meter is used to measure the acidic and basic nature of the wastewater. Current improvements on instrumentation on many varieties of probe designs is making the measurement of pH almost as simple and suitable as that of temperature measurement.

3.5.3 Laboratory analysis

Most of the water and wastewater quality investigations are conducted in a laboratory Here different procedures are applied in the process analysis that involves chemicals and reagents.

For Total solid determination, a well-mixed sample was evaporated in a weighed dish and dried to constant weight in an oven at 103°C to 105°C. The increase in weight over that of the empty dish represents the total solids(Federation 1999).

Total dissolved solids analysis was conducted by filtering a representative sample through a standard glass fiber filter then the filtrate is evaporated to dryness in a weighed dish and dried to constant weight at 180°C. After all, the increase in dish weight represents the total dissolved solids(Federation 1999).

TSS (Total suspended solids) in a wastewater was also determined through filtering the sample over a weighed standard glass-fiber filter and the residue retained on the filter is dried to a constant weight at 103 to 105°C. The increase in weight of the filter represents the total suspended solids(.On the other hand, The residue from TS, TDS or TSS is ignited to constant weight at 550°C. The remaining solids represent the fixed total, dissolved, or suspended solids while the weight lost on ignition is the (VSS) volatile suspended solids(Federation 1999).

For Chemical oxygen demand (COD) determination a closed dichromate reflux method (chlorimetric method) was preferred over. A wastewater sample is refluxed in strongly acid solution vessel then after digestion in COD reactor at 160°C for 2 hours, oxygen consumed is measured using a spectrophotometer(Paul 2011).

A five-day BOD can be determined by, filling the sample within a clean and an airtight bottle of the specified size and incubating it at the specified temperature for consecutive of 5 days at 20^{o}C incubator. After the initial DO is determined shortly after the dilution is made, all oxygen uptake occurring after this measurement is included in the BOD_5 measurement (Seif and Malak 2001).

The other physico-chemical characteristics important to determine was Ammonia nitrogen, to know the concentration Titrimetric method is used on the wastewater samples that have been carried through preliminary distillation.

Macro-Kjeldahl Method is used to determine the TKN concentration which is used in the presence of Sulfuric acid (H_2SO_4), potassium sulfate (K_2SO_4), and cupric sulfate ($CuSO_4$) catalyst, amino nitrogen of many organic materials is converted to ammonium.

In order to know the total phosphorous concentration, wastewater sample was kept into a micro-Kjeldahl flasks to measure a sample containing the desired amount of phosphorus (this is determined by the colorimetric method used).

3.6 Description of the Existing Treatment Processes

The Bahir Dar textile factory has an activated sludge system wastewater treatment plant inside the compound where the wastewater coming from different direction of the processing units being treated and discharges to the closest river Blue Nile.

The treatment plant has various unit processes which are in sequence to increase the quality of the wastewater before reaching the river.

The plant has primary, secondary and tertiary wastewater treatment processing units including

- Bar screening
- Grit removal
- Equalization tank, pH adjustment and mixing appurtenances
- Coagulation and Flocculation basins
- Primary clarifiers
- Aeration tanks
- Secondary clarifier
- Sand filtration
- Collection tank to balance the effluent discharge

Detail of the treatment process at Bahir Dar textile wastewater treatment plant is described as follows.

3.6.1 Primary treatment

Screening

Bar screens are provided at the inlet point of the treatment plant with 75^{o} inclination to maintain proper screening and removing of large floatable suspended dirts, solids, thread and waxy materials then immediately, cloth mesh is provided for further screening of tiny particles.

Some industries also favour having a screening at the beginning of the treatment plant they have, this assist trap to oil preceding to equalization tank for removal of solids and oil and grease. Equalization ensures that the effluent have unvarying characteristics in terms of contamination load, temperature and pH variation.

Homogenization (Equalization)

To balance the hydraulic load and flows from different sources of the treatment sections the equalization tank help to adjust optimum pre-aeration to keep uniform particle distribution through the effluent wastewater and able to reduce odour generation in the tank and in subsequent treatment units.

Neutralization

To maintain the desired level of acidity or basicity of the wastewater in the equalization tank pH should be adjusted which is measured by an operator in every one-hour interval by applying sulfuric acid (H_2SO_4) 98% titrate drop by drop until the pH is float between the range of 6-7. In optimum pH and temperature microorganisms become active in biological treatment units.

Flow rate adjustment

The hydraulic load or water flow rate should be set throughout the system at the flow meter reading to ensure the load in every treatment units. This protects the structures as well as removes overflows. The optimum flow rate is between the range (15,000-20,000 l/hr). The maximum flow rate become 40,000 l/hr in the rainy season due to addition of 90 mm depth rainfall is added to the system.

Cascade and zetap Reactor

Cascade and Zetap are one of treatment systems consisting of several similar stages with each processing the output from the previous stage. In this treatment process the electrolysis is used to separate the inorganic compounds (desired isotopes) from the wastewater. After setting the current and flow meter at each reactor the ions gather at the anode and cathode side of the system then, the droplets are collected at the bottom of the reactors for further treatment.

Primary and secondary settling section

After coagulation and flocculation process, wastewater flow into primary settling tank maintain at 15000l/hour stand quiescent in the tank for 6 hours until coagulated particles settle at the bottom of the conical shaped tank.

3.6.2 Secondary treatment section

Aeration process

In order to keep each inlet water molecule in the tank the adjusted flow stay in the aeration tank for 3 days period. The aeration is balanced with site DO measurement and valve adjustment. For effective treatment the DO out come from after 3 days aeration must be above 5mg/l

Secondary clarifier

Clear decanted water goes to secondary clarifier which circular tank for further clarification to 18-hour total retention period in a circular tank for one day at the adjusted flow rate. Microorganisms degrade the available substrate by anaerobic reaction and settling takes place as the same time. Solid and liquid mixture of sludge removed from the tank for 2-4 hours per day to the sludge thickening section.

Coagulation and flocculation section

Poly Aluminium Chloride(magna) and poly cromamide (PC) are used as coagulate to precipitate out metallic compounds and suspended matter and for de colorization of wastewater color.

For flocculation purpose, Anionic organic polymer (AP-POLY) is being used as suspended matter to large density and the floc aggregated to less decomposable organic sludge.

3.6.3 Tertiary treatment section

Sand filtration section

Treated wastewater goes to sand gravel layer in the metallic sand filter flow from top to bottom flow. All suspended solid impurity, turbid matter, colour causing particles removed here for final discharge. Back flow two times per day for 10-30 minutes back washing.

3.6.4 Sludge treatment section

Sludge is a solid content material which is coming from different unit processes like screening, primary and secondary clarifiers and other processes.

Sludge thickening

Sludge generated from the clarifiers goes to sludge thickening tank with AP-poly flocculant into large sludge blankets to separate solid from liquid in order to reduce liquid volume. Using a flocculator sludge and AP-poly chemical must well mix at the top of the tank in the mixing chamber.

At sludge thickening tank maintain sludge layer to half of tank volume to accomplish effective absorbance of solid separation. Chemical dose is 120l/hr-240l/hr or depend on sludge thickness in the tank. At least 5-10% of the moisture is reduced from the process.

Filter press

Thickened sludge is squeezed in the filter press plant to produce cake sludge. Its moisture drops between 70-80%. The sludge production is 2-5 grams per liter of wastewater volume. The minimum sludge production per day is 720kg from 400,000liters of wastewater in a single day in a dry season.

Sludge dryer sand bed

Solar sludge dryer sand bed used to dry sludge coming from thickener tank. The solid liquid mixture dries at this tank using solar heat source dried sludge is picked in sack for put in the store.

Sand beds fills with sludge coming from the thickener tank. In Ethiopian winter season it takes 6-9 day to remove solar dried from the bed. Sand bed dried sludge physically looks cracked black solid. The daily sludge production reaches 720 kilo grams where it is stress in a metal container for disposal.

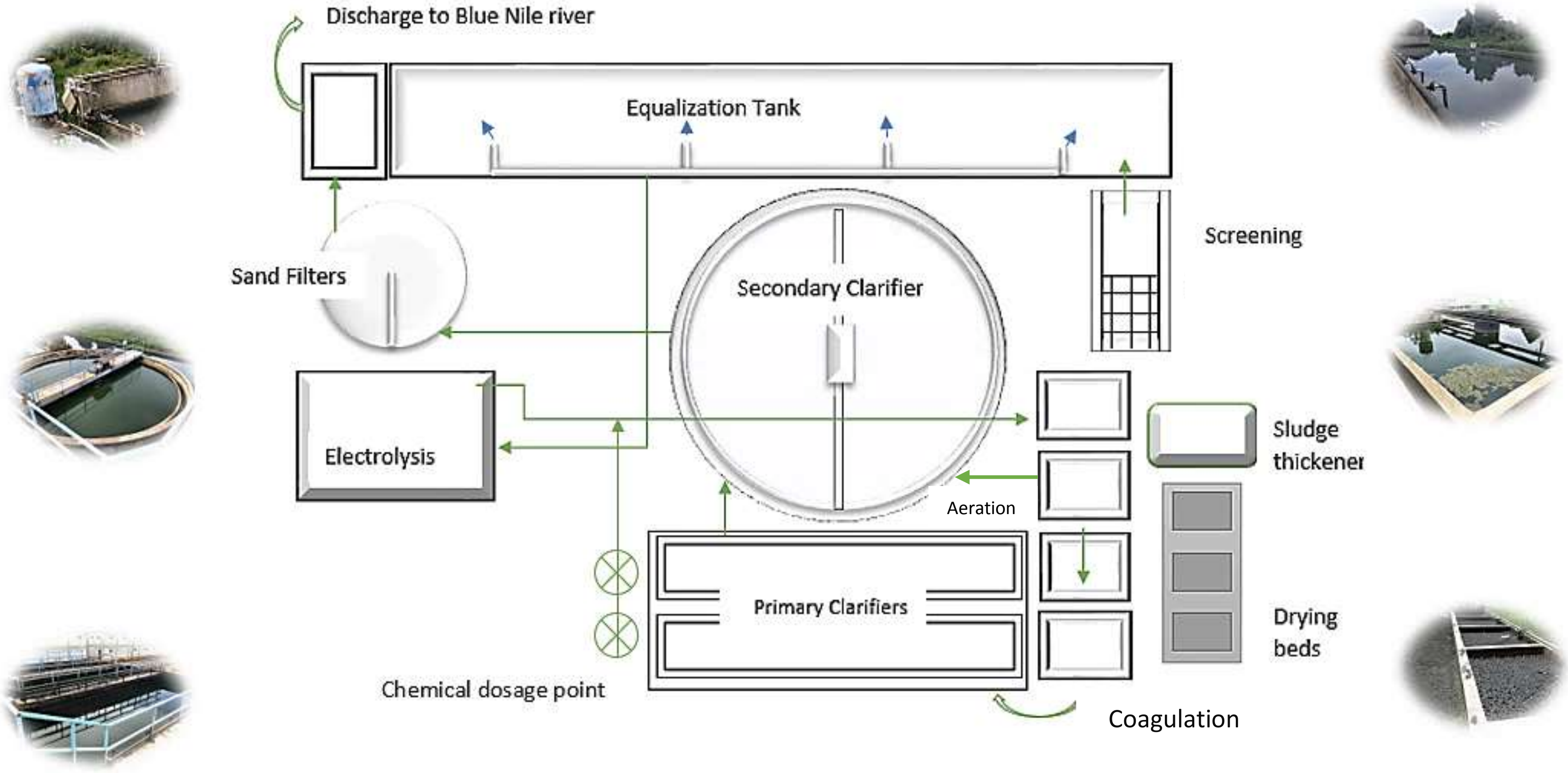


Figure 3.3 Schematic representation of BDT wastewater treatment plant

3.7 Treatment Efficiency Determination

To assess the efficiency of any treatment plant one should conduct standard wastewater quality analysis with proper follow up with the procedures this can help to determine the treating capacity of the treatment system for further investigation.

The treatment efficiency of a process E (which is expressed in percentage) is defined by the ratio between removed concentration of polluting and their initial concentration. The removed efficiency of component A in the system is given by the equation.

$$E_A = \frac{C_{A1-}C_{A2}}{C_{A1}} * 100 \quad , [\%]$$

Where:

C_{A1} and C_{A2} are the mass concentration of component A at the system input [mg/l] and output.

3.8 Optimization the Treatment Plant by GPS-X

Upgrading an existing system will advances the capacity in each process units to achieve the desired level of outcome. In case of wastewater treatment plants upgrading the process will help to optimize the plant for better effluent quality, reduction in energy use and cost minimization (El-sheikh 2011).

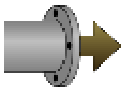
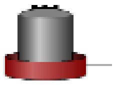
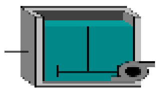
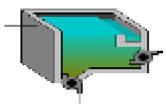
For a purpose of optimization, upgrading a treatment plant can be applied in different ways. From this methods computer programs are becoming very helpful in this time in terms of saving time and energy. From this software for this study GPS-X wastewater treatment plant software is used for optimization of the existing treatment plant under study.

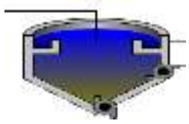
Graphical representation of each unit processes is depicted on the interface of GPS-X software. Each icon has its own parameters to be filled by the user, if input parameters are not available one can use the default values.

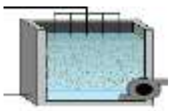
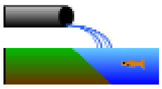
After getting the schematic diagram of the treatment plant, the first step will be building the plant layout in a graphical arrangement.

To build the system on the GPS-X interface each objects(icons) drag individual icons from GPS-X’s unit process library were selected and connected with a stream lines following the arrow.

Table 3.1 Symbolic representation and data used in the calibration of the model

Unit process	Physical data	Value and Unit	Operational data	Value and unit
	Temperature	33°C	Flow or discharge	400-1200m^3/d Average floe of 800m^3/d
	Influent pH	5.77		
	Local Temperature	20 °C	Chemical for pH adjustment	H_2SO_4 (conc.98% HCl (conc.35% HNO_3 (conc.68%)
	Liquid temperature	33 °C		
	Type	Rectangle	Aeration method	Blower
	Tank depth	0.75meter		
	Temperature	33°C	Maximum flow Liquid	1200m^3
	Surface area	2*24=48m^2	Oxygen transfer	Using DO controller
	Number of tank	3	Underflow rate	10m^3/d
	Clarifier type	Conical		
	Surface area Water depth	40 m^2 for each (total 120m^2)	Pumped flow	12l/s

	Local temperature	20^oC	Chemical dosage for flocculation	Aluminium Sulfate-$Al2(SO4)3.18H_2O$ (50%). Sodium Aluminate-NaAlO2(10%) Ferric Chloride-FeCl3(40%)
	Type	Bar screen (Metal)	Underflow	Constant flow of $10m^3/d$
	Inclination	75^o		
	Maximum flow	$800m^3$		
	Temperature	33^oC		
	Number of reactors	1	Aeration method	Diffused air
	Tank depth	4m	Total airflow	$3,190m^3/h$
	Max.volume	$800m^3$		
	Temperature	33^oC		
			Recycle fraction	Ras 1 0.3 Ras 2 0.7
	Clarifier type Surface area	Circular	Underflow rate	10% of maximum flow
			Pumped	12l/s
	Water depth	$4.5*8m=36 m^2$ 4m	flow Design MLSS concentration	30mg/l
	Type	Cylindrical		

	Depth	2m	Backwash flow Fraction	10% of maximum flow 0.02
	Maximum flow in	600m^3	Sold mass Fraction	0.8
	Surface area	7.5m^2	Pumped flow	12l/s
	Depth	1.5m	Removal efficiency	98%
	-	-	Flow data	Average discharge of 600 ^{3}/day
	-	-	Flow data	Average disposal of 720kg/d

GPS-X software has a set of models which can be applied depending on the necessity of a certain parameter to describe the other inputs. The choice depends on the available data that is needed for solving the behaviour of the required process.

The influent section has six models available to proceeded to modeling the entire treatment plant, which are based on basic variables corresponding to BOD_5, COD, TSS and sludge and this are bodbased, codfractions, codstates, states and tssfrac and sludge respectively. For this modeling purpose codstates is applied for the entire system since COD is the basic parameter to estimate other parameters.

Model selection for other process unit is based on the data available and the preference for the better approximation of the reality on the ground. The following table describes the reason for model selection.

Table 3.2 Model selection for each process units in the GPS-X software

Unit process	**Model type**	**Reason**
Influent	codstates	To determine the corresponding parameters based on COD value input
Screen	differential	Based on the behaviour of the unit process on allowing significant solids to the system
Equalization tank	noreact	The tank is serving to homogenize the influent for subsequent treatment
Chemical	acidfeed	The chemical input to the system is acid based
Coagulant	metaladd	Coagulants applied in the system id metal based
Aeration tank	mantis2	Which is the successor of ASM2
Primary clarifier	simple 1d	Biological reactions were considered to happen in a small extension
Secondary Clarifier	simple 1d	Incoming solids are distributed instantaneously and uniformly across the entire cross-sectional area
Sludge thickener	empiric	Due to the lack of specific data such as the solids capture, minimal sludge concentration for processing and organic and nutrient fractions of the sludge
Sand Filter	continuous	The flow of organic matter and wastewater in the filters is supposed to be non-stop
Effluent	default	It is the discharging point; no treatment is occurred

There are six libraries in the system, which have default values and expressions for the calculation of state variables. In this modeling the interest is in modelling carbon, nitrogen, phosphorus and pH then, the Comprehensive-Carbon, Nitrogen, Phosphorus, pH(mantis2lib) library was selected.

3.8.1 Calibration of the model

Model calibration is important for estimation of model parameter to fit a certain data obtained from treatment plant history and investigations.

For calibration propose an historical data of the treatment plant was gathered from previous laboratory results. The data used for calibration of the plant was from April to June which represents the dry and the wet weather conditions. The discharge entering the treatment plant was varying due to rainfall and direct runoff, these leads to the variation of concentration on some wastewater characteristics.

In GPS-X modelling program, there are state variables which can be adjusted by the user and composite (calculated) variables which does not need user input, instead the system calculates them as a fraction of total COD. The defaults values can be left as it is or the user can change them depending on the requires accuracy.

After physical and operational data was completed based of the available data from field measurements, the influent was characterized, in terms of COD, TKN and TP which are main parameters as input for the software. Influent characterization is the main calibration tool in GPS-X modeling program. User input section allows the user to feed the data based on available information.

Table 3.3 Calibration of parameters using influent data

Influent composition			
cod	total COD	gCOD/m^3	546.0
tkn	total TKN	gN/m^3	26.5
tp	total phosphorous	gP/m^3	13.5
Nitrogen compounds			
snh	Ammonia nitrogen	gN/m^3	12.5
snoi	nitrite	gN/m^3	0.0
snoa	nitrate	gN/m^3	0.0
Phosphorous compounds			
sp	Ortho-phosphate	gP/m^3	6.5
xpp	Stored-poly-phosphate in PAO	gP/m^3	0.0
Influent fraction			
ivsstotss	VSS/TSS ratio	gVSS/gTSS	0.72
Organic fractions			
frsi	Soluble inert fraction of total COD		0.25
frss	Readily biodegradable fraction of total COD		0.15
frxi	Particulate inert fraction of total COD		0.5
frscol	Colloidal fraction of slowly biodegradable COD		0.01
Nitrogen fractions			
frsnh	Ammonia fraction of soluble TKN	gN/gCOD	0.55
insi	N content of soluble inert material	gN/gCOD	0.005
inxi	N content of inert particulate material	gN/gCOD	0.0

The measured values from the treatment plant are applied to calibrate the system for further simulation. Once the influent characterization is applied the influent characteristics should be similar or close enough to the measured data. If it is not possible to get approximations modification of kinetic coefficients will be applied to procced to the simulation and evaluation processes (Learning and Gps-x n.d.)

3.8.2 Model simulation

The first simulation is run considering the default values which are already fixed by the software. The simulated and measured data are compared for their best approximation using a graph. When the accuracy is wide, further calibration (input values adjustment) is applied. For further simulation and interpretation of the model simulation will keep the system to be exact or close to the input parameters.
Close similarity of the measured data from laboratory and simulated values form the GPS-X software of the influent wastewater quality depicts the reality of the entire system. The influents characterization section of the simulation software allows to calibrate the values of the measured values for better accuracy by trial and error.

After calibration of the model measured data is used as an input and the simulation values are compared to actual data from the laboratory. For better approximation the electrolysis section of the treatment plant is ignored because of high disturbance of solid matters in the system of the treatment plant.

When an estimation of the parameters of a model has been carried out, it is important to check if the resulting model is satisfactory. This is done by model validation. This is often carried out by applying several methods. The figures below show the closeness of the simulated values with laboratory results in a batter way. This shows that the calibration section of the model was completed in a good manner.

After better fitment of the simulated values with measured data the next thing was to optimize the plant by applying different treatment options for better treatment especially, COD, TSS and pH. The plant can treat the carbonaceous BOD_5 more efficiently.

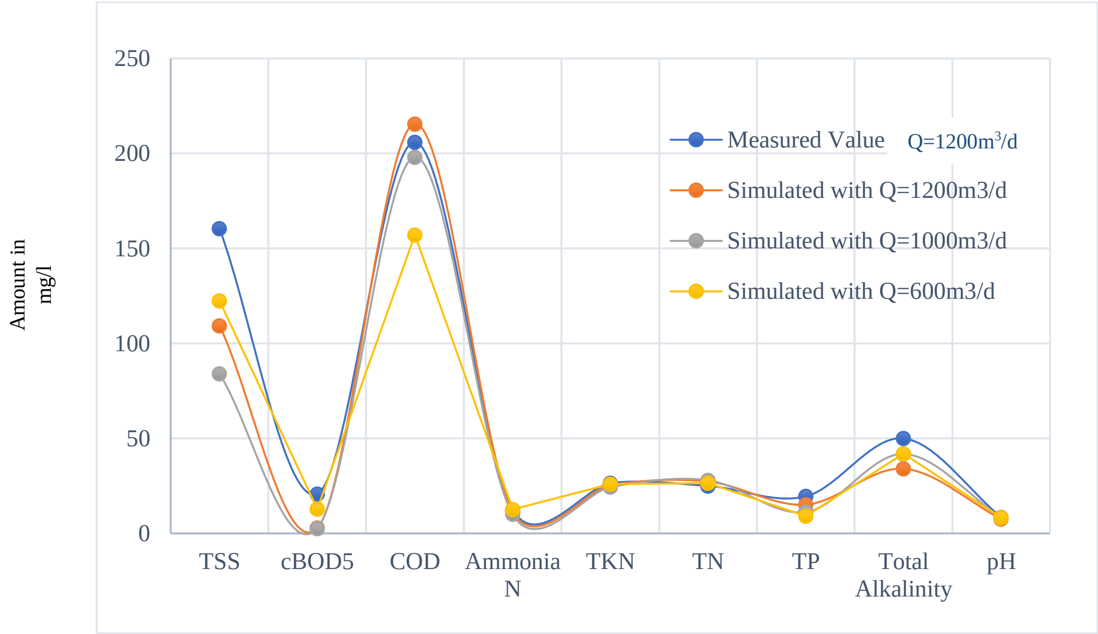


Figure 3.4 Comparison between laboratory results verses model output

As it is shown in the bar graph above, the basic input variables to the software and the measured values like COD, TKN, TN and Ammonia are the same because, they are the main input data in influent characterizing section. The others are generated after a calibration and validation procedures.

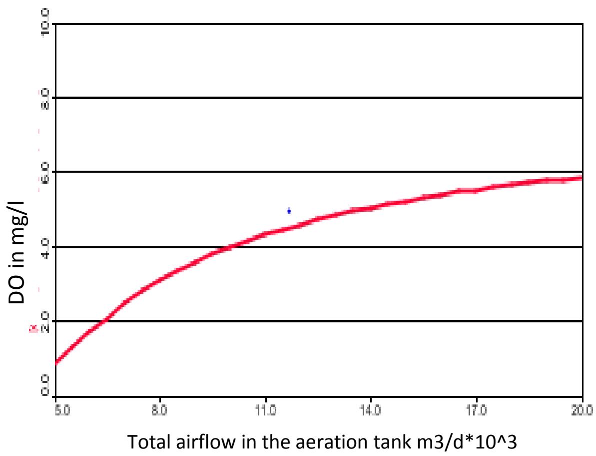
3.8.3 Sensitivity analysis

After the model parameters are sated up and calibrated the next thing following to achieve the simulation process for optimization of the system it is important to determine the impact of specific parameters which have a certain impact on the model outputs in a significant way.

The sensitivity of a parameter can be determined by increasing and decreasing its value and by observing the resulting changes in the simulation output. A little variation of the parameters considered having an impact of the entire system will be considered as more sensitive parameter compared to other inputs (Milathianakis 2017).

In this work, the determination of main wastewater quality parameters is used to calibrate the model as well as to determine the reliability of the model by using influent characterization section which is the main calibration procedure in GPS-X simulation program.

To identify the most sensitive parameters in the system the controller section of the software was used which helps to see the impact of the parameters on some of selected output variables. So that, the initial influent flow and the total air flow into the aeration tank are taken as the most sensitive variables which has a significant impact on Dissolved oxygen, TKN, Total nitrogen and Ammonia of the effluent characteristics section. A significant change is observed on ammonia concentration and dissolved oxygen as it is observed below.



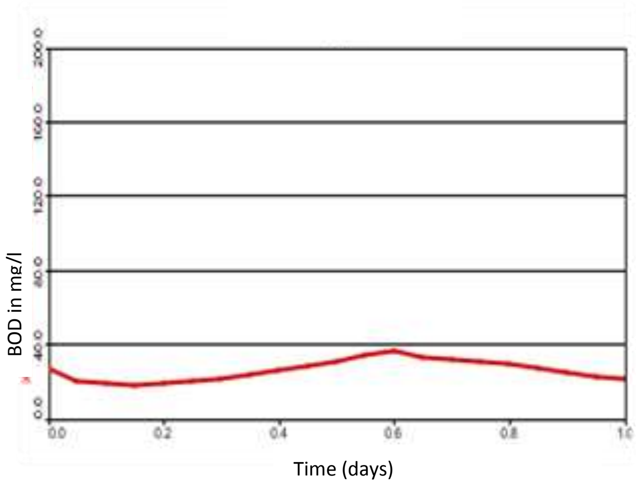


Figure 3.5 Phase and time dynamic sensitivity analysis

The above figures represent, the change in air flow in the aeration tank that affects the concentration of dissolved oxygen and BOD_5 in the final effluent. From this we can validate the model of the treatment plant since, the increase in air flow will automatically increase the DO in the wastewater.

3.9 Process Optimization

A better effluent quality can be achieved by upgrading the system and rearranging some of the parts of the treatment plant. Various methods and treatment options can be applied for treating the industrial wastewater coming from the system of manufacturing. The preference depends on the effluent quality required and in treatment without ignoring the operation and maintenance(O&M) costs.

To optimize the treatment plant the following options are considered,

I, Addition of a grit chamber and one more sand filter at the end of the treatment plant which enable to reduce the TSS concentration at the out let of the treatment plant

II, Introduction of a hybrid of anaerobic and anoxic tanks which is supposed to be located after the primary clarifier and activated sludge system. The aim of this configuration is to reduce the COD concentration.

III, Using MBR (Membrane Biological Reactor) technology after the primary clarifier section.

Chapter 4:

RESULT AND DISCUSSION

4.1 Performance Evaluation of BDT-WWTP

The raw wastewater is entering the treatment system from the inlet which is called Influent whereas the treated wastewater (effluent) which is discharged to the receiving water system. In order to assess the performance of the treatment plant, the amount of substance removed from the system can be determined by calculating the percentage removed from the raw water to end up as effluent concentration.

After the samples are analysed for physic-chemical parameters following the procedures mentioned in the methodology section, the following results are generated as an average data of the wastewater characteristics from the influent and effluent unit of the treatment plant.

The following equation was used to determine the efficiency of the rest of the parameters and the sample calculations of TSS and BOD_5 were done as follows

$$\text{TSS} = \frac{349.5-98}{360.7} * 100 \ = 71.96\%$$

$$\text{BOD}_5 = \frac{80.8-6.4}{80.8} * 100 \ = 92.07\%$$

The efficiency of the treatment plant in terms of TSS reduction was found to be 71.96% which is quite impressive, however the treatment plant should remove solids content up to 80% based on the requirement of surface discharge by WHO. If the TSS concentration is not controlled it affects the downstream river quality, so further improvement can be required.

The BOD_5 removal efficiency from the existing treatment plant system was around 92.07%. The concentration of the BOD_5 at the influent section was somewhat low due to the characteristics of the manufacturing process since, the textile industry has very low organic content compared of other industries.

As shown in the table below, the treatment capacity of the BDT wastewater treatment plant to reduce the chemical oxygen is nearly 62.27% of the COD is removed from the system at the outlet. The amount of COD remaining at this point was 206mg/l which is very far from EEPA and WHO guideline limits. For a better treatment the existing plant need to be improved for a better treatment which accepts the guideline.

The presence of excess ammonia in wastewater leads to undesirable and polluting species, etherification and stagnation along the river course. From the result below it was observed that the treating efficiency of the plant to remove total ammonia from the wastewater is 66.40 % which is low but the amount left to discharge to the river system may not be affected it because, if it is less that 20mg/l it is acceptable for surface discharge.

Total Nitrogen and Phosphorous removal should be not less than 80% based on standard discharge limits (Federation 1999). The removal of nitrogen is better compared to Phosphorous which need further removal from the system.

Table 4.1 Summary of treatment efficiency of BDT-WWTP

Parameters	**Unit**	**Inlet**	**outlet**	**Efficiency (%)**
Temperature	^oC	33	26.7	-
Turbidity	NTU	15.81	8.35	47.19
TSS	mg/l	349	98	71.92
VSS	mg/l	252	114.6	54.52
DO	mg/l	0.36	7.18	-
$cBOD_{5\ at\ 20^oC}$	mg/l	80.8	6.4	92.08
Total COD	mg/l	546	206	62.27
Soluble/ Filtered COD	mg/l	101.5	11	89.16
Ammonia Nitrogen	mgN/l	12.5	4.2	66.40
Total TKN	mgN/l	26.5	18.5	30.19
Filtered TKN	mgN/l	22.8	7	69.30
TN	mgN/l	25	7.56	69.76
TP	mgP/l	13.5	6.03	55.33
Total Alkalinity	$mgCaCO_3/l$	50	40	20.00
pH	pH unit	5.77	11.3	-

The amount of Nitrogen and Phosphorous shouldn't be in excess, because some algae and weeds spread with a little amount of this compounds. This may lead to eutrophication and stagnant condition of the river in locations where the river flow is very low.

Temperature, dissolved oxygen and pH are another very important quality of the wastewater for better treatment process in the treatment plant as well as after disposal of the effluent. Optimum level of this parameters protects the aquatic environment.
The optimum temperature of the effluent should be 25^{o}C based on the WHO standard. When the temperature is not in the optimum range it affects different part of the system. The pH is also another element should be seen for better discharge effluent. As shown in the table above the pH low at the inlet of the system where 5.77 which is below the range and acidic, this may be due to the addition of some chemical like Hydrochloric acid for pH adjustment at the beginning of the treatment process.

The amount of oxygen required by aquatic animals to survive is depend on the oxygen that is present in the water which is called dissolved oxygen present in water bodies in a dissolved means. The maximum limit of DO in water is less that 5mg/l (WHO,1999) for survival of fish species. At the inlet of the system the amount of DO is very low which is 0.36 but after all treatment process it increased to 7.18 which is still beyond the required amount by international standards.

The following graph summarizes the treatment capability of the system in percentage. Some parameters are well treated and most of them are not.

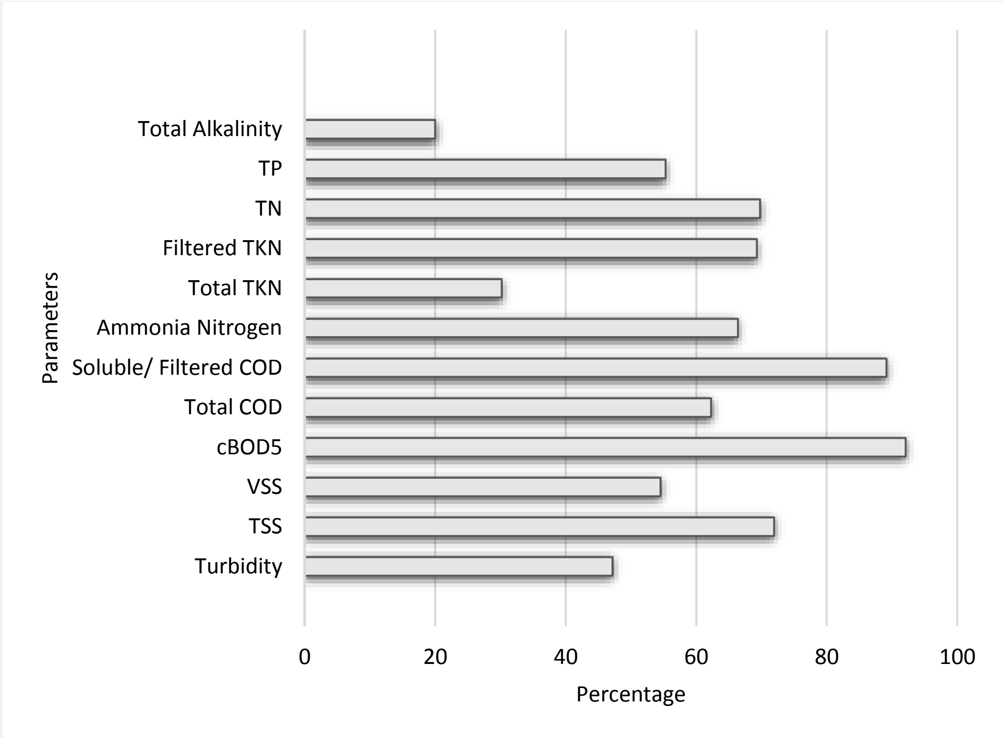


Figure 4.1 Treatment efficiency of the BDT wastewater treatment plant

The mean and the standard deviation shows the variability of the samples measurement in each parameter. For a matter of reducing uncertainty coming from the uncalibrated instruments and other external factors affecting the expected value of required parameters, it was important to take more than one analysis per parameter.

Three sample were grabbed from each sampling points for analysis of the parameters listed above. As we see from the table the deviation of the measured values is provided with standard deviation of the samples taken. The average or mean value is used in most places of the optimization process of the plant as well as for input for the software.

As it is seen on the above table most of the wastewater characteristics at the inlet of the treatment plant have high strength and far beyond the guideline limits. Turbidity, TSS, VSS and Total COD are on the other had pH and DO are below the standards. The temperature is in optimum level as well as the dissolved oxygen

Table 4.2 Average data of wastewater quality parameters of study sites compared to discharge limits of WHO, EEPA

Parameters	**Unit**	**Inlet (Influent)**	**outlet (effluent)**	**Upstream**	**Downstream**	**WHO Limit**	**EEPA Limit**
Temperature	^{O}C	33±1.2	26.7±1.5	24.5±0.7	27±0.5	<25	40
Turbidity	NTU	15.81±0.6	8.35±0.1	4.6±0.2	5.2±0.2	30	NA
TSS	mg/l	349.5±17.7	98±2.5	120±1.4	134±1.0	35	30
VSS	mg/l	252±3.3	114.6±1.7	135.1±1	121±1.1	30	NA
DO	mg/l	0.36±0.13	7.18±0.7	7.89±0.5	7.2±0.1	>10	NA
$cBOD_5$	mg/l	80.8±0.04	6.4±1.2	5.6±0.4	10.6±0.1	<40	50
Total COD	mg/l	546±9.6	206±3.1	45±0.5	313±11.3	120	<150
Soluble/ Filtered COD	mg/l	101.5±1.2	11±0.6	5.15±0.1	2.45±0.1	120	NA
Ammonia Nitrogen	mgN/l	12.5±0.9	4.2±0.2	9±0.1	64.3±1.1	30	20
Total TKN	mgN/l	26.5±1.2	18.5±0.1	ND	9.5±0.1	25	30
Filtered TKN	mgN/l	22.8±0.5	7±0.1	ND	7.45±0.4	20	NA
TN	mgN/l	25±1.9	7.56±0.1	9.8±0.4	63±0.2	60	<40
TP	mgP/l	13.5±0.5	6.03±0.2	4.82±0.4	9.8±0.5	10	<10
Total Alkalinity	$mgCaCO_3/l$	50±1.5	40±0.5	93±1	93.5±0.1	<75	NA
pH	-	5.77±0.3	11.03±0.7	7.8±0.05	7.1±0.2	5-9	6-9

Values are presented as mean of three samples and ± SD (standard deviation) ND = Non-Determined, NA=Not available

4.2 Impact of The Textile Effluent on The Receiving River

Effluent from industries which are disposed to a receiving stream, river or any water body likely affects the water quality of the system and the life around it. When water quality is poor, it affects not only aquatic life but the surrounding ecosystem as well the concentration change may lead to harm the aquatic life in significant way as well as human activities and it can be a threatening issue for their life and the animals they are rising (Zhezhova, Risteski, and Saska 2014).

Surface water has a high vulnerability of pollution compared to ground water since the discharge from industries is directly joining the system without any natural purification like subsurface waters. The river has its own self-purification process at various speed and momentum. For example, when the clay or organic particles settle out of the water, they take the metal atoms with them.

Unfortunately, few pollutants are very persistent in the water and can collected at downstream this can be an immense danger. This section presents the results of physio-chemical parameters as determined in samples at upstream and downstream head of the river Blue Nile and looking the impact of the effluent from the textile factory after a treatment process.

4.3 Status of Blue Nile River Around the Discharging Point

During sampling campaign beside determining the influent and effluent quality of the river, the water quality of the river is analyzed in a laboratory. The sampling points were at downstream and upstream of the Blue Nile river which is close to the textile effluent discharge point. The upstream point was 150m far from the point of treated wastewater discharge and the downstream point were 300m to the north of the textile factory.

The samples are taken in the same time from each point and analyzed in a laboratory for different parameters. This assists to know the impact of the effluent from the factory as well as other additional impacts from the surrounding non-point sources.

This is becoming obvious that, through the pollution of water bodies and human environment in the major rivers and lakes affected which present in the city. Likewise, Bahir Dar textile is discharging its effluent into Blue Nile River. In sight of the harmful impact of this effluent on the environment, the present study aimed at determining the levels of physico-chemical pollutants in effluent samples from this factory and assessing its impact on Blue Nile River.

As indicated on the above table, the average concentration of pollutants along the River showed that the concentration of the various pollutants varies depending on other contaminant sources at the downstream from the point where the effluent joins the river. There is no known evidence that shows the criteria used for the selection of the area as dumpsite regarding prior study of environmental issues.

4.4 Quality of Effluent and Trends

The physico-chemical characteristics of the effluent and the receiving stream should agree in a sense that the pollution is not significant for the water system as well as microorganisms living around the system. The following section will describe the trend of the wastewater analysed on the treatment plant respect to the river water quality.

4.4.1 TSS and Turbidity

Suspended solids are caused by the presence of matter like clay, silt as well as finely divided organic and inorganic matter and algae. This solids in a moving body of water tends to settle out at a various point or be carried longer distances, depending on their size and the rate of the flow this increase it turbidity.

From the sampling results it can be seen that the TSS (total suspended solids) are increased in a significant amount at the downstream of the river. The treatment plants were poor in solid reduction due to high solid content of the influent coming from the process of production. Only 71.9% of solid is reduces as it is shown at the first section of this chapter. The upstream of the river is also contains high solids which is 134±1.0 mg/l which is very far from the guideline limit.

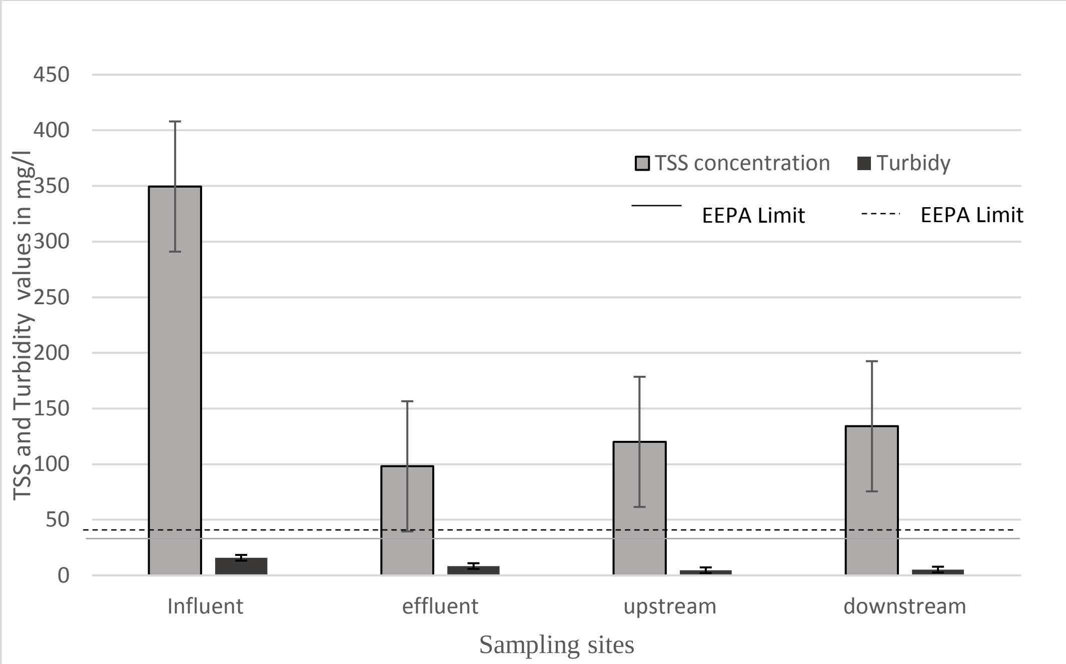


Figure 4.2 TSS and Turbidity concentration at sampling points

Suspended matter can affect the amount of light entering water and therefore restrict the amount of photosynthesis that can occur and therefore the growth of plants. Small particles settling out in large amount on the bottom of a water body can prevent some organisms from living there as well as preventing green plants from photosynthesising.

The increase in value of the TSS at the downstream of the river can be due to high influent load where the chemical application is inappropriate. The other reason can be the introduction other non-point sources to the system and this are sources are difficult to determine and mitigate.

4.4.2 Temperature and pH

Raising the temperature of the water lowers the level of dissolved oxygen and upsets the balance of life in the water. Some microorganism can't survive in the temperature less than 25^{o}C, this directly affects microbial degradation in the biological treatment processes.

pH value of waste water has no health implication but many chemical reactions are controlled by pH. Biological activities and some chemical treatment processes are usually restricted by pH.

The surface discharge guideline limit of pH value ranges from 6 to 9, as either high or low pH will be harmful to man, aquatic animals and it affects biological activity of the river if discharged untreated. The pH at the two points is falling between the guideline limit which are 7.8 and 7.1 at upstream and downstream points respectively.

Low pH level is a cause of fish kill by stressing animal systems and causing physical damage, which in turn makes them more vulnerable to disease and cause drastic changes in pH can have detrimental effects on river ecosystem. The pH is this case it between the allowable limit so there is no harm to the receiving water system.

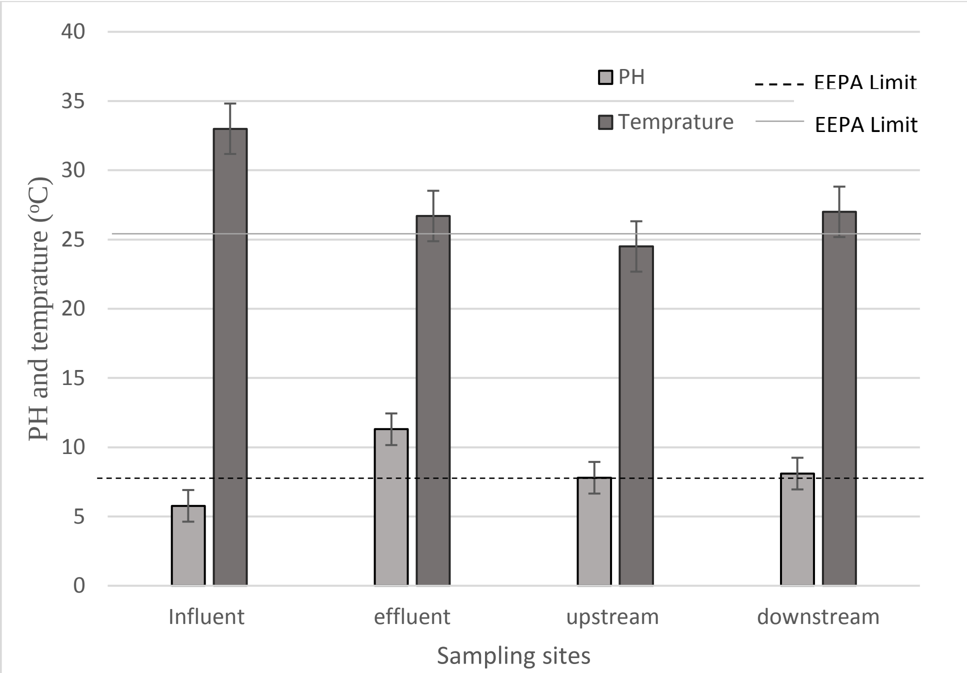


Figure 4.3 Temperature and pH variation at sampling sites

4.4.3 Dissolved oxygen

Oxygen is a vital compound for survival of aquatic organisms in a water system. Beside its biochemical property it has aesthetic impact on water odour, clarity and taste of the water system. Dissolved oxygen is essential to all forms of aquatic life including those organisms responsible for the self-purification processes in natural waters(Engineering 2015).

A little increase in concentration of some parameters like dissolved oxygen can lead to a significant alert on the fish life because the only source of oxygen for their survival is depends on the oxygen which is dissolved the water system.

From the analysis it is obvious that DO ranges from 7.89±0.5 at the upstream to 7.20±0.1 at the downstream. The dissolved oxygen is reduced slightly with 0.69 which is not a significant change considering the distance between the sampling points and self-purification of the river system.

The value can be related to the excess aeration of the treatment plant during homogenization and activated sludge treatment units as well as other sources at downstream of the river. The Do can be reduced by operational activities at the treatment plant as well as looking for other sources which lead to increase in DO at the upstream of the river.

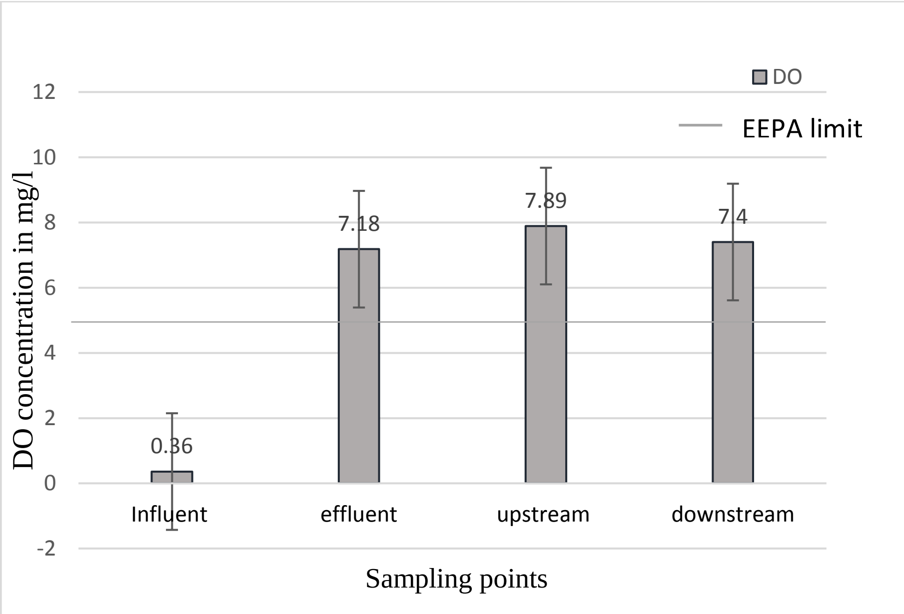


Figure 4.4 Variation of Dissolved oxygen concentration

4.4.4 BOD_5 and COD trend

The amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period is referred as BOD_5. The continued disposal of biodegradable organic waste into the water system leads to increased consumption of dissolved oxygen thus affecting the aquatic life.

The slightly low levels of BOD_5 at upstream and downstream sites which can be due to dilution effect and natural purification systems along the stream while the high value downstream could be due the vegetation cover and presence of decaying plant debris.

High BOD_5 indicates that there could be low oxygen available for living organisms in the waste water. The high BOD_5 may deplete dissolved oxygen, causing death of aerobic organisms and increase anaerobic properties of water (Jody and Dons, 2003). On the other hand, COD is a measure of oxygen consumption of water to decompose organic matter and some inorganic chemicals such as nitrates and ammonia.

The influent section of the wastewater was too high as 546±9.6 mg/l and the treated effluent about 206±3.1mg/l which was a significant reduction. However, it is still not satisfying the guideline limits to dispose it to the river. The water upstream had COD below EPA standards of 45±0.5mg/l. High concentrations of COD above EEPA standards were recorded at downstream indicating a heavy load of organic and inorganic pollution that require more oxygen to oxidise under increased thermal conditions. A high level of COD implies toxic conditions and the presence of biologically resistant organic substances in waste water.

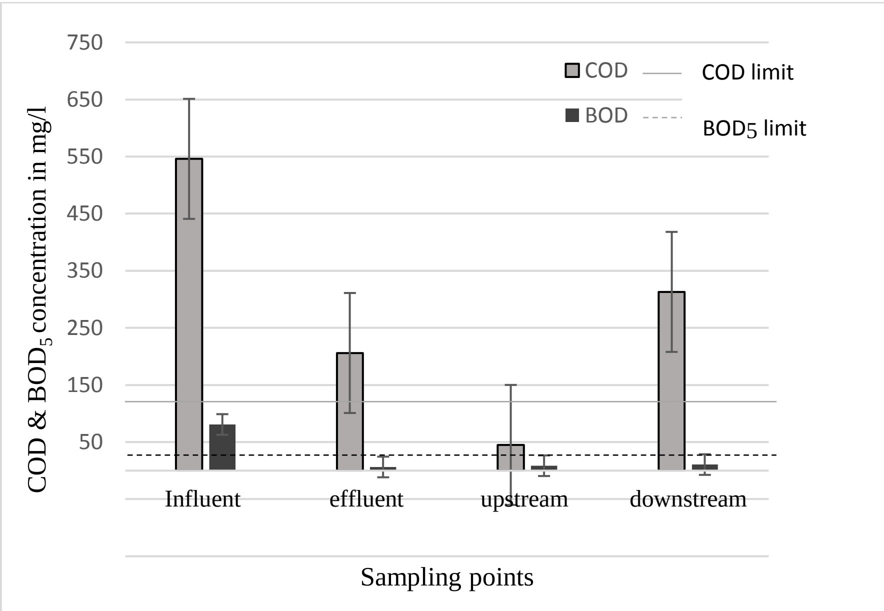


Figure 4.5 COD and BOD_5 concentration at sampling points

The COD concentration is expected to reduce at the downstream of the river however, their introduction of other sources at the downstream which is joining from other industries like tannery and car washing a significant increase of COD is observed.

4.4.5 TKN, TN and Ammonia Nitrogen

Nitrogen is an essential element for treatment plants and is often the limiting nutrient in water environment. Which is an important nutrient for the growth of biological life, and one of the primary components in living organisms. Total Nitrogen is a measure of all forms of nitrogen (organic and inorganic) which can present in industrial wastewater on the other had TKN includes other nitrogen compounds except nitrate and nitrites.

Total Nitrogen from the inlet of the treatment plant was 25±1.9 mg/l, after a treatment plant operation, it reduced to 7.56±0.1 mg/l, this shows the plant has a good performance in reduction of organic and inorganic nitrogen.TN at the upstream was as low as the treated effluent which was around 9.8mg/l, on the other hand high value of TN is observed at the downstream which was 63 mg/l, is probably due to joining of other non-point sources of pollutants which can be released from other small-scale industries around the river course.

TKN value was also significantly decreased from 26.5±1.2 mg/l to 18.5±0.1mg/l, which indicates the reduction was substantial from the treatment plant. It was not possible to get any TKN concentration from the upstream of the river whereas 9.5±0.1mg/l of TNK was observed at the downstream point. Excessive amounts of nitrogen in wastewater can be poisonous for water dependent organisms like habitat of fish and it is the main cause of eutrophication. However, the values of TN and TKN was not risky since it lies under the guideline limit.

The concentration of ammonia at the inlet of the factory was 12.5±0.9 mg/l and 4.2±0.2 mg/l at the outlet whereas 9±0.1mg/l of ammonia was observed at the upstream also a significant increase in ammonia recorded at the downstream which was 64.3±1.1mg/l. expect this value the other three are both values are far below the 30 mg/L maximum permissible national limit. High level of aeration at the treatment operation can be the reason for very low ammonia effluent concentration and the highest value at the downstream was due to tannery discharges and car washing enterprises at the downstream.

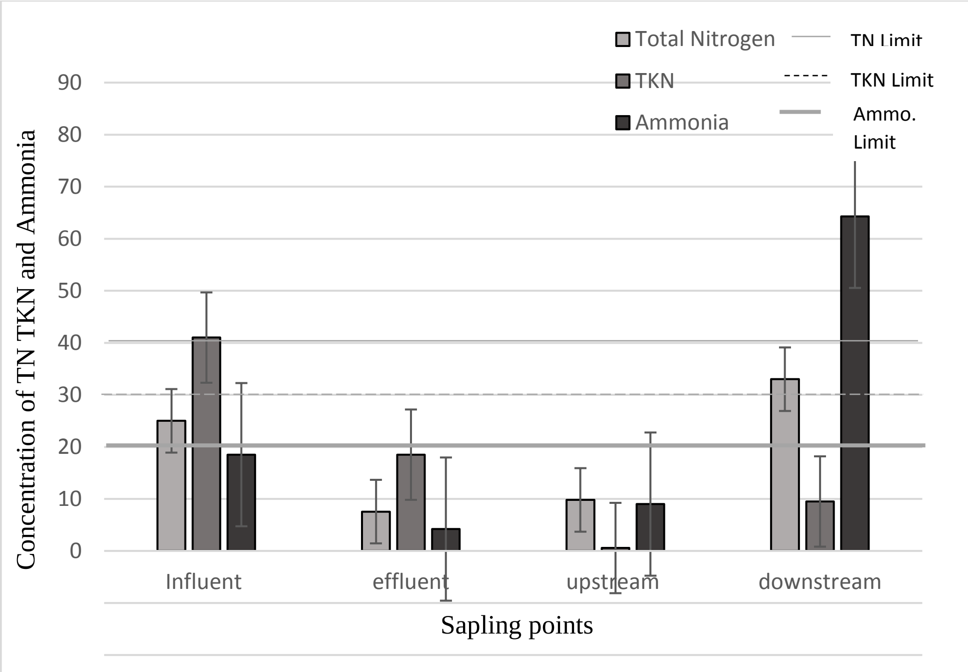


Figure 4.6 Concentration of TKN, TN and Ammonia at sampling points

As shown above, the ammonia concentration is higher at the downstream stream of the river. This can be due to introduction of nitrogen compounds at the river from other sources. Two tannery and small-scale car washing exist industries at downstream of the river the result is expected to increase due to the effluent from these factories.

The excess release of ammonia can be toxic to some forms of aquatic life. Other aquatic organisms, such as algae, may be limited in their growth until a nutrient such as ammonia or nitrate leads to an incident of explosive growth.

4.4.6 Alkalinity and Total Phosphorous

Alkalinity is the capacity of water to neutralize acid and is characterized by the presence of hydroxyl ions which is expressed in mg $CaCO_3$/l. Adequate alkalinity concentration should be available for the biological nitrification reaction to reach completion in water systems.

The amount of Alkalinity present at the influent was 50±1.5 mg$CaCO_3$/l and 40±0.5 mg$CaCO_3$/l at the exit of the treatment plant whereas 9±0.1 mg$CaCO_3$/l of ammonia is observed at the upstream which was very far difference from 64.3±1.1 mg$CaCO_3$/l at the downstream. This is may be due to addition of some compounds from other industries at downstream of the river.

Total alkalinity has been reported as a major factor which influences pH which leads to affect some treatment processes like biological units by creating unfavourable condition for microorganisms.

Total Phosphorus is a measure of both inorganic and organic forms of phosphorus. Phosphorus can be present as dissolved or particulate matter. It is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water.

The value of TP at the inlet and outlet of the plant was around 13.5±0.5 mgP/L and 6.03±0.2 mgP/L respectively. On the other hand, the concertation of TP along the river system was low compared to the above values which are 4.82±0.4 at the upstream and 9.8±0.5 at downstream.

If too much phosphate is present, algae and water weeds grow wildly, block the water way and consume large amount of oxygen resulting into death of aquatic organisms. This explains the low levels of total phosphorus observed along the stream because algae were observed at some sections along the stream.

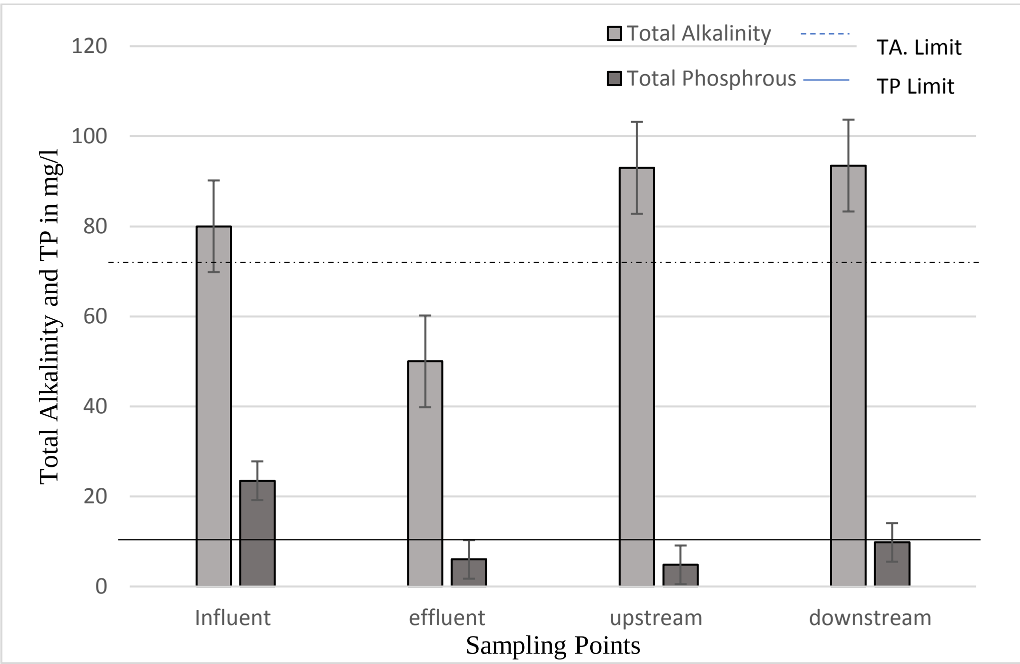


Figure 4.7 Concentration of TP and Total Alkalinity at sampling sites

Furthermore, excess concentration of Nitrogen, phosphorus, or both may cause aquatic biological productivity to increase, resulting in low dissolved oxygen and eutrophication of lakes, rivers, estuaries, and marine waters (Perry et al, 2007).

Generally, the downstream water quality of the river is affected with increase in some characteristics or parameters. This is happened due to two significant reasons

1. The poor treatment performance of the treatment plant from the textile factory in terms of treating TSS, COD and other parameters which have a significant impact on the river ecosystem.
2. Some other non-point sources which are directly getting into this location from upstream side. From this suspected site small scale leather and car washing industries are located on the other side of the river which are disposing their wastewater directly to the river. The optimization of the treatment plant and upgrading the entire system can solve this problem of downstream pollution.

4.5 Optimization Using GPS-X program

In order to optimize the given system, GPS-X software program is used to assess the BDT-WWTP and optimize the system for better quality effluent. The development of the model relies on the available measured data. GPS-X is the most advanced tool available for the mathematical modeling, simulation, optimization and management of wastewater treatment plants with comprehensive database of unit processes. In order to do that it is mandatory to enter characterization data and run simulations.

To optimize the treatment plant there are two options considered to be applied in order to get a better effluent quality. The first option is optimizing the existing treatment plant without upgrading physical units in a sense that the operational parameters and concentration of dosage of chemicals and related section of the plant can be alerted to increase the performance in terms of the required wastewater characteristics.

The second option is upgrading the plant by removing some units and replacing them with new ones. The process can affect the efficiency of each unit process which are successor unit of the system. This is mainly by upgrading the system through adding other treatment options or by removing inefficient treatment units from the system to achieve the desired effluent quality.

4.5.1 Optimization of the existing system

Optimizing refers to making something as good as possible to meet a certain activity. In case of wastewater treatment plants, as mentioned at the literature section of this paper the optimization strategy goes to the following points

- Better quality of effluent
- Better hydraulic performance and operation
- Better energy use and consistency

Modeling has been used in several treatment plants to evaluate and optimize operations. GPS-X software has a specific tool which comprises a library of target variables and specific variables which can be subjected to change for a better optimized system.

The target variables can be the parameters which shows the effluent quality in terms of concentration. For instance, to reduce the COD in the final effluent some specific variables must be alerted which are corresponding to COD increment and reduction in treatment course. While doing tis the operation of the plant should not be affected in a significant way.

In this research in order to achieve the above points two options are taken as a better improvement of the treatment plant of Bahir Dar Textile factory where as the options are modelled simulated applying adjustment of physical operational and other parameters which can have an impact on the effluent quality at the end of the treatment process.

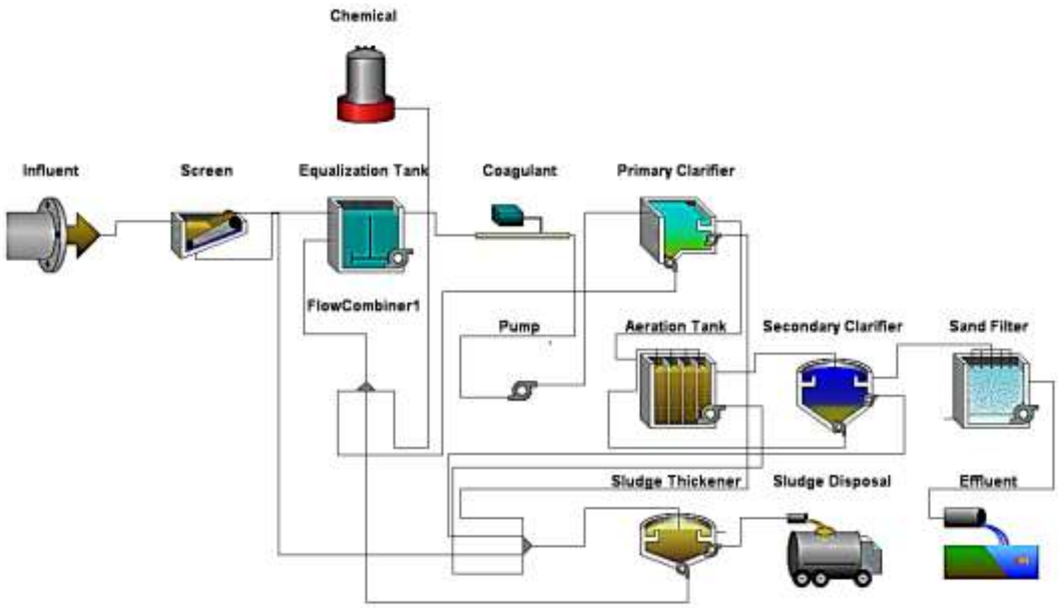


Figure 4.8 Schematic diagram of BDT-WWTP by GPS-X modelling program

The above figure demonstrates the model created representing BDT-WWTP where most of the unit process are adjusted to fit the existing system as mentioned in the first section of this chapter. In order to optimize this system for better performance, the following variables alerted and the reduction of most of the parameters were observed.

Table 4.3 Some variables change for optimization of the actual system

Target variables	**The model**	**Optimized model**
Flow type	Constant flow	Considering the fraction of influent flow
Primary clarifier Sludge blanket concentration	500mg/l	200mg/l
Air flow in the aeration tank	10000 m^3/d	14233m^3/d
Sand filter	Backwash flow fraction=0.02	Backwash flow fraction=0.2

After a simulation of the system where some variables are adjusted a 7-day simulation is applied in order to see the changes in water quality parameters at the end of the treatment system. The GPS-X software generates an effluent quality in a tabular form and it was possible to see and compare the optimized results with the data of the existing treatment plant performance.

Table 4.4 Overall results after optimization of the treatment plant

Parameters	**Unit**	**Actual system**	**Optimized system**	**Difference**
TSS	mg/l	206.5	97.6	8.9
$cBOD_5$	mg/l	20.8	9.3	11.5
COD	mg/l	206	77.6	128.4
Ammonia N	mgN/l	6.5	0.9	5.6
TKN	mgN/l	26.5	3.06	23.44
TN	mgN/l	17.56	21.3	3.74^-
TP	mgP/l	11.5	9.2	2.3
Tot. Alkalinity	$mgCaCO_3/l$	45	11.2	33.8

From the above changes we can see that, there is a substantial reduction after optimization of most of the parameters except a bit increment of nitrogen concentration. About 97.6mg/l of TSS was observed after optimization where the actual concentration was 106.5mg/l which is around 8.9mg/l.

The system was well optimized in terms of COD reduction which was 206mg/l in the actual system and it goes to 77.6mg/l which was more that 100% reduction. Furthermore, the total alkalinity and TKN reduced in a significant amount.

Generally, a limited number of specific variables brought this much significant change in the effluent quality without any further construction. The optimization is recommended for a better effluent quality BDT-WWTP. In case of no possibility to implement this method, the following section of this chapter will describe the other methods to optimize the system in an intricated way.

In order to improve the effluent performance of the treatment plant the other possibility was to upgrade the system by replacing or removing the inefficient unit processes. The treatment plant was observed in poor treatment performance in some wastewater parameters were this parameter can be addressed to reduce their quantity and impact on the receiving water system.

To upgrade the system, it was very important to determine what type of treatment technology can be applied to get a required concentration a certain water quality parameter. Various options are considered to improve the effluent performance by implementing the simulations and analysis using a GPS-X software.

4.5.2 Upgrading to reduce TSS concentration

Most of solid concentration is trapped at the beginning of the treatment flow especially at mechanical treatment section with the help of screens and grit chamber. Beside the role of clarifiers to reduce the solid reduction tertiary treatment option like sand filters can play a great role on this.

The first upgrading option was an addition of a grit chamber immediately after screening and one more sand filter at the end of the treatment plant which enable to reduce the TSS concentration at the out let of the treatment plant in a significant amount.

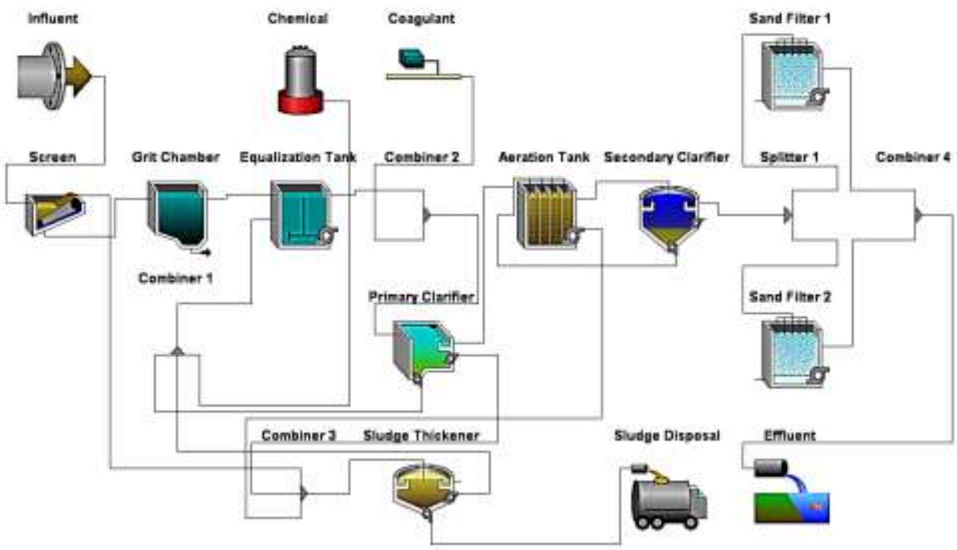


Figure 4.9 Diagram of proposed modeling of TSS reduction in GPS-X

Where most of the solids are retained at the screening structure however, suspended solids have a high possibility to pass from the screening because they are smaller than the screen size.

In order to reduce such solids addition of a girt chamber helps in trapping the grit materials from entering the system. On the other hand, adding sand filter at the end of the treatment plant also reduces some amount of the residue remaining in the system. The following table summarises the effluent quality after simulation.

Table 4.5 Summary table for results of proposed plant effluent.

Parameters	**Unit**	**Value**
Flow	m^3/d	1200
TSS	mg/l	17.89
$cBOD_5$	mg/l	6.15
COD	mg/l	165
Ammonia N	mgN/l	0.16
TKN	mgN/l	9.93
TN	mgN/l	154
TP	mgP/l	37
Total Alkalinity	$mgCaCO_3/l$	6.08

From the above table, it is clearly seen that, the reduction of TSS, BOD_5 and Ammonia was in a significant amount due to the change in some operational parameters. The TSS value reduced to 17.89 mg/l from 98 mg/l, ammonia from 4.2 to 0.16 mg/l and BOD_5 from 20.8 to 6.15 mg/l also a reduction of Alkalinity was seen in a substantial way. Whereas, the COD concentration is not in a required level. The amount of COD at the end of discharging point should not be more than 120mg/l which needs further treatment to reduce the concentration.

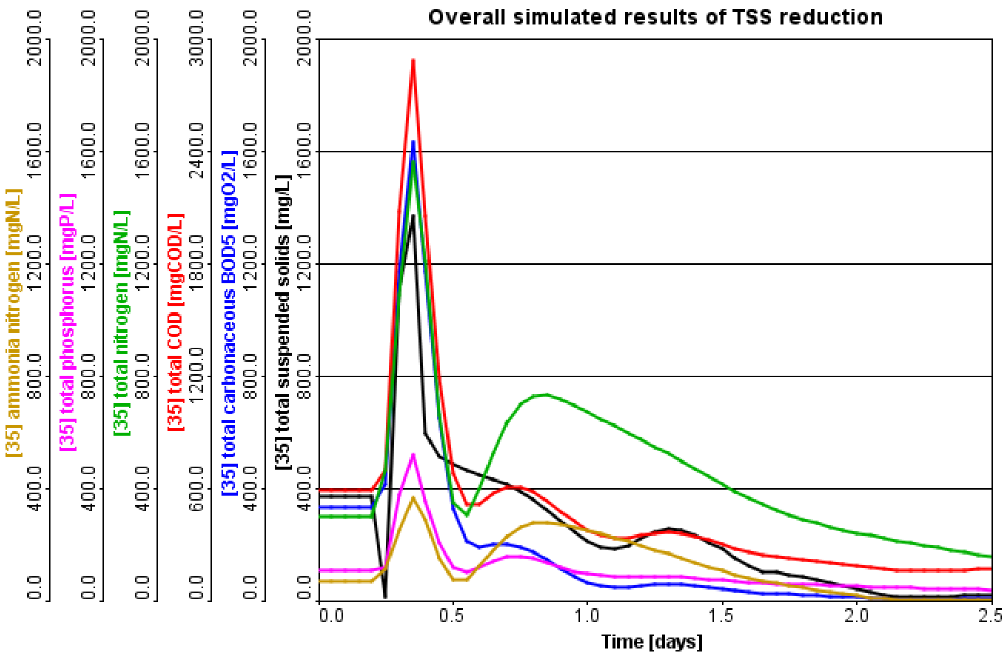


Figure 4.10 Reduction of TSS and BOD_5 after first upgrading

In comparison to other technologies maintenance and operating costs are low as well as the no need of chemical dosing or pumping system since influent can flow by gravity into the filter unit from the top of the tank.

4.5.3 Upgrading with a hybrid of anaerobic and anoxic tank

This layout demonstrates the process for COD, ammonia and phosphorous removal where the secondary treatment consists of an anaerobic tank, anoxic tank, aerobic plug flow reactor, and a secondary clarifier.

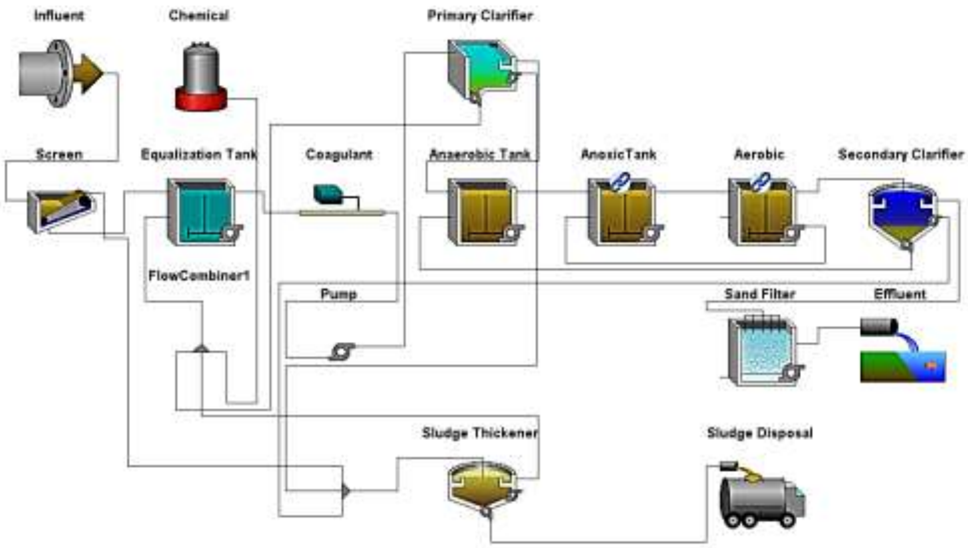


Figure 4.11 Layout of the treatment plant with series of biological reactors

As it is shown above, the existing plant is followed by two tanks after the primary clarifier. The maximum volume in each tank was fixed to be 1000m^3/d with a pumped flow of 50m^3/d and the dimensions are 46m length, 6.5 width and 4m depth. The remaining parameters are left as default.

The RAS (reversed activated sludge) stream returns to the first anoxic zone, reducing the number of nitrogen compounds like nitrates and ammonia nitrogen those are entering the anaerobic zone. In the treatment process high level of aeration can be applied in order to have very low ammonia effluent concentration.

Figure 4.6 Simulation results after upgrading with hybrid of anaerobic and anoxic tank

Parameters	**Unit**	**Value**
TSS	mg/l	1.17
$cBOD_5$	mg/l	8.98
COD	mg/l	38.61
Ammonia N	mgN/l	2.88
TKN	mgN/l	4.59
TN	mgN/l	30.84
TP	mgP/l	0.69
Total Alkalinity	$mgCaCO_3/l$	10.66

The influent COD into the system was 546mg/l which is reduced to 38.6 mg/l. the existing treatment plant was treating 206mg/l only 62.3% removal which was still above the guideline limit of EEPA and WHO too. So, the proposed system here reduced the concentration by 93%. On the other hand, a significant reduction of phosphorous is observed at the end of the treatment where 0.69mg/l from influent concentration of 23.5mg/l which shows 97% removal.

This showed that has high performance to remove COD and Phosphorous concentration. This technology can remove a considerable amount of TSS too. When the mixture enters the first clarifier, a fraction of anaerobic microorganisms also settling down with the recycled sludge from the secondary clarifier and it has the ability to remove ammonia through nitrification.

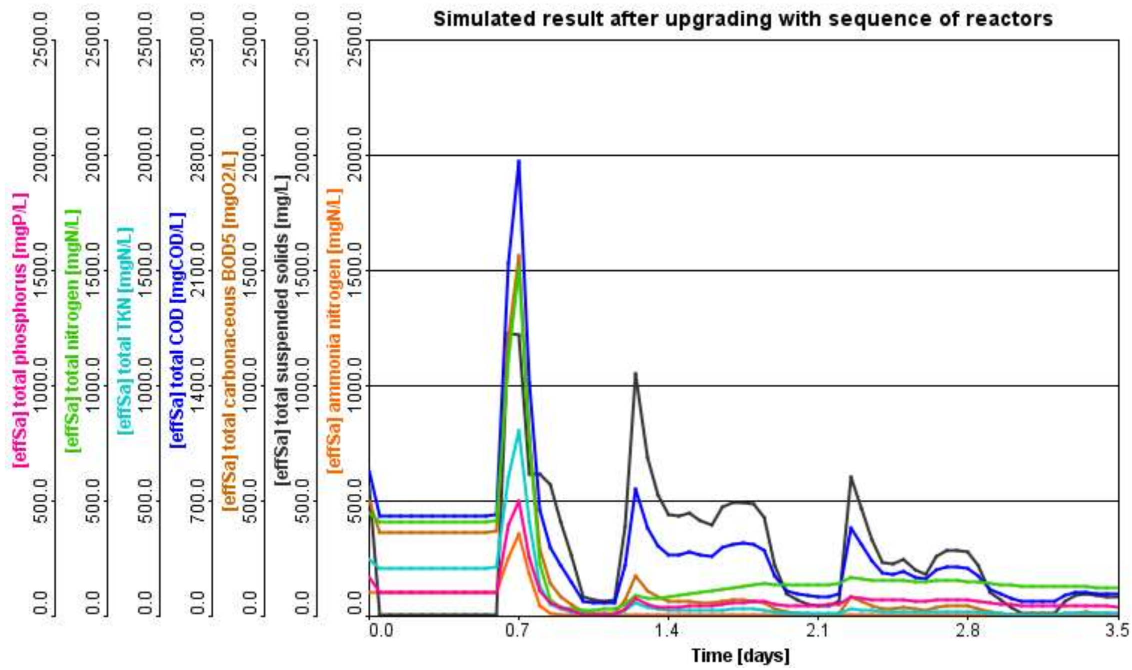


Figure 4.12 Final effluent concentrations diagram for the proposed system

As shown from the graph above, the first days the flow was going smoothly until some chemicals and coagulants are added to the system to balance the pH and help settling of solids. After the mixed flow passes from the equalization tank to anaerobic tank the reduction of most of the parameters was observed.by the end of the 3.5 days most of the parameters are reduced in a significant manner.

The proposed plant shows a high reduction of most of the pollutants to a desired level of effluent quality. Therefore, using this sequence of treatment train for upgrading the plant has an important effect in the future improvement of the treatment plant of the BDT wastewater treatment plant.

The simulation was applied for a week which is seven days since the reaction takes time because of microbial degradation at the anaerobic tank. For a clarity purpose the above graph is captured for 3.5 days this helps to see the lines clearly and neatly.

Both in aerobic and anaerobic treatment there is an urgent need for better control and regulation. Particularly on-line monitoring of the biologically removable load (BOD_5, COD) and the possible presence of toxicants is necessary, to improve both types of processes as well as their combined application.

It is evident that a long solids residence time (SRT) is necessary for the treatment of sewage by anaerobic processes, because of the low specific growth rates associated with anaerobic bacteria.

anaerobic sewage treatment may be economically feasible only in warmer climates. The use of solids filtration in conjunction with an anaerobic reactor might be a useful combination.

4.5.4 Replacing the activated sludge with MBR technology

MBR is one of the new technologies which separates the water from the sludge within the aeration tanks and therefore, the secondary precipitation is not required. The reactor is promising to reduce nitrogen, TSS and very low amount of sludge production.

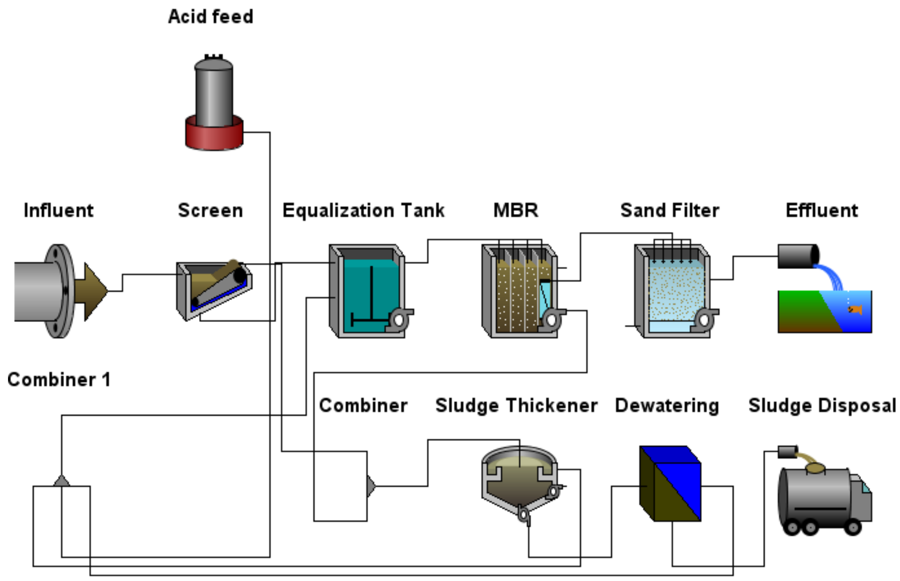


Figure 4.13 Schematic diagram after replacing with Membrane Batch Reactor (MBR)

This treatment is a combination of conventional activated sludge system with membranes of micro or ultrafiltration to retain biomass. This is why the reduction of TSS was well improved.

Table 4.7 Simulation outputs after MBR is introduced,

Parameters	**Unit**	**Value**
TSS	mg/l	0.15
$cBOD_5$	mg/l	6.75
COD	mg/l	12.5
Ammonia N	mgN/l	0.23
TKN	mgN/l	0.714
TN	mgN/l	1.6
TP	mgP/l	4.7
Total Alkalinity	$mgCaCO_3/l$	3.4

The proposed plant shows a high reduction of most of the pollutants to a desired level of effluent quality.

Table above shows a significant reduction of almost all of the parameters included in the analysis process. Therefore, using this sequence of treatment train for upgrading the plant has an important effect in the future improvement of the treatment plant of the BDT wastewater treatment plant.

The simulation was applied for a week which is seven days since the reaction takes time because of microbial degradation at the anaerobic tank. For a clarity purpose the above graph is captured for 3.5 days this helps to see the lines clearly and neatly.

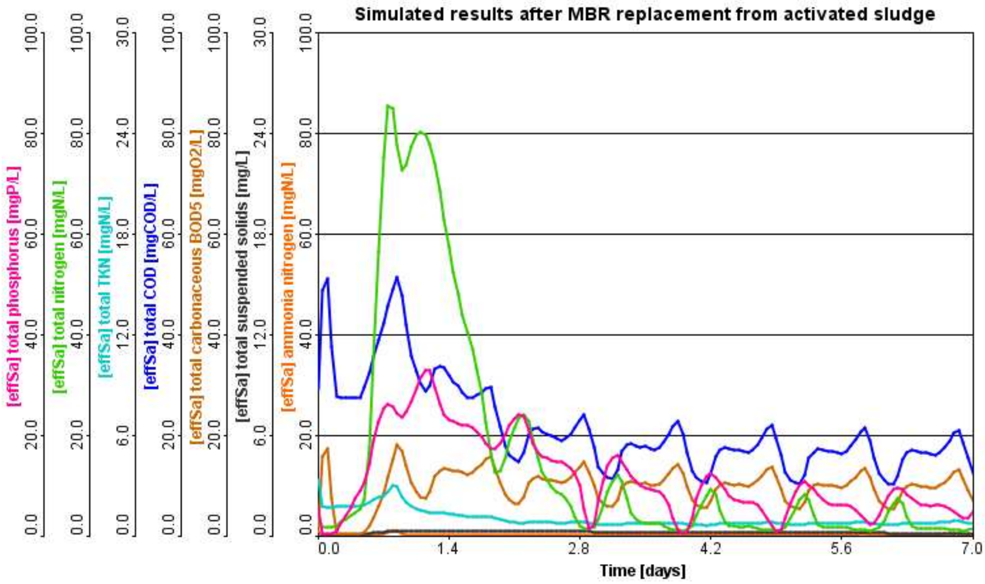


Figure 4.14 Schematic diagram after replacing with anaerobic and anoxic tank

As shown from the graph above, the first days the flow was going smoothly until some chemicals and coagulants are added to the system to balance the pH and help settling of solids. After the mixed flow passes from the equalization tank to anaerobic tank the reduction of most of the parameters was observed.by the end of the few days most of the parameters are reduced in a significant manner.

Comparing the optimization options discussed above will help to discover the most feasible option for sustainability of the BDT-WWTP in terms of better effluent quality. The choice depends on the cost of upgrading the system as well as the energy consumption required in operating the system. In terms of effluent quality, optimization of the treatment plant after an introduction of MBR technology is considered as a best option relatively. This is because most of the pollutants are removed in a desired level as it is observed in the corresponding section. The second option can be self-optimization of the treatment plant by adjusting some operating and physical parameters. The last one can be addition of sand filter at the end of the treatment train since it is cost effective and the reduction TSS is significant whereas the COD reduction is not as required.

4.6 Sustainable Improvements

A wastewater treatment plant to be useful for the intended use sustainable measures and practices are essential to be considered. During operation of the plant some of the resources can be used in a wise way to insure the saving of this resources and this will lead to save money and time to improve the facility even better.

4.6.1 Water use in production process

The textiles industry has often been considered as a water-intensive sector. most textile preparation steps are desizing, scouring, bleaching, mercerizing which are processed under aqueous systems. The wastewater contains dyes, chemical and the characteristics depend upon the processing stages where some stages are totally dry without wastewater generation (Balachandran and Rudramoorthy 2009).

Bahir Dar textile consumes 1600m^3 of water everyday where the raw is water taken from Abbay at the upstream of the Blue Nile river. The water is collected and treated with a series of sand filters at the point of source and conveyed to the factory by a pipe system to two huge containers inside the factory. Around 75% of the water is becoming a wastewater to the treatment plant. The treatment plant itself utilizes a significant amount of water for sand filter backwashing, to wash screens, thickeners and surface cleaning of the treatment plant units. Water is also consumed for the process of mixing chemical for pH adjustment. In some anaerobic treatment systems floating materials cleaned with water pressure at the surface of clarifiers to control stagnation and odour.

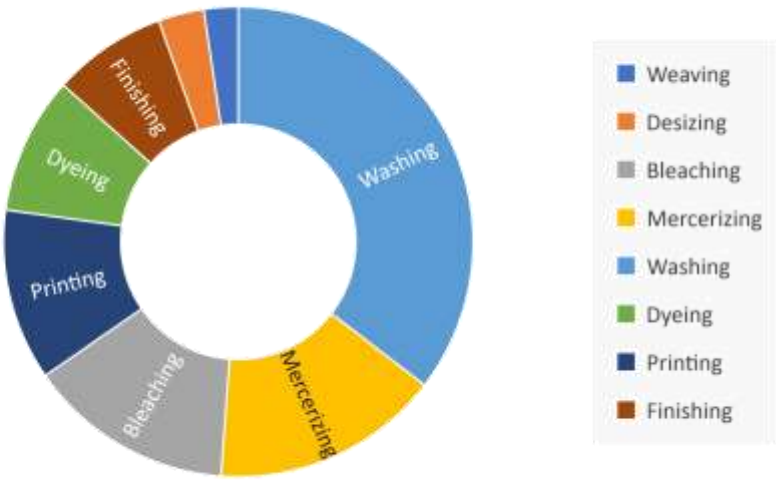


Figure 4.15 Water consumption in textile manufacturing (Rudramoorthy, 2009)

4.6.2 Possible water conservation measures

A number of measures can be implemented for saving water in manufacturing and treatment processes.

4.6.2.1 Water use reduction

Reduction of water volume in the process of manufacturing can save a huge amount of water especially in washing and wetting processes. Reducing the number of washing operation can lead to minimize water usage by a significant amount.

An optimal amount of water consumption is the best way to save water before getting to polluted and used for other purpose this can lead to have a manageable influent to the treatment plant and reduces overloading and failure of the structures.

In addition, in case of process of textile production, the chemicals used in bleaching, dyeing and finishing process can be mixed with treated effluent or other means instead of using clean water as well as for pH adjustment and coagulation processes the chemicals are mixed with water, instead those chemicals can be applied directly to the process

4.6.2.2 Reuse of treated water

Getting an alternative water source can help to meet various water demands in present and future(Balachandran and Rudramoorthy 2009). Water reuse is not only good to the environment but also has some chemical properties which can facilitate some of the manufacturing processes like finishing and dyeing.

The effluent from the factory was not planned for any reuse or recycle for any purposes so far. From the laboratory results the effluent has a suitable property for agricultural applications if a little improvement of treatment applied. Some of the nutrient are very important for soil conditioning and also used as fertilizer which can reduce cost of buying commercial fertilizers(Branch, 2011).

Using the effluent from treatment plants will save a considerable amount of water consumption in terms of saving the cost related to raw water pumping, treatment and conveyance.

4.6.3 Improvements in energy use

For a wastewater treatment plant to be efficient and reliable it is not only the effluent quality that matters similarly, the requirement of energy required, operation and maintainace cost need to be optimized for sustainable system.

4.6.3.1 Current energy consumption in the treatment process

The energy for the all manufacturing and wastewater treatment system processes and other uses is coming from the national electric provider EEPCO (Ethiopian Electric production corporation). The plant consumes around 1.046kWh of energy for every cubic meter of wastewater. As shown in the figure below the maximum consumption is recorded in the use of the aeration system, electrolysis and other uses which consumes 39%, 15% and 10% respectively. There was no attempt is made to take optimization measures in the process of treatment at the treatment plant except, turning of the equipments which are not used in the process. Minimized energy usage leads to reduction of operation costs, energy consumption and achieve carbon neutrality in terms of environmental safety.

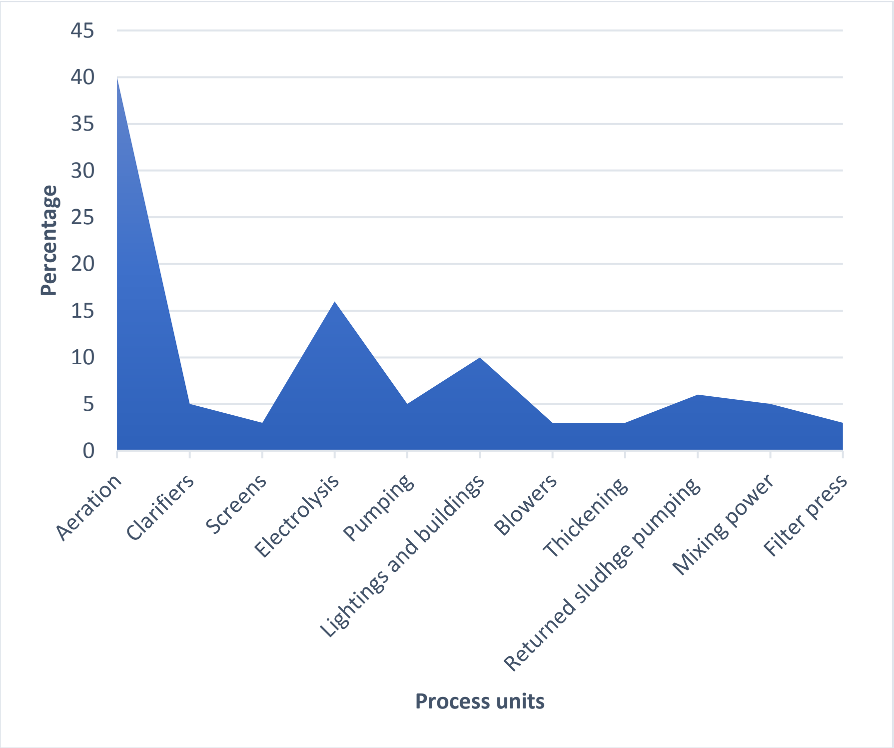


Figure 4.16 Energy use of the treatment plant in percentage

4.6.3.2 Energy minimization practices

To use the energy available efficiently there are different things which can be done to the existing system.

- Regular inspection control and operational unit for fair energy consumption.
- Replacing weary equipments and measuring devices then installing more energy-efficient equipments and controlling devices considering affordable cost.
- Self energy production from biogas, hydroelectric power and other renewable energy options from the plant itself.
- Reduction of energy usage which enhance the efficiency of individual units and sections
- Reduction of excess aeration energy at the mixing points and blowers

According to Ali Asadi, about 31% of saving in air flow rate can be obtained while keeping the water quality within acceptable limit.

4.6.4 Hydraulic performance improvement

Hydraulic optimization of a wastewater treatment plants can lead to increase the treatment capacity as well as reduces the head losses in plants. The following points can be considered as a way to improve the performance of a treatment system under study.

- Rise the freeboard by raising walls around the treatment units, this lead to reduce the runoff and overloading of the wastewater coming from outside of the system.
- Head losses can be reduced by changing the flow direction, replacing wear out flow control structures flume, venturi meter, valves and gates, uncalibrated flow meters and so on.
- Modify shape or the size, or replacing the existing connecting system with more hydraulically capable structures
- Adjusting the inlet and outlet structures of unit process can lead to efficient flow of wastewater into the system as well as outside the system.

- Improve the performance of the control and flow meters and regulate the effluent weirs of primary and secondary settling tanks.
- Adjusting the hydraulic loads of unit processes based on performance criteria and application intermediate pumping if extra hydraulic capacity is needed.
- Flow equalization tank could be used to improve treatment plant efficiency since the variable loading will be dampened.

4.7 Cost Benefit Analysis

Cost benefit analysis can be defined as the summation of the expected benefits from the optimized system minus the cost utilized for the system. The analysis comprises different financial expenditures this are including Investment cost, operation & maintainace cost, depreciation cost and other miscellaneous costs. In this study it was considered for the comparison and evaluation of wastewater treatment alternatives.

4.7.1 General cost of the project

Which is an initial cost which is applied to implement the treatment structures and network as required by the specification for a better treatment facility. The cost of construction of wastewater treatment plant involves both civil and mechanical costs. The civil cost includes the cost of all excavation, filling up and construction works some type of treatment plants are assembled onsite.

Knowing the design and construction period is another point that should be considered in cost estimation which help to decide which type of treatment plant is effective for a given time with the available investment. The cost related to civil works and mechanical installations which also includes,

- Material and labour mobilization
- Site investigation and preparation
- Pipe and pump installation
- Instrumentation and
- Laboratory, administration buildings

Non-construction costs like, legal and technical costs, engineering design payment, contingency, and miscellaneous costs should be considered in the process of estimation of total investment of the project.

Operation and maintainace costs are other most important costs should be considered in any project. Costs which are considered to cover the running cost of the treatment plant after implementation which is incessant and very important cost for sustainable usage of the treatment plant. The treatment plant needs uninterrupted source of electricity for a desired operation and functioning and the availability of water during construction, implementation and operation phases.

Cost of chemicals for treatment operation should obviously be considered ae well. The cost of labour is the sum of all wages paid to employees, as well as the cost of employee benefits and payroll taxes paid by an employer.

Interest rate is another charge for loans in percentage from any financial source which is mostly expressed in percentage and this should be added in the total cost of the treatment plant implementation. Cost is considered to know the value of a certain equipment or structure after a certain use. Which often decrease through time where the structure is not able to give the service planned to achieve in the desired process.

Benefit over cost ratio should be more than a unity for a proposed project to be beneficial, here is the equation for calculating the ratio,

$$\frac{B}{C} Ratio = \frac{\Sigma(^{Bt}/_{(1+r)^t}}{\Sigma(^{Ct}/_{(1+r)^t}}$$

Where, r = discount rate
Ct = total cost
Bt = total benefit
t= years

Cost benefit analysis is very useful in the decision-making process of choosing a treatment technology for the desired benefit. In order to meet this, the cost and the benefits should be compared and the benefits exceeds the expenditures since, the overall process is to be beneficial from the given alternatives.

Table 4.8 Cost of treatment processes used for optimization (AS, Sand Filter, MBR, hybrid of Anaero-Anoxic Tank)

Technology process	Capital cost	Operating and maintainace cost	Total Cost in USD (***Rough estimation***)	Source of Literature
Activated sludge	High construction cost Sophisticated mechanical parts Small area requirement Need of skilful professional for design and construction	High electricity consumption for aeration purpose High cost of maintenance for mechanical failures pumps and aerators	For upgrading a single system $23,146,833.5 Yearly O & M cost 3,600+26,400=$30,000 Running and depreciation, cost= $197,253 Total cost=$23,374,086.5	Chougule & Sonaje, 2013)(Addis Ababa Water and Sewerage Authority 2014)
Sand Filtration	Low construction cost and area requirement High cost of assembling compared to rapid sand filter	Low operation cost due to no need of energy High cost of gravel filling and replacement Cost of operation for sludge removal	Construction cost Cost=$4,046,760.8 O&M cost=$1,340 Depreciation and other costs= $12,588 Total cost=$32,160,761.8	(Jafarinejad 2017) (University of New Hampshire Filtration cost, 2014.)

Membrane Bioreactor (MBR)	High degree of skill and investment of construction compared to other bioreactors High cost of materials like membrane filters replacement Requires small place for construction	High cost of energy for air supply, diffusers and liquid pumping Medium cost of Sludge removal Highly automated and needs expertise for proper functioning	Single Plant construction cost= \$12,942,140 Operation and Maintenance: Membrane replace=\$100,200 Deprecation and other costs=\$150,000 Total cost= \$13,192,340	www.costwater.com (Jafarinejad 2017) (“APEX Cost Estimate Sequencing Batch Reactor,” n.d.)
Hybrid of Anaerobic Anoxic Tank	low construction and assembling cost Requires large area Needs skilled personnel for design and implementation	Aeration is the main cost for aeration treatment whereas, the anaerobic an anoxic tank does not need direct oxygen supply. Instead, low energy and maintenance is required. Cost pre-treatment inspection. in anoxic tank	Construction of Anaerobic and Anoxic for 72 m^2 ranges \$15,000 to \$20,000 O and M cost = \$200,000 per year Others=\$1100 Total cost= \$21,300,000 The aerobic tank is already existing in the treatment plant so there is no need of implementing again.	(Chapter 5 anoxic and anaerobic systems n.d.) (Technologien and Wirtschaftsberatung 2001)

Chapter 5:

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Bahir Dar textile factory is one of the textile industries located at the head of Blue Nile river having a wastewater treatment plant to treat a maximum discharge of $1200m^3/d$. Since the effluent from industry possess a significant impact on the receiving water, this research attempted to investigate the wastewater characteristics of the plant to observe its performance and optimize it for a better effluent quality.

When the wastewater quality analysis was conducted, the plant performed well in the reduction BOD_5 and Ammonia, whereas the performance in TSS and COD and Nitrogen compounds were very poor and above guideline limited set by WHO and EEPA. To improve the performance of the treatment plant a software program called GPS-X then different scenarios and options are provided.

To optimize the plant different approaches were considered in terms of increasing the efficiency with and without any further construction. The first option was alerting (adjusting) some parameters in the existing system to reduce TSS and COD concentration. Compared to the existing system it was observed that reduction of TSS and COD by 62.4 % and 90.9% respectively.

With the intention of upgrading the existing plant different scenarios were conducted. Addition of a grit chamber and sand filter at the end of the treatment plant is considered as a better way to improve the solid reduction and the results were promising. Then MBR (Membrane Bioreactor) introduced to reduce the COD concentration by a significant amount, this was achieved by integrating the new technology with the existing activated sludge system.

For further reduction on nitrogen compounds and other physico-chemical characteristics of the wastewater a hybrid of anaerobic and anoxic tank is introduced to the treatment system after a primary clarifier. Considering the cost and operation difficulties the recommended scenarios can be applied for a better-quality effluent which highly favours the receiving water system.

5.2 Recommendations

The treatment plant is overloaded in a wet season because of addition of rainfall and surface runoff into the existing treatment plant as a result the treatment plant leads to fail accommodating the upcoming flow without any interruption. The maximum flow should be considered in any operations this will ensure the treatment plant to perform well in wet season.

The treatment plant lacks skilful professionals for operation and maintenance as well as operating conditions are different from designed values. This should be improved by proper operation and maintenance activities for a better performance of the system.

The factory has a water quality laboratory for checking the effluent quality once in a while. However, very few physico-chemical characteristics are analyzed and this was one of the limitations affected the research progress. There should be well equipped laboratory to carried out and assess the quality of effluent and to ensure that it lies within the standards.

For better pH and chemical balance, the dosing mechanism should be studied well so that, accurate chemicals dosing will improve the effluent quality that favours the quality of the receiving water body.

There are many immediate downstream users of the water river for drinking, fishing, bathing, and irrigation; thus, proper treatment and regular monitoring is critically important.

Including energy minimizing practices and cost analysis in operation and maintenance section will help to optimize the treatment process further and potentially save money by reducing the chemicals and energy consumed to run the system.

In this research, only the physico-chemical characteristics of the wastewater is considered. It is highly recommended to have further study on the heavy metal characteristics of the wastewater and it impact on the river Blue Nile since other industries are also contributing to the pollution of the river. This will reinforce the knowledge to protect the natural resource as well as human welfare around the river system.

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APPENDICES

APPENDIX (A)

Annex a1: Sample results of wastewater influent

Parameters	**Units**	**Sample 1**	**Sample 2**	**Sample 3**	**Average**	**SD**
Temperature	^oC	33.5	32	34	33.17	1.04
Turbidity	NTU	15.95	16.35	15.3	15.87	0.53
TSS	mg/l	349.5	350	348.5	349.33	0.76
VSS	mg/l	114.5	115.5	113.8	114.60	0.85
DO	mg/l	0.38	0.33	0.36	0.36	0.03
$cBOD_5$	mg/l	80.95	79.5	80	80.15	0.74
Total COD	mg/l	553	554.5	532	546.50	12.58
Filtered COD	mg/l	102.5	99.5	102.6	101.53	1.76
Ammonia N	mgN/l	4.2	4	4.6	4.27	0.31
Total TKN	mgN/l	26	26.5	27	26.50	0.50
Filtered TKN	mgN/l	22	23.7	22.6	22.77	0.86
TN	mgN/l	24.5	25.6	25	25.03	0.55
TP	mgP/l	14	14.6	12	13.53	1.36
Alkalinity	mgCaCO3/l	50	50	50.3	50.10	0.17
pH	-	10.2	11.5	11.4	11.03	0.72

Annex a2: Sample results of the effluent after treatment

Parameters	**Units**	**Sample 1**	**Sample 2**	**Sample 3**	**Average**	**SD**
Temperature	ºC	25.20	26.80	28.10	26.70	1.45
Turbidity	NTU	8.40	8.45	8.20	8.35	0.13
TSS	mg/l	98.00	98.50	98.00	98.17	0.29
VSS	mg/l	114.50	115.50	113.80	114.60	0.85
DO	mg/l	7.56	7.64	6.35	7.18	0.72
$cBOD_5$	mg/l	6.40	7.20	5.60	6.40	0.80
Total COD	mg/l	206.50	208.40	204.50	206.47	1.95
Soluble COD	mg/l	11.20	11.50	10.30	11.00	0.62
Ammonia N	mgN/l	4.20	4.00	4.60	4.27	0.31
Total TKN	mgN/l	18.42	18.54	18.53	18.50	0.07
Filtered TKN	mgN/l	6.89	7.10	7.00	7.00	0.11
TN	mgN/l	7.50	7.65	7.54	7.56	0.08
TP	mgP/l	6.10	5.70	6.20	6.00	0.26
Alkalinity	$mgCaCO_3/l$	40.50	41.76	39.00	40.42	1.38
pH	-	10.20	11.50	11.40	11.03	0.72

Annex a3: Water sample results from the upstream of Blue Nile River

Parameters	**Units**	**Sample 1**	**Sample 2**	**Sample 3**	**Average**	**SD**
Temperature	^oC	24.50	23.80	25.20	24.50	0.70
Turbidity	NTU	4.80	4.60	4.40	4.60	0.20
TSS	mg/l	118.50	120.30	121.20	120.00	1.37
VSS	mg/l	135.00	134.20	136.10	135.10	0.95
DO	mg/l	8.00	7.38	8.30	7.89	0.47
$cBOD_5$	mg/l	6.00	5.30	5.50	5.60	0.36
Total COD	mg/l	45.50	44.60	44.90	45.00	0.46
Soluble COD	mg/l	5.25	5.00	5.20	5.15	0.13
Ammonia N	mgN/l	8.90	9.10	9.00	9.00	0.10
Total TKN	mgN/l	20.50	18.20	19.60	ND	1.16
Filtered TKN	mgN/l	22.60	22.51	23.43	ND	0.51
TN	mgN/l	10.20	9.32	9.89	9.80	0.45
TP	mgP/l	4.85	4.45	5.15	4.82	0.35
Alkalinity	$mgCaCO_3/l$	92.00	93.00	94.00	93.00	1.00
pH	-	7.80	7.76	7.85	7.80	0.05

Annex a4: Upstream sampling results from Blue Nile river

Parameters	Units	Sample 1	Sample 2	Sample 3	Average	SD
Temperature	ºC	27.60	26.80	26.60	27.00	0.53
Turbidity	NTU	5.00	5.20	5.40	5.20	0.20
TSS	mg/l	135.00	134.00	133.00	134.00	1.00
VSS	mg/l	120.50	120.25	122.25	121.00	1.09
DO	mg/l	7.20	7.30	7.10	7.20	0.10
$cBOD_5$	mg/l	10.54	10.60	10.67	10.60	0.07
Total COD	mg/l	313.50	301.50	324.00	313.00	11.26
Filtered COD	mg/l	2.50	2.42	2.43	2.45	0.04
Ammonia N	mgN/l	63.20	64.35	65.34	64.30	1.07
Total TKN	mgN/l	9.39	9.60	9.52	9.50	0.11
Filtered TKN	mgN/l	7.20	7.90	7.24	7.45	0.39
TN	mgN/l	62.77	63.20	63.02	63.00	0.22
TP	mgP/l	13.00	13.50	14.00	9.75	0.50
Alkalinity	$mgCaCO_3/l$	93.50	93.60	93.39	93.50	0.11
pH	-	7.10	7.30	6.90	7.10	0.20

Annex a5: The wastewater treatment units of Bahir Dar textile factory

Equalization Tank

Coagulation tanks

Primary clarifiers

Secondary Clarifier

Sand filtration

Effluent storage

APPENDIX (B)

Annex b1: Wastewater discharge guideline limits

Parameter	**Unit**	**Maximum permissible limit**(Paul 2011)		
		WHO		**EEPA**
		Land/ Underground	**Surface water courses**	
Total Suspended Solids (TSS)	mg/l	45	35	30
Temperature		25	25	40
Turbidity		45	30	NA
Colour	-	Not objectionable	Not objectionable	-
pH	-	5 – 9	5 – 9	6-9
Chemical Oxygen Demand (COD)	mg/l	120	120	150
BOD_5	mg/l	40	40	50
Chloride	mg/l	750	750	NA
Total Phosphorous	mg/l	15	10	10
Total Alkalinity	mg/l	75	75	NA
Dissolved Oxygen	mg/l	10	5	5
Ammonia	mg/l	30	30	20
Total Kjeldahl Nitrogen (TKN)	mg/l	25	25	30
Total Nitrogen	mg/l	60	60	40

APPENDIX

Annex c1: Simulation results after sand filter introduction

Parameter	Unit	Wwif	effSc	Peff	MLSS	effC2	effSa	effSa2	effluent
Flow	m^3/d	1480	1472.6	1472.6	1472.6	1432.6	701.974	701.974	1403.95
TSS	mg/L	561.548	229.425	139.082	264.662	8.39359	1.71298	1.71298	1.71298
	kg/d	831.091	337.851	204.812	389.741	12.0247	1.20247	1.20247	2.40493
VSS	mg/L	202.157	82.0149	52.7998	108.015	3.4104	0.696	0.696	0.696
	kg/d	299.193	120.775	77.753	159.063	4.88574	0.48857	0.48857	0.97715
Soluble $cBOD_5$	mgO2/L	3.28139	3.28139	8.78239	3.02947	3.71114	3.71114	3.71114	3.71114
	kg/d	4.85646	4.83217	12.933	4.46119	5.31659	2.60513	2.60513	5.21025
$cBOD_5$	mgO2/L	3.28139	3.28139	25.4211	41.016	4.90303	3.95439	3.95439	3.95439
	kg/d	4.85646	4.83217	37.4352	60.4002	7.02408	2.77588	2.77588	5.55175
Soluble COD	mgCOD/L	118.99	118.99	162.455	147.011	145.616	145.616	145.616	145.616
	kg/d	176.106	175.225	239.232	216.489	208.61	102.219	102.219	204.437
COD	mgCOD/L	475.962	261.779	244.495	325.301	151.227	146.761	146.761	146.761
	kg/d	704.423	385.496	360.043	479.038	216.647	103.022	103.022	206.045
Ammonia Nitrogen	mgN/L	10.4775	10.4775	14.8981	0.82717	1.39207	1.39207	1.39207	1.39207
	kg/d	15.5066	15.4291	21.939	1.21809	1.99428	0.9772	0.9772	1.95439
Nitrite	mgN/L	0	0	1.25817	0.25873	0.33987	0.33987	0.33987	0.33987
	kg/d	0	0	1.85279	0.38101	0.4869	0.23858	0.23858	0.47716
Nitrate	mgN/L	0	0	1.25817	21.5341	20.2817	20.2817	20.2817	20.2817

	kg/d	0	0	1.85279	31.7111	29.0555	14.2372	14.2372	28.4744
Soluble TKN	mgN/L	19.0499	19.0499	27.3792	13.5619	14.491	14.491	14.491	14.491
	kg/d	28.1939	28.0529	40.3186	19.9713	20.7598	10.1723	10.1723	20.3446
TKN	mgN/L	22.2122	21.2635	32.4944	18.5997	14.6593	14.5253	14.5253	14.5253
	kg/d	32.8741	31.3127	47.8513	27.3898	21.0009	10.1964	10.1964	20.3928
TN	mgN/L	22.2122	21.2635	35.0108	40.3925	35.2808	35.1469	35.1469	35.1469
	kg/d	32.8741	31.3127	51.5569	59.482	50.5433	24.6722	24.6722	49.3444
	kg/d	5.58239	5.55448	9.08382	14.7025	14.0009	6.86042	6.86042	13.7208
TP	mgP/L	11.3157	7.98161	15.3206	26.1629	10.2947	9.87951	9.87951	9.87951
	kg/d	16.7472	11.7537	22.5611	38.5275	14.7483	6.93516	6.93516	13.8703
Dissolved Oxygen	mgO2/L	0	0	1.9999	2.1644	1.97621	1.97621	1.97621	1.97621
	kg/d	0	0	2.94505	3.1873	2.83111	1.38724	1.38724	2.77449
Acetate	mgCOD/L	0	0	1.25817	0.16342	0.22967	0.22967	0.22967	0.22967
	kg/d	0	0	1.85279	0.24065	0.32903	0.16122	0.16122	0.32244
Propionate	mgCOD/L	0	0	1.25817	0.16194	0.22624	0.22624	0.22624	0.22624
	kg/d	0	0	1.85279	0.23847	0.32412	0.15882	0.15882	0.31764
Methanol	mgCOD/L	0	0	1.25817	0.0207	0.03302	0.03302	0.03302	0.03302
	kg/d	124.32	123.698	125.389	7.35267	9.36281	4.58778	4.58778	9.17556
TOC	mgC/L	152.308	83.7692	79.4265	107.305	48.5029	46.9945	46.9945	46.9945
	kg/d	-	-	-	-	-	-	-	-
Alkalinity	mgCaCO3/L	77.4058	77.4041	78.4635	4.52133	5.94432	5.94432	5.94432	5.94432
pH	-	5.77	5.77	5.77	5.77	5.77	5.77	5.77	5.77

Annex c2: Simulation outputs after upgrading with anaerobic and anoxic tanks

t(days)	TSS (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TKN (mg/l)	TN (mgN/l)	TP (mgP/l)
0	556	495	880	242	442	164
0.05	1.82	359	601	205	405	100
0.1	1.05	359	601	205	405	100
0.15	0.822	359	600	205	405	100
0.2	0.718	359	600	205	405	100
0.25	0.661	359	600	205	405	100
0.3	0.628	359	600	205	405	100
0.35	0.606	359	600	205	405	100
0.4	0.592	359	600	205	405	100
0.45	0.582	359	600	205	405	100
0.5	0.575	359	600	205	405	100
0.55	0.569	359	600	205	405	100
0.6	5.73	364	610	208	410	103
0.65	1220	1200	2140	599	1110	395
0.7	1220	1560	2750	805	1510	497
0.75	612	777	1410	404	762	250
0.8	615	292	644	130	222	108
0.85	567	138	418	48.3	67.8	57.8
0.9	407	80.7	300	26.9	37.9	34.4
0.95	264	48.9	209	17.1	29.7	20.8
1	78.6	14.4	87.5	6.63	22	6.4
1.05	68.8	12.6	81.7	6.09	24.2	5.72
1.1	64.3	11.7	79.6	5.87	26.5	5.47
1.15	65.8	11.9	81.6	5.97	29.3	5.7
1.2	384	65.9	300	23	49.6	28.3
1.25	1050	171	771	56.9	89.6	72.2
1.3	683	107	530	37.1	77.8	47.8
1.35	520	78.1	423	28.5	77	38.5
1.4	439	64	371	24.4	80	35.1
1.45	431	61.5	370	24.1	86.3	36.4
1.5	448	62.7	387	24.8	93.6	39.3
1.55	413	57	365	23.1	98.3	39.5
1.6	395	54	355	22.3	103	41
1.65	470	63.6	414	25.8	113	47.8
1.7	492	66.1	434	26.8	120	51.9
1.75	493	65.9	438	26.9	126	54.9
1.8	486	64.8	436	26.7	131	57.5
1.85	429	57.5	396	24.2	134	56.9
1.9	225	30.5	245	15.1	129	46.9

1.95	96.5	13.4	150	9.39	126	40.5
2	67.5	9.58	129	8.05	127	39.5
2.05	52.4	7.57	119	7.31	128	39.1
2.1	43.2	6.33	112	6.84	128	38.9
2.15	40.3	5.94	110	6.65	129	39.2
2.2	63.6	9.06	128	7.63	131	41.1
2.25	627	85.1	548	32.9	158	75.7
2.3	476	65	435	26	154	68.5
2.35	337	46.5	332	19.9	149	61.3
2.4	246	34.3	264	15.9	146	55.8
2.45	237	33.2	256	15.4	146	54.5
2.5	254	35.9	269	16.2	147	54.5
2.55	215	30.7	239	14.4	145	50.8
2.6	196	28.3	225	13.5	144	48.3
2.65	275	39.6	281	16.9	147	51.8
2.7	300	43.5	299	18	147	51.8
2.75	302	44.3	299	18	146	50
2.8	297	44.1	293	17.7	144	47.2
2.85	238	36.1	249	15.1	139	40.4
2.9	103	16.9	149	9.1	131	28.2
2.95	73.1	12.7	126	7.72	128	23.6
3	39	7.89	101	6.13	125	19.3
3.05	12.5	4.11	81.4	4.89	123	15.9
3.1	9.28	3.75	78.1	4.64	122	14.7
3.15	8.63	3.67	77.1	4.53	121	13.6
3.2	12.4	4.19	79	4.6	120	12.8
3.25	72.5	12.9	121	7.07	121	15.7
3.3	100	16.9	139	8.16	120	16.5
3.35	108	18.1	142	8.46	118	15.7
3.4	102	17.7	137	8.21	116	13.5
3.45	97.9	17.5	133	7.99	113	11.3
3.5	97.6	18.1	132	7.9	111	9.83
3.55	91.7	17.6	127	7.55	108	8.53
3.6	86.1	17.2	122	7.23	106	7.75
3.65	92.2	18.7	125	7.4	103	8.2
3.7	102	20.7	131	7.72	101	9.07
3.75	113	23.2	137	8.12	99	10.1
3.8	135	27.5	151	8.95	96.9	12.2
3.85	120	26.7	139	8.28	93	11.2
3.9	79.9	21.4	112	6.57	88.6	7.69
3.95	40.9	16	84.9	4.89	84.7	4.2
4	11.4	12	64.4	3.56	81.9	1.69
4.05	8.39	11.9	62	3.35	80.6	1.4
4.1	6.14	11.7	60.2	3.17	79.5	1.18

4.15	4.42	11.4	58.5	3.02	78.5	1
4.2	5.37	11.4	58.3	2.96	77.4	1.15
4.25	15.5	12.4	63.1	3.24	76	2.14
4.3	18.1	11.6	61.8	3.23	73.9	2.45
4.35	18.6	11.4	60.4	3.26	71.8	2.48
4.4	17.3	11.9	59.3	3.24	69.6	2.27
4.45	16.4	12.9	59.2	3.2	67.7	2.12
4.5	16.1	14.1	59.6	3.14	65.8	2.05
4.55	14.9	14.9	59.2	3.04	63.9	1.91
4.6	13.8	15.5	58.6	2.94	62.1	1.78
4.65	14.5	16.5	59.2	2.91	60.3	1.83
4.7	15.7	17.5	60.1	2.91	58.5	1.94
4.75	17.4	18.7	61.4	2.94	56.6	2.09
4.8	19.4	20.3	63.3	3.03	54.7	2.27
4.85	19.8	22.2	64.8	3.09	52.6	2.3
4.9	13.9	22.8	62.2	2.9	50.5	1.71
4.95	7.05	22.9	59	2.64	48.9	0.936
5	4.15	23.7	57.5	2.47	47.8	0.813
5.05	3.09	23.9	57	2.36	47	0.696
5.1	2.3	23.9	56.4	2.24	46.3	0.598
5.15	1.76	23.8	55.7	2.13	45.7	0.54
5.2	2.01	23.5	54.9	2.02	45	0.579
5.25	4.28	22.3	53.5	1.95	43.9	0.816
5.3	5.23	19.7	49.6	1.87	42.4	0.938
5.35	5.14	18.2	46.7	1.9	41	0.929
5.4	4.28	18.5	46.2	1.97	39.8	0.811
5.45	3.76	20	47.3	2.03	38.7	0.75
5.5	3.73	21.5	48.8	2.04	37.6	0.726
5.55	3.55	22.8	49.9	2	36.6	0.693
5.6	3.36	23.8	50.7	1.96	35.6	0.664
5.65	3.49	24.7	51.6	1.94	34.6	0.665
5.7	3.68	25.5	52.3	1.91	33.6	0.674
5.75	3.93	26.4	53.1	1.92	32.5	0.69
5.8	4.2	27.8	54.5	1.99	31.4	0.71
5.85	4.31	29.6	56.6	2.12	30.3	0.712
5.9	3.37	31.4	58.3	2.24	29.4	0.59
5.95	2.44	33.1	59.7	2.32	28.7	0.486
6	1.81	34	60.3	2.31	28.2	0.429
6.05	1.41	34.3	60.4	2.25	27.7	0.382
6.1	1.18	34.3	60.2	2.16	27.4	0.35
6.15	1.04	34.1	59.7	2.04	27	0.323
6.2	1.04	33.3	58.5	1.88	26.6	0.302
6.25	1.51	31	55.1	1.62	25.8	0.344
6.3	1.97	26.9	49.1	1.42	24.9	0.398

6.35	2.09	24.4	45.2	1.46	24.1	0.41
6.4	2.03	24.5	45	1.65	23.4	0.392
6.45	1.95	26	46.7	1.82	22.9	0.366
6.5	1.92	27.6	48.7	1.92	22.4	0.341
6.55	1.86	29.1	50.4	1.96	22	0.31
6.6	1.78	30.3	51.8	1.97	21.5	0.272
6.65	1.79	31.6	53.4	1.98	21.1	0.228
6.7	1.87	32.9	55	1.99	20.6	0.347
6.75	1.97	33.5	55.6	1.98	20.1	0.678
6.8	2.03	34.3	56.4	2.05	19.5	0.881
6.85	1.97	35.7	58.1	2.22	19	0.926
6.9	1.75	37.4	60.2	2.42	18.6	0.917
6.95	1.48	38.8	61.9	2.59	18.2	0.875
7	1.2	39.5	62.7	2.66	18	0.81
Min	0.569	3.67	45	1.42	18	0.228
Max	1220	1560	2750	805	1510	497
Mean	137.70523	87.9421831	235.083803	40.560563	129.4542254	33.433993
Std Dev	231.91774	196.665486	345.871843	104.50822	186.2026383	62.9535726

Annex c3: Simulation outputs after MBR upgrading

t(days)	TSS (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TKN (mg/l)	TN (mgN/l)	TP (mgP/l)
0	0	1.58	29.2	3.35	3.55	5.27
0.05	0	15.6	48.8	1.72	1.73	0.326
0.1	0	17.2	51	1.7	1.71	0.352
0.15	0	7.52	37.5	1.7	1.71	0.371
0.2	0	0.48	27.7	1.72	1.96	0.836
0.25	0	0.34	27.5	1.72	2.62	2.46
0.3	0	0.322	27.4	1.73	3.27	4.09
0.35	0	0.315	27.4	1.73	3.92	5.71
0.4	0	0.311	27.4	1.73	4.56	7.31
0.45	0	0.309	27.4	1.73	5.2	8.9
0.5	0.0993	0.696	29.5	1.86	7.03	10.6
0.55	0.141	2	32.4	2.01	17.4	14.1
0.6	0.175	3.62	35.4	2.14	35.5	18.7
0.65	0.201	5.77	38.7	2.27	56.6	22.9
0.7	0.222	8.43	42.2	2.4	75.3	25.4
0.75	0.239	11.6	45.7	2.64	85.4	26.2
0.8	0.253	15.1	49.1	2.98	84.7	25.6
0.85	0.265	18.1	51.2	2.94	77.5	24.2
0.9	0.274	16.9	47.7	2.31	72.6	23.6
0.95	0.279	13.9	41.9	1.98	73.6	24.5
1	0.281	10.4	35.8	1.76	77.2	26.7
1.05	0.281	8.74	32.5	1.62	79.7	29.3
1.1	0.28	7.78	30.2	1.52	80.2	31.4
1.15	0.279	7.37	28.8	1.44	79.6	32.8
1.2	0.278	8.66	29.8	1.4	77.8	32.8
1.25	0.279	11.7	33	1.4	73.9	29.5
1.3	0.281	13	33.6	1.38	68.4	26.1
1.35	0.283	13.5	33.3	1.36	62.7	24
1.4	0.284	13.2	31.8	1.32	57.2	23
1.45	0.284	12.9	30.6	1.28	52.4	22.7
1.5	0.284	12.9	29.8	1.24	48	22.3
1.55	0.284	12.5	28.5	1.2	43.8	22
1.6	0.283	12.2	27.4	1.16	40.5	21.9
1.65	0.282	12.6	27.4	1.13	37.1	21.4
1.7	0.281	13.3	27.8	1.12	33.1	20.5
1.75	0.281	14.2	28.5	1.11	28.2	19.5
1.8	0.28	15.3	29.3	1.11	22.5	18.3

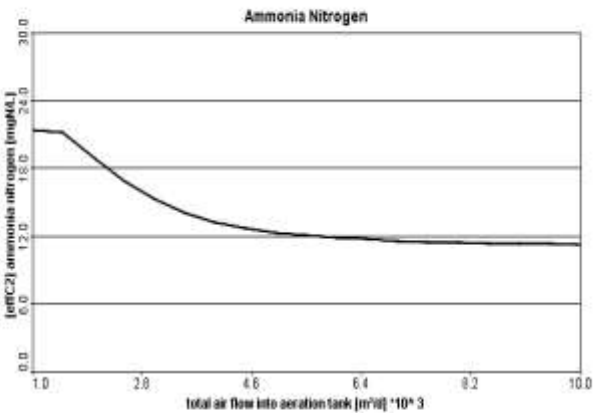
1.85	0.28	15.7	29.4	1.1	16.3	17.2
1.9	0.279	13.3	25.7	1.02	12.6	17.3
1.95	0.277	10.6	21.6	0.936	12.7	18.3
2	0.274	8.08	17.7	0.86	15.4	20
2.05	0.27	7.04	16.1	0.82	18.8	21.9
2.1	0.266	6.46	15.1	0.79	21.4	23.3
2.15	0.262	6.31	14.7	0.768	23.1	24.1
2.2	0.258	7.69	16.5	0.775	24	23.8
2.25	0.256	10.5	20.2	0.805	22.7	20.9
2.3	0.254	11.4	21.2	0.811	19	18.2
2.35	0.252	11.7	21.4	0.813	15.4	16.6
2.4	0.25	11.3	20.6	0.803	12.6	15.8
2.45	0.248	11	20.1	0.795	11	15.4
2.5	0.246	11	19.9	0.791	9.74	15
2.55	0.244	10.7	19.3	0.778	8.67	14.7
2.6	0.242	10.4	18.9	0.77	8.11	14.6
2.65	0.24	10.9	19.4	0.774	7.39	14.1
2.7	0.238	11.6	20.2	0.783	5.94	13.4
2.75	0.237	12.5	21.4	0.796	3.88	12.3
2.8	0.236	13.7	23	0.81	2.04	10
2.85	0.235	14.6	24.1	0.803	1.39	5.29
2.9	0.235	12.6	21.3	0.758	1.31	1.32
2.95	0.233	9.92	17.4	0.717	1.64	2.33
3	0.23	7.32	13.7	0.676	3.14	6.78
3.05	0.227	6.36	12.4	0.658	5.99	11
3.1	0.223	5.85	11.6	0.643	8.64	13.8
3.15	0.22	5.74	11.4	0.634	10.7	15.5
3.2	0.216	7.04	13.2	0.652	12	16
3.25	0.214	9.66	16.8	0.693	10.9	14.6
3.3	0.213	10.5	18	0.705	7.46	13
3.35	0.211	10.8	18.4	0.712	4.65	11.8
3.4	0.21	10.5	17.9	0.708	3.18	10.8
3.45	0.208	10.4	17.6	0.708	2.79	10.1
3.5	0.207	10.4	17.7	0.711	2.58	9.56
3.55	0.205	10.1	17.2	0.706	2.41	9.13
3.6	0.204	9.92	16.9	0.705	2.5	8.99
3.65	0.202	10.4	17.6	0.716	2.37	8.8
3.7	0.201	11.2	18.6	0.73	1.87	8.02
3.75	0.2	12.2	20.1	0.746	1.41	6.19
3.8	0.2	13.5	21.8	0.766	1.2	3.57
3.85	0.2	14.1	22.7	0.767	1.07	1.25
3.9	0.2	12.2	20	0.726	1.04	0.504

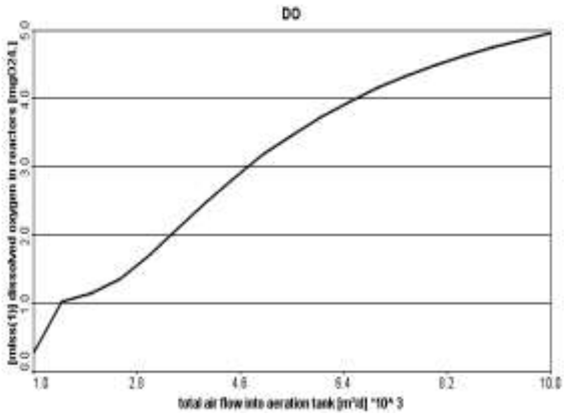
3.95	0.198	9.64	16.4	0.69	1.18	0.838
4	0.196	7.07	12.8	0.655	1.98	3.61
4.05	0.194	6.09	11.4	0.642	4.04	7.38
4.1	0.191	5.6	10.8	0.63	6.22	10.1
4.15	0.188	5.5	10.6	0.623	8.03	11.8
4.2	0.185	6.76	12.3	0.647	9.25	12.5
4.25	0.184	9.27	15.8	0.695	8.15	11.6
4.3	0.183	10.1	17	0.708	4.97	10.4
4.35	0.182	10.5	17.5	0.715	2.68	9.29
4.4	0.181	10.3	17.2	0.71	1.87	8.05
4.45	0.18	10.1	17	0.713	1.83	7.23
4.5	0.179	10.2	17.1	0.718	1.79	6.84
4.55	0.178	9.9	16.7	0.714	1.74	6.59
4.6	0.177	9.7	16.4	0.716	1.84	6.62
4.65	0.176	10.2	17	0.73	1.78	6.65
4.7	0.176	10.9	18.1	0.747	1.5	6.14
4.75	0.175	11.9	19.5	0.766	1.26	4.97
4.8	0.176	13	21	0.79	1.13	3.46
4.85	0.176	13.6	21.8	0.791	1.04	2.05
4.9	0.176	11.8	19.2	0.746	1	0.944
4.95	0.175	9.35	15.9	0.707	1.12	1.23
5	0.174	6.92	12.5	0.671	1.74	3.42
5.05	0.171	5.96	11.1	0.659	3.46	6.4
5.1	0.169	5.48	10.5	0.647	5.38	8.62
5.15	0.167	5.37	10.3	0.641	7.03	10
5.2	0.164	6.61	12	0.669	8.19	10.7
5.25	0.163	9.06	15.5	0.723	7.14	10
5.3	0.163	9.89	16.6	0.736	4.15	9.1
5.35	0.162	10.3	17.2	0.743	2.15	8.11
5.4	0.162	10.1	16.9	0.736	1.61	7.02
5.45	0.161	9.95	16.7	0.74	1.62	6.42
5.5	0.161	9.99	16.8	0.746	1.6	6.19
5.55	0.16	9.73	16.4	0.742	1.57	6.05
5.6	0.16	9.54	16.1	0.744	1.66	6.1
5.65	0.159	10	16.8	0.76	1.62	6.16
5.7	0.159	10.7	17.8	0.779	1.4	5.84
5.75	0.159	11.7	19.1	0.801	1.22	5.09
5.8	0.159	12.7	20.6	0.828	1.13	4.13
5.85	0.16	13.3	21.3	0.828	1.05	3.18
5.9	0.16	11.4	18.8	0.776	1.01	2.22
5.95	0.159	9.13	15.6	0.733	1.1	2.37
6	0.158	6.82	12.3	0.693	1.61	4.01

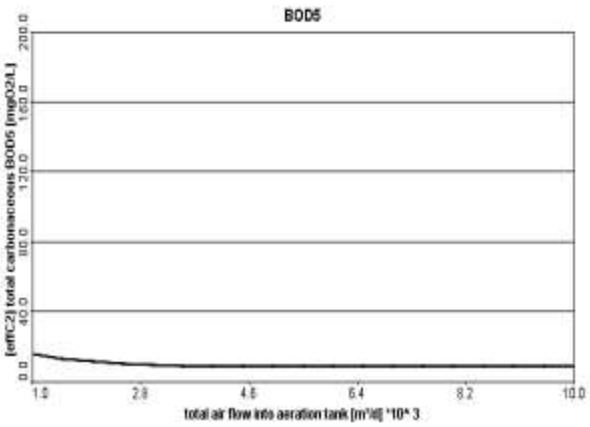
6.05	0.156	5.88	11	0.682	3.1	6.25
6.1	0.154	5.41	10.3	0.67	4.83	7.98
6.15	0.152	5.3	10.2	0.663	6.36	9.11
6.2	0.15	6.52	11.9	0.695	7.46	9.61
6.25	0.149	8.93	15.3	0.755	6.48	9.1
6.3	0.149	9.76	16.4	0.767	3.64	8.31
6.35	0.149	10.2	17	0.773	1.87	7.48
6.4	0.149	9.99	16.7	0.766	1.49	6.62
6.45	0.149	9.82	16.5	0.77	1.52	6.2
6.5	0.148	9.86	16.6	0.776	1.5	6.05
6.55	0.148	9.61	16.2	0.77	1.48	5.97
6.6	0.148	9.43	15.9	0.773	1.55	6.02
6.65	0.147	9.87	16.6	0.79	1.52	6.07
6.7	0.147	10.6	17.6	0.811	1.35	5.86
6.75	0.148	11.5	18.8	0.834	1.21	5.35
6.8	0.148	12.5	20.3	0.865	1.14	4.71
6.85	0.149	13	21	0.862	1.06	4.05
6.9	0.149	11.2	18.4	0.803	1.01	3.4
6.95	0.149	8.98	15.3	0.757	1.08	3.53
7	0.148	6.75	12.2	0.714	1.51	4.7
Min	0	0.309	10.2	0.623	1	0.326
Max	0.284	18.1	51.2	3.35	85.4	32.8
Mean	0.1911936	9.63668794	21.5503546	1.012	14.9799290	11.394687
Std De	0.0706593	3.5760762	9.0309912	0.5305089	23.435879	8.075293

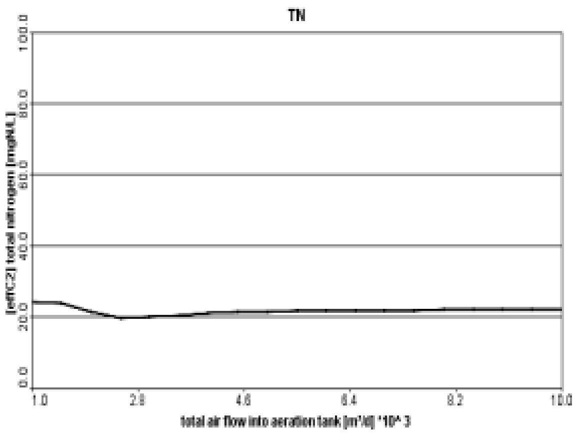
APPENDIX D

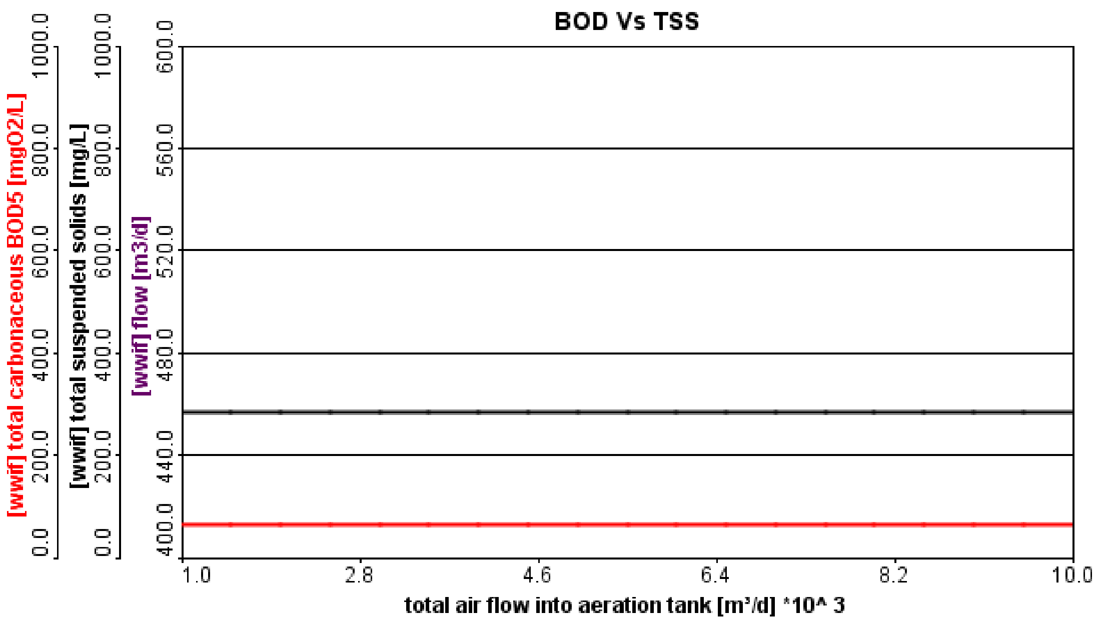
Annex d1: Overall results on sensitivity analysis



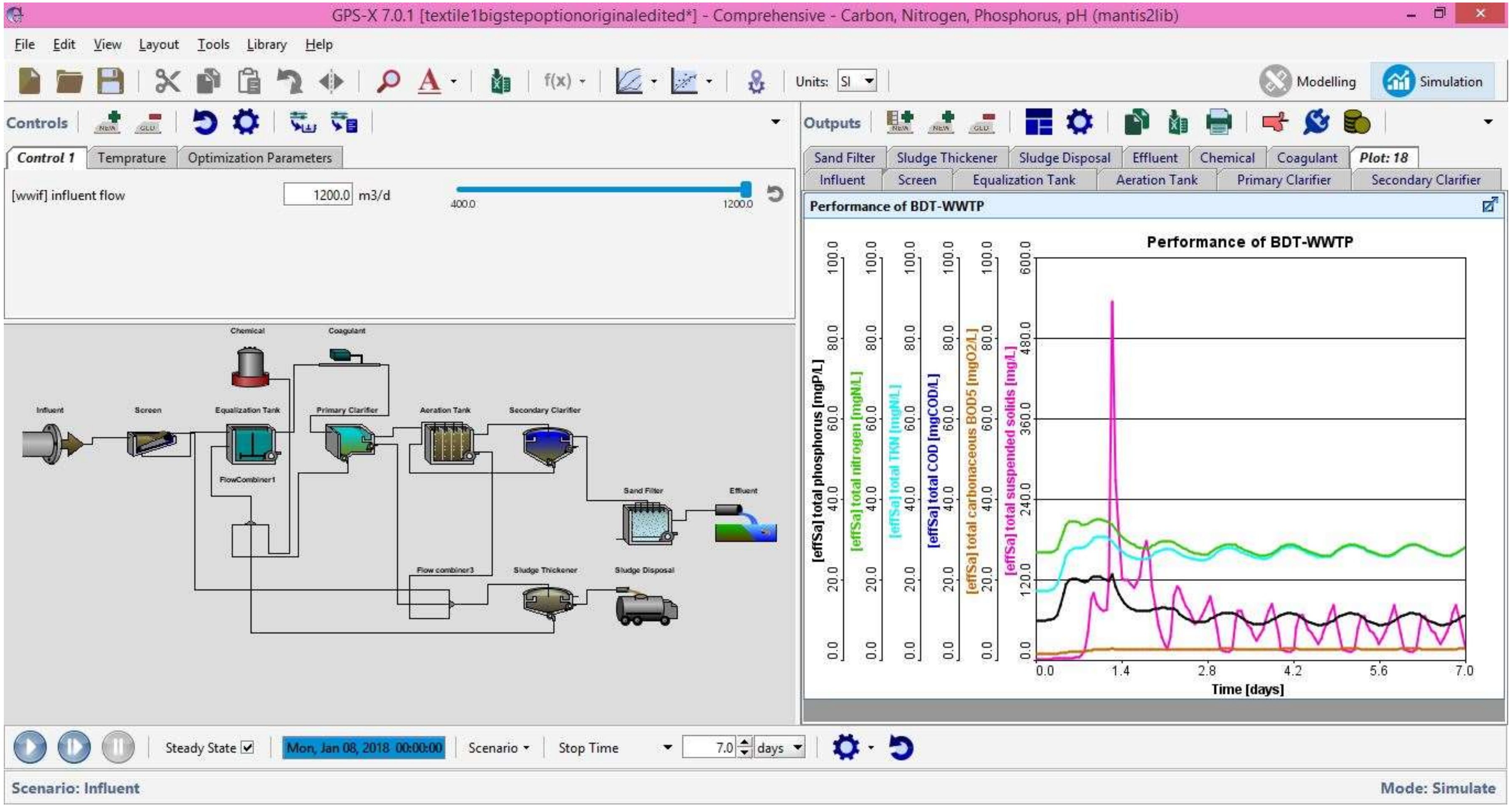








Annex d2 : GPS-X interactive simulation interface



Annex d3: Flow intensity of the BDT-WWTP using Sankey diagram (GPS-X)