



ETHIOPIAN INSTITUTE OF
WATER RESOURCES

Evaluation of Selected Municipal Decentralized Wastewater
Treatment Plants for Condominium Houses in Addis Ababa,
Ethiopia

by

Wubalem Mulugeta

February, 2023

Addis Ababa, Ethiopia

Addis Ababa University
Ethiopian Institute of Water Resources

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A Thesis Submitted to Ethiopian Institute of Water Resources, Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Water and Health with a Specialization in Water and Wastewater Treatment.

by

Wubalem Mulugeta

Main-advisor Meseret Dessalegne (PhD)

Co-advisor Tena Alamirew (PhD)

February, 2023

Addis Ababa, Ethiopia

THESIS APPROVAL SHEET

This is to certify that the thesis presented by **Wubalem Mulugeta Wubishet** entitled **“Evaluation of Selected Municipal Decentralized Wastewater Treatment Plants for Condominium Houses in Addis Ababa, Ethiopia.”** is submitted in partial fulfillment of the requirements for the degree of Master of Science in Water and Health with a Specialization in Water and Wastewater Treatment to the Graduate Program of Ethiopian Institute of Water Resources, Addis Ababa University complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the examining committee:

Main advisor		Signature _____	Date _____
Co-advisor		Signature _____	Date _____
External Examiner	<u>Dr. Kifle Kassa</u>	Signature: 	Date _____
Internal Examiner	<u>Geremew Sahilu (Ph.D)</u>	Signature: 	Date: <u>21/02/2023</u>
Chairman		Signature _____	Date _____
Education Coordinator		Signature _____	Date _____
Director		Signature _____	Date _____

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ABBREVIATIONS AND SYMBOLS

AAWSA	Addis Ababa Water and Sewerage Authority
AAWSAPO	Addis Ababa Water Sewerage Authority Project Office
ABR	Anaerobic Baffled Reactor
ANOVA	Analysis of Variance
BOD ₅	Biological Oxygen Demand
CPHEEO	Central Public Health and Environmental Engineering Organization
CCME-WQI	Canadian Council of Ministers of the Environment Water Quality Index
COD	Chemical Oxygen Demand
DWWT	Decentralized Wastewater Treatment
DO	Dissolved Oxygen
EEPA	Ethiopian Environmental Protection Authority
HRT	Hydraulic Retention Time
MBR	Membrane Bioreactor
MCDMT	Multi Criteria Decision Making Techniques
MoWIE	Ministry of Water Irrigation and Energy
pH	Power of Hydrogen
SRT	Sludge Retention Time
TDS	Total Dissolved Solid
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TSS	Total Suspended Solids
WAWQIM	Weighted Arithmetic Water Quality Index Method
WSP	Waste Stabilization Pond
WWTP	Wastewater Treatment Plant

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ABSTRACT

One way removing the wastewater is to use decentralized wastewater treatment plant which is regarded as technologically simple, flexible management, and cost-effectiveness. Addis Ababa Water Supply and Sewerage Authority (AAWSA) implemented different technologies for decentralized municipal wastewater treatment system for 37 condominiums sites. However there has not been is no systematic study to evaluate performance of the different technologies in terms of removal efficiency performance for both physical and chemical parameters. Hence this research is made to generate a comparative efficiency evaluation for some selected technologies. In this study, (i) Membrane Bio-reactor (MBR), (ii) Waste Stabilization Pond (WSP) and (iii) Anaerobic Baffle Reactors (ABR) wastewater treatment technology were selected at six treatment plants. The performances of treatment plants were measured in terms of physico-chemical and bacteriological. Sampling was made monthly for three months in dry season in the period of December 2021 to February 2022 at a point of inlet and outlet of treatment plants and the collected samples were analyzed and the overall removal efficiency were calculated. The treatment plants also compared by Multi-criteria Decision Making (MCDM) tool using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The study revealed that there was statistical significance difference effluent between the wastewater treatment plants except nitrate ($p < 0.05$, two tailed) and MBR reduced BOD by 98%, COD 97% and TSS by 99%, the WSP reduced BOD by 85%, COD by 84% and TSS by 89% and ABR reduced BOD by 30%, COD by 38% and TSS by 51%. Total coliform and E. coli were removed upto 99% for all treatment plants. However, the concentration of most effluents did not meet the discharge standards, MBR reduced BOD, COD and TSS to the level set by (EEPA, 2003) and WSP and ABR effluent did not meet the standard discharge limit. The wastewater quality index indicate the average of three months of wastewater quality index at Asko, Repi, Gelan and Mekanisa was unsuitable, at Bole Bulbula poor and at Kilinto good water quality was determined. Kilinto, Bole Bulbala and Mekanisa MBR were ranked 1, Gelan WSP was ranked 2, and Asko and Repi ABR were ranked the least.

Key words: *Anaerobic Baffle Reactors (ABR), Membrane Bio-reactor (MBR), Multi-criteria decision making, Waste Stabilization Pond (WSP), Water quality index, Weighted Arithmetic Method,*

1 INTRODUCTION

1.1 Background of the Study

Domestic wastewater is wastewater that is produced from various household activities such as from grey water (washing machines, shower, sinks), toilets black water (Asian Development Bank, 2017). Safe removal of municipal wastewater is one of the challenges affecting one-fifth of the water bodies in the world (EPA, 2018). Rapid urbanization commonly exceeds the capacity of sanitation infrastructure in developing cities (Narayan and Charles, 2017). Usually out of 70-80% of total water supplied for domestic use gets generated as wastewater (CPHEEO, 2012).

The wastewater usually requires some type of preparation or treatment before it is rendered fit for disposal or reuse. The degree of treatment provided to the wastewater will largely be based on the effluent standards prescribed by the regulatory agencies when the treated effluent is to be discharged into a watercourse or land. Municipal sewage can be treated close to where it is created (in septic tanks, bio filters or aerobic treatment systems), or collected and transported via a network of pipes and pump stations to a municipal treatment plant (Albion et al., 2012). Generally, there are two types of wastewater treatment system centralized and decentralized wastewater treatment system. Decentralized systems employ a combination of on-site and/or cluster systems for wastewater treatment and often used for individual houses, scattered and low-density communities and rural areas while centralized wastewater treatment system collects and treats huge volume of wastewater for the whole community (Sharma, 2018).

In Ethiopia, the habit of open field disposal of liquid waste is one of the main causes of soil and water contamination and consequently a cause of many communicable diseases (MoWIE, 2015). In order to enhance the problems of wastewater management, AAWSA currently reach to implement decentralized municipal wastewater treatment system especially for condominium houses for about 37 sites and common applicable decentralized wastewater treatment systems in Addis Ababa for condominium houses are (i) Membrane Bio-reactor (MBR), (ii) Waste Stabilization Pond (WSP) and (iii) Anaerobic Baffle Reactors (ABR) wastewater treatment technology (AAWSA, 2020).

Membrane Bio-reactor, by the mid1990s, the development of less expensive submerged membranes made a real alternative for high flow, large scale municipal wastewater applications. Over 1500 MBRs are currently in operation around the world in Japan, Europe and North America (Abdel Kader, 2007). This technology is the most recent developing in wastewater treatment systems and it makes a significant contribution since membranes have the ability to produce water of exceptional purity that can be recycled for reuse in a variety of places (Karim and James, 2017). ABR has been known since early 1980s, afterward it extensively use to treat wastewater due to numerous advantages such as: unaffected by shock loading both organic and hydraulic, can be constructed by local materials due to simple design, no electrical needed, greywater can managed simultaneously, odor and flies problems are minimum if used properly, highly reduce organics, relatively low-moderately cost depending on user number and maintenance.

Waste stabilization ponds are a popular form of wastewater treatment because of their low capital (except for land requirement) and operating costs, and their ability to handle fluctuating organic and hydraulic loads. Ponds are often classified according to the nature of the biological activity that is taking place, i.e., aerobic, anaerobic, and aerobic anaerobic (facultative). Aerobic ponds are used primarily for the treatment of soluble organic wastes and the polishing of effluents from facultative ponds or wastewater treatment plants, while anaerobic ponds are normally employed for stabilization of strong organic wastes. Facultative ponds are the most common type, and have been used to treat domestic and a variety of industrial wastewater (Mara, 2003). Many countries in tropical climates use waste stabilization pond (WSP) for wastewater treatment. For instance, Tanzania, Kenya, Malawi, Uganda, Zambia, Botswana, and Zimbabwe utilize this system. However, many of these systems have been performing below the required standards due to lack of proper operation and maintenance, improper positioning of inlet and outlet and sludge accumulation among others (Gruchlik et al., 2018).

The main advantages of using the municipal wastewater treatment plants effluent (WWTPE) are availability, being inexpensive to irrigate farmland, being a constant source of water. Other benefits of wastewater reuse are the possibility to recover the nutrients in the wastewater, reducing the use of fertilizers, resolving the problems associated with wastewater disposal and groundwater recharge (Mohammad and Shiraz, 2013). Therefore, it is very important to properly monitor and assess the effluent quality of wastewater treatment plants

for sustainable water resources management and safeguarding the public health. It is not surprising that, due to the above factors, studying water quality is so much important to be carried out in order to keep our awareness and understanding of our environment.

In order to monitor and assess water quality, the term water quality index was developed to give an indication of how suitable the water is for human consumption. Water quality index (WQI) provides a single dimensionless value that indicates the overall water quality under specified conditions of time and location depending on various water quality parameters and it can be defined as a single value, which reflects the overall wastewater quality related to its input constituent parameters which has the purpose of establishing the ecological state of a body of water (Mohamed and Ahmed, 2021).

Performance appraisal practice of existing treatment plants is effective in generation of additional data which also can be used in the improvement in the design procedures to be followed for design of these plants. One of the primary considerations in evaluating an existing wastewater treatment plant is in the area of plant operation and control. A major tool required for proper process control is frequent and accurate sampling and laboratory analysis (Ramadan et al., 2017). Hence, in this study the removal efficiency, the effluent quality of treated wastewater for safe disposal and reuse purpose based on wastewater quality index approach and performance evaluation of municipal wastewater treatment using TOPSIS multi criteria decision making has been conducted on six wastewater treatment plants in Addis Ababa.

1.2 Problem Statement

The collection, treatment and disposal of wastes provide a benefit to communities by removing effluents. In Ethiopia, there are a frequent complains in almost all condominium houses related to the sanitation problems (Sisay and Birhanu, 2017). Addis Ababa is the city in Ethiopia with a sewerage network, although only about 10 percent of the population has access to the sewerage services (World Bank, 2017), also world bank mentioned that Addis Ababa has three sewerage catchments (Akakai, Kality and Eastern) but do not have adequate capacity to deal with the city's volumes of sludge, as result, decentralized wastewater treatment plants (DWWTPs) have been designed, operated to reduce the pollution of wastewater and minimize the adverse impacts on environmental quality and human health.

Installations of municipal decentralized wastewater treatment plants are a big step forward for Ethiopia. However, two major things are problems that are the failure to regularly monitor the performance of the already existing treatment plants and evaluation of treated wastewater quality. If wastewater treatment plants are not modified continuously with respect to population growth, additional load beyond the design capacities of wastewater treatment plants and technical problems will create inefficiency in their overall performance and they can discharge the effluents above the permission limits set by national and international standards. Therefore, along with installation the performance assessment is important. Performance evaluation of effluent quality has the benefit of assessing the wastewater treatment plant after commissioning the plant based on the removal efficiency of major parameters such as (BOD, COD, TSS, TDS, Phosphate, Nitrate, Ammonia, and Coliforms). The potential challenges of wastewater treatment plant and determining the status of the wastewater treatment plant to prevent urban water pollution and if the effluent can be used for water reuse purpose like irrigation. Besides based on these problems, there are no related researches on the removal efficiency particularly for condominium houses effluent treatment plants in Addis Ababa. Hence this study structured in such a manner to assess the removal efficiency of treatment plants, applying wastewater quality index to assess the quality of treated effluent and the status of the selected wastewater treatment in Addis Ababa.

1.3 Research Objectives

1.3.1 General objectives

The objective of this study has been to evaluate the performance of decentralized municipal wastewater treatment technologies in Addis Ababa.

1.3.2 Specific objectives

The specific objectives of this study include:

- ✓ To determine physicochemical and bacteriological characteristics of untreated and treated wastewater;
- ✓ To evaluate the treated effluent quality of wastewater using wastewater quality index;
- ✓ To compare wastewater treatment plants by using multi-criteria decision making.

1.4 Significance of the Study

This comparative performance study evaluates the current status of selected decentralized wastewater treatment systems for condominium houses. Hence this study will;

- ✓ Create an opportunity for further amendments for the operation of the treatment systems;
- ✓ Give the information and assurance for downstream communities regarding the effluent quality for agricultural purposes such as for irrigating crops, commercial and residential landscaping and horticulture; and
- ✓ Provide a baseline data for further study such as for governmental organizations (GO) and non-governmental organizations (NGO).

1.5 Limitation of the study

There are 37 municipal decentralized wastewater treatment technologies under AAWSA including all treatment systems like wetland and sand filtration. However, in this study only three types of technology are studied. Although there are 22 (11 MBR, 8 ABR and 3 WSP), the study only considered six stations due to logistic related challenges and the study was done for the three months in the dry season flow.

2 LITERATURE REVIEW

2.1 Wastewater Treatment in Developing Countries

The existence of wastewater and the need for wastewater treatment is not a new problem, on growing civilizations and increasing urbanization. With the introduction of the water closet and centralized wastewater collection, problems related to large accumulations of wastewater has arisen. In centralized systems for wastewater collection, one could also find other sources to wastewater than only domestic, such as storm water and industrial wastewater sources (Kvernberg, 2012).

During the late 19th and the early 20th century, there was an awakening in the development of centralized wastewater treatment systems, mainly in the United Kingdom and the United States. As an addition to collection and discharge of wastewater, physical, biological and chemical processes for the wastewater treatment were introduced, for the removal of pollutants. The idea of separated systems also sprung up at this time, as mixing of storm water and domestic wastewater lead to overloading of the treatment plants. Through the 20th century, there was an increasing public concern for environmental issues, leading to a wider focus on wastewater disposal practices (Britannica, 2012).

In developing countries, the release of untreated wastewater remains a common practice due to lacking infrastructure, technical and institutional capacity, and financing. Wastewater management services are generally inadequate, thus wastewater treatment and disposal is a matter of concern that needs to be addressed (Nansubuga et al, 2016). Most African countries, for instance Egypt, Ethiopia, and Malawi, the common treatment methods are lagoons and drying beds and most of the time the community uses decentralized sanitation systems such as pit latrines, ventilated pit latrines, and septic tanks. These facilities are mainly concerned with reducing the sediment load rather than removing most of the harmful chemicals and pathogens. These dominant treatment types mainly remove about 30% of the organic wastes and 50% of suspended solids and bacteria (Ravina et al, 2021)

In recent decades, urban sanitation interventions have focused on increasing access to improved toilet facilities, with little attention paid to ensuring that wastewater is adequately collected and treated before discharge into the environment. Despite the availability of Health Extension Workers (HEW) in all Ethiopian towns, more than 60% of households in urban

areas use traditional pit latrines and about 6% of urban residents are still practicing open defecation. Fecal sludge is often accumulated in poorly designed and built pits, and then discharged directly into storm drains, open water bodies, seep into the ground, or is manually removed from the pit and dumped into the environment (Abebe et al. 2015)

In general, there are conventional and non-conventional wastewater treatment methods. Some of conventional wastewater treatment methods include activated sludge, trickling filter, rotating biological contactor, membrane bioreactors and anaerobic baffle reactor methods. Non-conventional methods include stabilization ponds, constructed wetlands, oxidation ditch, and soil aquifer treatment. Sisay and Berihu (2017) stated that condominiums without connections to the central wastewater treatment plants placed the government under pressure to act quickly to address the lack of wastewater treatments in Ethiopia. Addis Ababa water supply agency uses typically three mechanisms to solve the problem of waste effluent from condominium houses in the city. The first option in the former ones had built septic tanks and collects mechanically by vehicles. The second option is by connecting condominium houses to sewer lines. More than 26,917 condominium houses have connected their effluent waste to sewer lines and treated at Kality wastewater treatment plant. That is 24.8 % of the total condominium houses have connected their waste to sewer lines of Kality treatment plant. But the treatment plant is not enough to treat the effluent waste that comes by sewer line and vehicles from the whole corner of the city because the plant was built to serve 50,000 people. But now it serves above 70,000 people and the third option is installing the treatment systems around the condominium houses. So, condominium houses are having their own treatment system in Addis Ababa.

Currently AAWSA reach to implement decentralized municipal wastewater treatment system especially for condominium houses for about 37 sites. There are some technologies that are operated municipal wastewater treatment systems owned by AAWSA in Addis Ababa city to treat municipal effluents. Some of them are wastes stabilization pond, membrane Bioreactor, anaerobic baffled reactor, sand filtration and wetland (AAWSA, 2020). Membrane bio-reactor (MBR), anaerobic baffle reactors (ABR) and waste stabilization ponds are the most common used wastewater treatment technology for decentralized system in Addis Ababa city. The sites of operating and design capacity are listed in Table 1.

Table 1 List of municipal wastewater treatment plants under AAWSA (AAWSA, 2020)

No	Site	Sub City	Technology	Type	Design capacity	Actual capacity	Operation Year GC
					m3/day	m3/day	
1	Kality	Akaki Kality	UASB+TF	Centralized	100,000	50,000	2018
2	Kotebe	Bole	WSP	Centralized	4000	11000	1998
3	Gelan	Akaki kality	WSP	Decentralized	5000	3000	2008
4	Mikililand	Kolfe Keranio	WSP	Decentralized	2500	2500	2006
5	Bole Arabsa 1A	Bole	MBR	Decentralized	2600	600	2018
6	Bole Arabsa 2A	Bole	MBR	Decentralized	3600	800	2018
7	Bole Arabsa 2B	Bole	MBR	Decentralized	4300	900	2018
8	Bole Bulbula	Bole	MBR	Decentralized	3000	600	2017
9	Kara Kore 1	Kolfe Keranio	MBR	Decentralized	400	400	2017
10	Kara Kore 2	Kolfe Keranio	MBR	Decentralized	1000	1000	2017
11	Kilinto	Akaki Kality	MBR	Decentralized	3000	1500	2018
12	Mekanisa Kotar	Nifasilk Lafto	MBR	Decentralized	1700	1700	2017
13	Oromia	Nifasilk Lafto	MBR	Decentralized	1200	700	2018
14	Tulu Dimtu 1	Akaki Kality	MBR	Decentralized	1000	400	2018
15	Tulu Dimtu 2	Akaki Kality	MBR	Decentralized	2000	2000	2018
16	Tulu Dimtu 3	Akaki Kality	MBR	Decentralized	2000	600	2018
17	Abo Commet	Akaki Kality	SPRAS	Decentralized	120	NF	2018
18	Bole Homes	Bole	Wetland	Decentralized	120	120	1975
19	Bole Bulbula	Bole	ABR	Decentralized	3000	Standby	2018
20	Bole Bulbula 2	Bole	ABR	Decentralized	600	600	2016
21	Crown	Akaki Kality	ABR	Decentralized	1000	NF	2016
22	Genet Menafesh	Akaki Kality	ABR	Decentralized	1000	NF	2016
23	Gerji	Bole	ABR	Decentralized	600	1500	2006
24	Kara Alo	Yeka	ABR	Decentralized	500	500	2020
25	Kara Kore 1	Kolfe Keranio	ABR	Decentralized	1000	Standby	2016
26	Kara Kore 2	Kolfe Keranio	ABR	Decentralized	1000	Standby	2016
27	Klinto	Akaki Kality	ABR	Decentralized	3000	Standby	2016
28	Kilinto 2	Akaki Kality	ABR	Decentralized	500	500	2018
29	Koye Feche	Akaki Kality	ABR	Decentralized	2000	2000	2017
30	Koye Feche	Akaki Kality	ABR	Decentralized	2000	2000	2017
31	Mekanisa Kotar	Nifasilk Lafto	ABR	Decentralized	2000	standby	2016
32	Asko	Kolfe Keranio	ABR	Decentralized	500	500	2017
33	Repi	Kolfe Keranio	ABR	Decentralized	500	500	2017
34	Tulu Dimtu 1	Akaki Kality	ABR	Decentralized	1000	Standby	2016
35	Tulu Dimtu 2	Akaki Kality	ABR	Decentralized	2000	Standby	2016
36	Tulu Dimtu 3	Akaki Kality	ABR	Decentralized	2000	Standby	2016
Total					148,120	88,520	

2.2 Characteristics of Domestic Wastewater

Wastewater is used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff or storm water, and any sewer inflow or sewer infiltration. (Tilley et al, 2014). Types of wastewater include: domestic wastewater from households, municipal wastewater from communities (sewage) and industrial wastewater. The characteristics of wastewater vary depending on the source. Wastewater characteristics can be classified in terms of physical, chemical and biological constituents. The main physical characteristics of wastewater are: odor, color, temperature, turbidity, and solid contents. Municipal wastewater has a slightly soapy or oily odor. The main chemical characteristics of wastewater include: organic matter (include BOD, COD), nitrogen, phosphorus, chlorides, sulfur, alkalinity, heavy metals (very low concentration for municipal wastewater), Gases like hydrogen sulfide, methane and ammonia. Biological characteristics of wastewater include bacteria, virus and pathogens. (Alzboon et al., 2012).

Grace (2010) reported that Phosphorus (as total phosphorus, TP) was detected in 97% of the household products evaluated, and is thus the most common element in this group of household products. Phosphorus was detected in: (a) All cleaning products, including all brands of surface and toilet cleaners, all toilet fresheners and floor cleaners; (b) Bathroom products: 97% of shower and bathroom personal care products, including all brands of shampoos, conditioners, shower gels, soaps, hair coloring, oral care products and 75% of other personal care products, (c) Personal care: 89% of deodorants, 71% sunscreens and all brands of other skin care products. (d) Kitchen products: all brands of manual and dish washing detergents. (e) Laundry products: all products, including fabric softeners, liquid detergents and laundry powder concentrates. Nitrogen was detected in 84% of the household products evaluated, Nitrogen was detected in: (a) cleaning products: in 91 % of all products, including all brands of surface and toilet cleaners, all toilet fresheners and in 50% of floor cleaners; (b) bathroom products: in 94% of shower and bathroom personal care products, including all brands of shampoos, conditioners, shower gels and hair coloring, 67% of soaps, 64% of oral care products: (c) personal care: in 44% of deodorants, 86% sunscreens and 78% of other skin care products: (d) kitchen products: all brands of manual and dish washing detergents: (e) laundry products: in 79% of all products, including all fabric softeners, 80% of liquid detergents and 62% of laundry powder concentrates; and (f) toilet paper: 100% products.

2.2.1 Physical/chemical parameters

2.2.1.1 Hydrogen-ion concentration (pH)

Since most microbial life occurs within a narrow pH range (typically 6-9), the hydrogen-ion concentration is great concern in relation to biological treatment. Influent water with exceptional high or low pH-values (typically industrial wastewater) can be hard to treat by biological means. Effluent water may also affect the pH of the natural waters in the recipient. The standard discharge effluent limit to environment is 6-9 (EEPA, 2003).

$$\text{pH} = \log_{10} [\text{H}^+] \quad (1)$$

Where: H^+ is the concentration of the hydrogen ion.

2.2.1.2 Electrical conductivity (EC)

The electrical conductivity (EC) of water is a measure of the ability of a solution to carry or conduct an electrical current since the electrical current is carried by ions in solution. It is also indirect measure of the saltiness of the water. Fish and other organisms that live fresh water cannot tolerate because they will not be able to keep water in their bodies and it is also the main parameters used to determine the suitability of water for irrigation and firefighting (APHA, 2005). Low conductivity (0 to 200 $\mu\text{S}/\text{cm}$) is an indicator of pristine or background conditions, mid-range conductivity (200 to 1000 $\mu\text{S}/\text{cm}$) indicate the normal background for most major rivers, Conductivity outside this range could indicate that the water is not suitable for certain species of fish or bugs. High conductivity (1000 to 10,000 $\mu\text{S}/\text{cm}$) is an indicator of saline conditions (USEPA, 2018).

2.2.1.3 Total suspended solids (TSS) and Total Dissolved Solids (TDS)

TSS gives an indication of the content of solid matter in the wastewater and derives from the total solids content (TS) which cover all types of solids found in a wastewater flow, normally a mixture of floating matter, settleable matter, colloidal matter and matter in solution. Typically, 60% of the suspended solids are settleable. TSS values are widely used to determine treatment efficiency for conventional treatment processes and to assess the need for effluent filtration in the case of reuse applications and these measures are helpful to the operators of the wastewater treatment plant because they roughly approximate the amount of

organic matter existing in the total solids of wastewater, activated sludge, and industrial wastes. Total dissolved solids (mg/L) (Metcalf & Eddy 2004).

2.2.1.4 Dissolved oxygen (DO)

Dissolved oxygen (DO) is considered to be one of the most important parameters of water quality in streams, rivers, and lakes. It is a key test of water pollution. The higher the concentration of dissolved oxygen, the better the water quality will be oxygen is slightly soluble in water and very sensitive to temperature. The actual amount of dissolved oxygen varies depending on pressure, temperature, and salinity of the water. Dissolved oxygen has no direct effect on public health, but drinking water with very little or no oxygen tastes unpalatable to some people (Metcalf & Eddy, 2003)

2.2.1.5 Organic content in wastewater

The level of organic components is widely used as a measure of contamination in wastewater, and to evaluate the performance of conventional treatment processes. The organic content is usually measured as biochemical oxygen demand, chemical oxygen demand or total organic carbon.

Biochemical Oxygen Demand (BOD): BOD is a measure of the concentration of biodegradable substances in the wastewater, normally composed of a combination of carbon, hydrogen, oxygen and nitrogen. These substances are broken down by energy-consuming bacteria, and can be measured by detecting the amount of oxygen that is used over a period of 5 or 7 days. Bacteria and other microorganisms use organic substances for food. As they metabolize organic material, they consume oxygen and the organics are broken down into simpler compounds, such as CO₂ and H₂O, and the microbes use the energy released for growth and reproduction. When this process occurs in water, the oxygen consumed is the DO in the water. If oxygen is not continuously replaced by natural or artificial means in the water, the DO concentration will reduce as the microbes decompose the organic materials. This need for oxygen is called the biochemical oxygen demand (BOD)(Metcalf & Eddy, 2003).

Chemical Oxygen Demand (COD): The chemical oxygen demand (COD) is a parameter that measures all organics: the biodegradable and the non-biodegradable substances and COD values are always higher than BOD values for the same sample (Metcalf & Eddy, 2003).

2.2.1.6 Total nitrogen

There are four forms of nitrogen in water and wastewater: organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. Nitrogen in the nitrate form is a basic nutrient to the growth of plants and can be a growth-limiting nutrient factor (APHA, 2005).

Raw domestic wastewater normally holds a large fraction of nitrogen, either as organically bonded nitrogen or in inorganic forms such as ammonium (NH_4^+), nitrite (NO_2^-) or nitrate (NO_3^-). The term total nitrogen refers to the sum of the organic and inorganic compounds of nitrogen. When the term Kjeldahl nitrogen is used, it refers to the sum of organic nitrogen and inorganic nitrogen from ammonium. Urea and proteins are normally the main contributors to the nitrogen content in raw wastewater. Nitrogen is an essential nutrient for the growth of microorganisms, plants and animals. Since it is an essential building block in the synthesis of protein, it is a necessity in biological treatment processes. The content of nitrogen in the effluent of wastewater cause an environmental concern, as it contributes to eutrophication. On the other hand, if reuse of the wastewater effluent for irrigation is desirable, the nitrogen content should be conserved as it makes an important nutrient for this purpose (Metcalf & Eddy, 2003).

2.2.1.7 Phosphorus

Just like nitrogen, phosphorus is an essential nutrient for growth of biological life. Raw wastewater normally holds a large fraction of phosphorus, and as it makes a significant contribution to eutrophication when led untreated into a natural water body, it should be removed during treatment. Phosphorus is, just like nitrogen, of great interest in relation to reuse purposes, since it constitute a resource that can be utilized for irrigation means. Typical phosphorus containing compounds found in wastewater are orthophosphate, condensed phosphate or organically bound phosphate (Kvernberg, 2012).

2.2.1.8 Sulfate

Sulfate ions (SO_4^{2-}) occur in natural water and in wastewater. The high concentration of sulfate in natural water is usually caused by leaching of natural deposits of sodium sulfate (Glauber's salt) or magnesium sulfate (Epson salt) (Davis, 2010).

2.2.2 Biological parameters

One of the most helpful indicators of water quality may be the presence or lack of living organisms (APHA, 2005). Some organisms can be used as an indication for the existence of pollutants based on their known tolerance for a specified pollutant. Microorganisms exist everywhere in nature therefore human bodies maintain a normal population of microbes in the intestinal tract; a big portion of which is made up of coliform bacteria. Although, there are millions of microbes per milliliter in wastewater, most of them are harmless, it is only harmful when wastewater contains wastes from people infected with diseases that the presence of harmful microorganisms in wastewater is likely to occur. A lot of dangerous waterborne diseases are caused by bacteria, namely, typhoid and paratyphoid fever, leptospirosis, tularemia, shigellosis, and cholera. Sometimes, the absence of good sanitary practices results in gastroenteritis outbreaks of one or more of those diseases (Wiesmann et al, (2007).

2.3 Wastewater Treatment Systems

Wastewater treatment is more vital for the reduction of biodegradable organic substances in the environment, reduction of nutrient concentration in the environment, elimination of pathogens and recycling and reuse of water (Amoatey and Bani, 2012). There are two types of wastewater treatment systems namely centralized and decentralized wastewater treatment systems. Both systems can serve individual dwellings, industrial or institutional facilities, clusters of homes or businesses, and entire communities. Centralized wastewater system uses a series of sewer pipes, tunnels, and pumps to collect wastewater and to transport it to a central treatment plant while decentralized wastewater treatment systems convey, treat and dispose or reuse wastewater from small and low-density communities, buildings and dwellings in remote areas, individual public or private sectors (EPA, 2018).

Table 2 Comparison between Centralized and Decentralized systems, (Diana and Ines, 2015)

Parameters	Centralized system	Decentralized system
Collecting system	Large diameters, long distances	Small diameters, short distances
Requirement for space	Large area in one place	Small areas in many places
Operation and maintenance	Full time technical staff requirements	Less demanding, can be monitored remotely
Technically	High energy consumption, pumping required, sludge easier to manage	Less energy for pumping, sludge handling is difficult
Uniformity of water	Many types of water	More uniform water
Social aspects	Located far from human settlements	Located near/ within/ human settlements
Potential to reuse	All water is concentrated in one point	Water can be reused locally

2.4 Membrane Bioreactors (MBR)

Membrane Bioreactor (MBR) technology is an efficient technology for municipal and industrial wastewater treatment. It is a novel technology due to its divergent advantages over conventional bioreactors. It is a mixture of a conventional biological treatment system and physical liquid–solid separation using membrane filtration in one system. Membrane bioreactors are composed of two primary parts, the biological unit responsible for the biodegradation of the waste compounds and the membrane module for the physical separation of the treated water from mixed liquor (Hasnine et al., 2017).

The most widely applied membrane separation processes are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), electro dialysis (ED) and electro deionization (EDI). The separation ranges are as follows: 100 to 1000 nm for MF, 5 to 100 nm for UF, 1 to 5 nm for NF, and 0.1 to 1 nm for RO (Radjenovic et al., 2008). MBR systems can be classified into two major groups according to their configuration. The first group, commonly known as the submerged MBR system, involves outer skin membranes that are internal to the bioreactor (Figure b1).

The second configuration is the external MBR (Figure b2), which involves the recirculation of the mixed liquor through a membrane module that is outside the bioreactor and both inter

skin and outer skin membranes can be used in this application. Several types and configurations of membranes have been used for MBR applications. These include tubular, plate and frame, rotary disk, hollow fiber, organic (polyethylene, polysulfone, etc.), metallic, and inorganic (ceramic) microfiltration and ultrafiltration membranes.

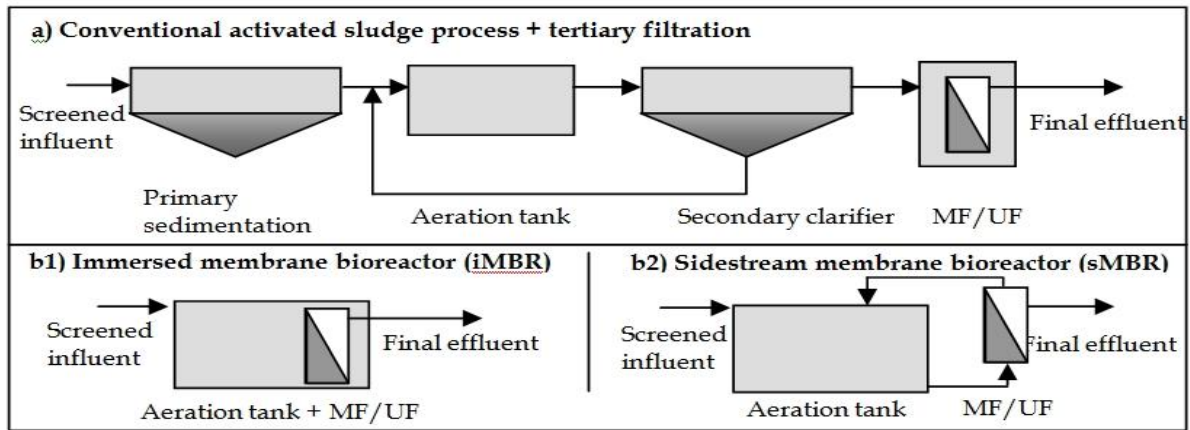


Figure 1 Membrane bioreactor wastewater treatment process.

2.4.1 Performance of MBR wastewater treatment technology

MBR process can produce an effluent of much better quality in terms of organic matter, suspended solids, and nutrients. Since this technology have been introduced for biological wastewater treatment, it is important to evaluate their performance in heavy metal removal. Some researchers found that MBR system with UF membranes have good removal efficiency of heavy metals for industry effluents and MBR offers the advantage of higher product water quality and low footprint. Due to its advantages, membrane bioreactor technology has great potential in wide ranging applications including municipal and industrial wastewater treatment (e.g. textile) and process water recycling (Deowan et al, 2019).

Kitano et al (2018) concluded that from their study MBR pilot plant can achieve high removal efficiencies in domestic wastewater treatment and that MBR permeate is suitable for urban, agricultural and recreational reuse according to the quality criteria for water reuse and water reuse and reclamation increases, MBR technology can make reclaimed water more accessible by achieving wastewater treatment standards.

In Morocco, Kitanou et al. (2018) studied on external pilot-scale membrane bioreactor (MBR) with a ceramic membrane compared to a conventional activated sludge process (ASP) plant

technologies that are received their influent from domestic wastewater, the MBR produced an effluent of much better quality than the ASP in terms of total suspended solids (TSS), 5-day biological oxygen demand (BOD₅) and chemical oxygen demand (COD), total phosphorus (TP) and total nitrogen (TN). The small size of the pores of the UF membrane makes it possible to block all bacterial species. The results of this study indicated that the MBR system can achieve better microbial removal. Hence the author concluded that in the case of domestic wastewater, MBR treatment has good removal efficiency.

Biological Performance, BOD and COD removal in conventional wastewater treatment processes like activated sludge process removal of COD and BOD₅ varies from 80-95 % while in MBR process can reach upto 96-99 % depending upon the quality and pore size of membranes. The pollutant uptake rate of MBR is higher than conventional processes due to high number of microorganisms in the reactor tanks. This leads to better degradation of organic matter in a given time span and smaller requirement of reactor volumes than the conventional methods. MBR technology is an attractive alternative for nitrogen and phosphorous technologies applied in conventional ASP method to achieve low nutrient effluent (Singh and Reghu, 2015). The technology has some common operational problems that includes membrane fouling, process control parameters like aeration tank volume, mean cell residence time (MCRT), Food/Microorganism ratio (F/M Ratio), sludge volume index (SVI) and sludge wasting. Methods to control fouling for MBR operation, several key parameters can be modified. The most important strategies are concentration polarization suppression, optimization of physical and chemical cleaning protocols, pre-treatment of feed wastewater, and mixed-liquor modification (Hasnine et al., 2017).

2.4.2 Advantage and disadvantage of MBR technology

MBR system's has advantages and disadvantage. Some of advantages are the following (CS)

- Almost complete solids and bacteria (Giardia and Crypto) removal and high effluent quality, modular design with good expandability;
- Robustness in recovery resistant to upsets due to shock loadings or peak and fluctuating flows, sludge age or SRT (solids retention time) and hydraulic residence time (HRT) are controlled separately;
- Less odor, Sophisticated but yet simple controls.

Disadvantages of MBR technology are:

- Membrane fouling high cost of membranes and higher energy consumption to overcome transmembrane resistance and to prevent fouling using aeration.

2.5 Waste Stabilization Pond (WSP)

Waste stabilization ponds (WSPs) are open basins enclosed by earthen embankments or fully or partially lined with concrete or synthetic geo-fabrics. They employ natural processes to treat domestic wastewater, seepage and sludge, as well as animal or industrial wastes. They can be used in centralized or semi-centralized sewerage systems, serving cities or towns and they can also be used as onsite systems serving a single community center (Verbyla et al, 2017).

The most common types of WSPs are anaerobic ponds, facultative ponds, maturation ponds, aerated ponds, and high-rate algal ponds (HRAPs). These ponds differ in terms of their function in the overall wastewater treatment system. The main function of anaerobic, facultative and aerated ponds is the removal of carbon-containing organic matter, to remove suspended solids, and organic matter (BOD). While the main function of maturation ponds is the removal of pathogens and nutrients (especially nitrogen). HRAPs were developed to optimize the efficiency of organic matter removal while simultaneously allowing for the recovery of dissolved nutrients that become incorporated into the algal biomass. Waste stabilization pond technology is the most cost-effective wastewater treatment technology for the removal of pathogenic microorganisms (Kamyotra and Bhardwaj, 2011).

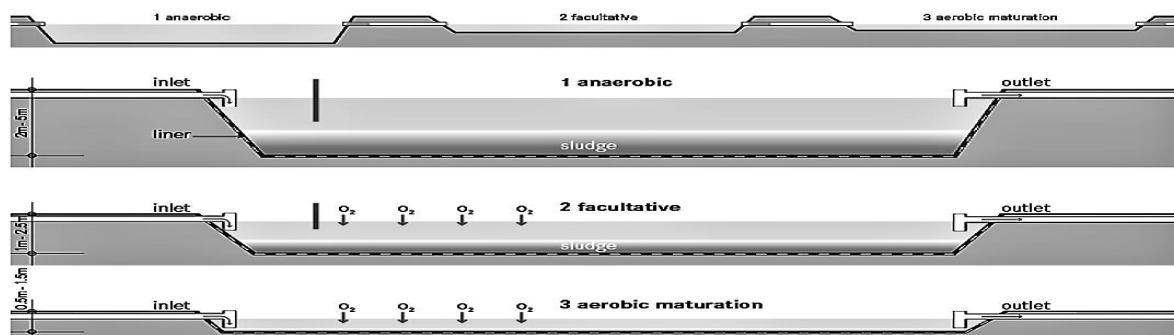


Figure 2 Waste Stabilization Pond Treatment Process

2.5.1 Performance of waste stabilization pond wastewater treatment

In Tanzania, Mkude and Saria (2014) evaluated the efficiency of waste stabilization ponds in Swaswa, Dodoma municipality. The results indicated very low removal efficiency for most of the parameters evaluated. The system recorded no removal of Biochemical Oxygen Demand (BOD), Total Dissolved Solids (TDS) and Electrical Conductivity (EC) with efficiency as low as 26.7%.

According to (Oberlin, 2018), Waste stabilization ponds system in Mwanza was found to be performing well regarding the studied parameters such as (Temperature, pH, DO, BOD₅, pathogens and TSS) that play a key role in waste stabilization ponds performance. The findings of this study were within the allowable limits by Tanzanian Bureau of Standards (TBS), subsequently ensuring protection of receiving water body- Lake Victoria. The average BOD₅ at inlet and outlet were 357 and 27mg/l respectively, the BOD₅ removal meet the Tanzania Standard of 30mg/l. This suggests that the pond system is working properly. The BOD₅ removal efficiency was 92.43%. Average pathogen in influent was 5800 count/100ml and effluent was 100 count/100ml respectively, the pathogen removal is within Tanzania standard. The average pathogen removal efficiency is determined to be 98.30%. The concentration of the fecal coliforms of the final effluent is very low compared to the recommended TBS guideline value of 10,000 counts/100 ml. This indicates that the final pond effluent discharged into Lake Victoria does not pose threat to humans and the ecosystem in general. TSS at inlet, and outlet were 324mg/l and 72mg/l. The calculated removal efficiency of TSS was 77.77%. Other wastewater parameters (temperature, pH, and DO) of the final pond effluent compare well with their respective recommended values laid down by TBS. Hence the author concluded that Mwanza waste stabilization pond system provides a useful method for treating and disposing wastewater and therefore should be regarded as a method of choice for treating wastewater elsewhere in Tanzania.

In Ghana, (Emmanuel et al., 2015) tried to compare the two WSP wastewater treatment plants and the overall removal efficiency of the Ahinsan WSP were 2.6% for pH, 83.90% for TSS, 87.23% for NO₂-N, 52.00% for NH₃-N, 66.86% for TP, 42.86% for DO, 97.50% for TC, 93.14% for BOD₅ and 89.39% for COD. Whereas that of the KNUST Plant were 14.18% for pH, 86.07% for TSS, 72.84% for TP, 70.45% for TN and 69.85% for BOD₅. Hence the removal efficiency of BOD₅ in the Ahinsan WSP was higher than the KNUST

plant. The problem of hydraulic performance of the system can affect the removal efficiency of the treatment plant. Letshwenyo and Gopolang (2018) found that a dramatic reduction was observed between design and effective retention times for the anaerobic pond, also they suggest assessing the common operational problems and hydraulic performance of the system, hydraulic retention time, and pond geometry, surface organic loading measurements are important.

2.5.2 Advantage and disadvantage of WSP

There are some advantage and disadvantage of WSP system; some of them are as follow

Advantages of WSP

- Simplicity in design and construction
- Low production of biological sludge
- Low capital, operation and maintenance cost
- Less sensitive to shock loading
- Robust and relatively reliable and high treatment efficiency if properly designed

Disadvantages of WSP

- Large land requirement for the ponds
- Mosquitoes and other insects can breed if vegetation is not controlled
- Sludge accumulation will be higher in cold climates due to reduced microbial activity (US EPA, 2002b)
- If it is not designed properly, it may cause odor problem

2.6 Anaerobic Baffle Reactor (ABR)

An anaerobic baffled reactor (ABR) is an improved septic tank with a series of baffles under which the wastewater is forced to flow. Wastewater enters the reactor and flows under a natural head and over the hanging and standing baffles. No oxygen or mechanical mixing is applied in the ABR; treatment is achieved by anaerobic digestion by naturally selected anaerobic microbial (referred to as sludge). ABR has application in on-site and decentralized sanitation in conjunction with an appropriate post-treatment, such as membrane filtration for disinfection, rock filters or constructed wetlands. Depending on the scale of the application

and the type of post-treatment, the treated effluent should be reused for agricultural purposes or directed into a soak away. Certainly, where a septic tank is considered an acceptable sanitation system, an ABR would consistently achieve better effluent quality (Foxon and Buckley, 2006).

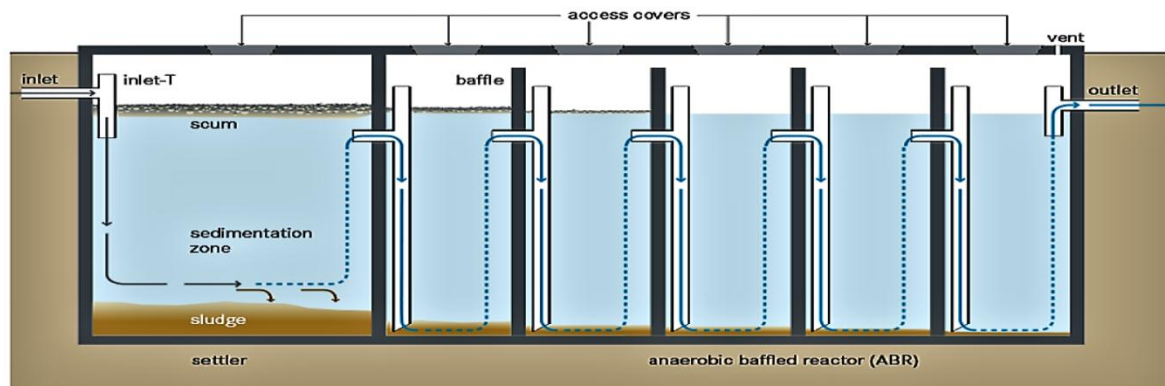


Figure 3 Anaerobic baffled reactor (ABR) treatment process

2.6.1 Performance of ABR wastewater treatment

Aerobic processes are widely used for municipal wastewater treatment. Because of for the advantages of aerobic treatment of municipal wastewater like high efficiency, reduced odor, nitrification of ammonia, and reduction of greenhouse gases compared to anaerobic treatment, but the disadvantages of this method include high capital cost for aeration equipment, high operating cost, high maintenance requirements, large amounts of excess sludge production and more nutrients required, which make this process costly, so anaerobic process like ABR seems to be an attractive alternative for the treatment of municipal wastewater treatment due to economic advantages over aerobic process (Moradghol, 2019).

In Nepal, Singh et al. (2008) developed a model for decentralized wastewater treatment plant with anaerobic baffled reactor (ABR) and hybrid constructed wetland to treat high-strength wastewater from households. The performance of the DEWATS was monitored from July 2006 to August 2007 for the parameters - TSS, BOD₅, COD, NH₄-N, Total Phosphorus (TP) and Fecal coliform (FC). The average removal efficiencies of the DEWAT model are 96% TSS, 90% BOD₅, 90% COD, 70% NH₄-N, 26% (TP) and 98% (FC). Hence the author concluded that there is high potential of using ABR as primary treatment. ABR is very effective in the removal of organic parameters and could achieve TSS removal up to 91%, BOD up to 78% and COD up to 77%.

In Iran, Moradghol (2019) found that ABR operation at hydraulic retention time (HRT) =24 hours, the average removal efficiency of Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total suspended solids (TSS), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), and log reduction value of coliforms were obtained to 71%, 75%, 79%, 23%, 30.3%, and 5.8 Log, respectively. In this phase, when the HRT was decreased from 24 to 18 hours and from 18 to 14 hours, the removal efficiency of all parameters by the ABR was decreased. Hence it can be concluded that retention time has effects on the removal efficiency on ABR treatment technology.

2.6.2 Advantage and disadvantage of ABR wastewater treatment technology

There are some advantage and disadvantage of ABR system; some of them are as follow

Advantage

- Resistant to organic and hydraulic shock loads
- No electrical energy is required
- Low operating costs
- Long service life
- High reduction of BOD
- Low sludge production; the sludge is stabilized
- Moderate area requirement (can be built underground)

Disadvantage

- Requires expert design and construction
- Low reduction of pathogens and nutrients
- Effluent and sludge require further treatment and/or appropriate discharge

2.7 Application of Wastewater Quality Index

Water quality index (WQI) provides a single dimensionless value that indicates the overall water quality under specified conditions of time and location depending on various water quality parameters. In most cases, it applied to assess the quality of water resources and potability of the treated water (Mohamed and Ahmed, 2021). The water quality index

represents a numerical expression which has the purpose of establishing the ecological state of a body of water. (Valentina-Andreea et al., 2018) described four methods for calculating the Water Quality Index. These are

- i. **NSF-WQI (National Sanitation Foundation-Water Quality Index)**: includes TDS (total of dissolved solids), pH, turbidity, phosphates, nitrates,, BOD (Biochemical consumption of oxygen), Coliforms, DO (dissolved oxygen), temperature parameters of quality. It presents a different contribution upon the modification of the water quality, a specific weight in the calculation. This index is calculated by using equation 2

$$NSF - WQI = \sum_{i=1}^n W_i Q_i \quad (2)$$

Where: WQI-NFS is a numerical value between 0-100; W_i is the weighting factor for each parameter; Q_i is the sub-index of the quality parameter i , which is obtained from the conversion curve (curves that convert parameters determined by values from the interval 0-100).

- ii. **OWQI (Oregon Water Quality Index)**: The eight physical, chemical and biological parameters used in this descriptive method for the water quality are: temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, ammonia+nitrate nitrogen, total phosphorus, total dissolved solids (TDS) and Coliforms. It used to describe the quality of surface waters bodies from Oregon, as well as from other geographical areas. This index was suggested starting from the model of NSF-WQI. This index is calculated based on equation 3.

$$OWQI = \sqrt{\frac{n}{\sum_{i=1}^n \frac{1}{S_i^2}}} \quad (3)$$

Where: n is the numbers of parameters and S_i is the sub-index of sub-index i th parameter

- iii. **Weighted Arithmetic Water Quality Index Method** provides information regarding to the quality evaluation of a body of water. This method uses the most commonly measured water quality parameters (pH, BOD, COD, DO, P- PO_4^{3-} , N-total, N- NO_3^- , N- NO_2^- , N- NH_4^+ , SO_4^{2-} , Cl⁻, Cr-total, Pb^{2+} , Cd^{2+} , Ni^{2+} , Fe-total, Mn-total, Zn^{2+} , As^{2+}). The equations mention in methodology sections.

- iv. **The Canadian Council of Ministers of the Environment Index (CCME-WQI)** utilizes the following parameters for determining the water quality in a stream: temperature, conductivity, color, turbidity, dissolved oxygen (DO), pH, alkalinity, Ca, Na, Mg, K, SO₄, Cl⁻, F⁻, Dissolved Organic Carbon, P, Nitrates, Nitrites, N, SiO₂, Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Se, Sr, V, Zn. This is calculated by using three main factors, F₁, F₂, F₃, which can be deducted directly through by equation 4

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} * 100, F_2 = \frac{\text{Number of failed test}}{\text{Total number of tests}} * 100, F_3 = \frac{nse}{0.01 nse + 0.01} \quad (4)$$

After determining all these factors, (CCME-WQI) may be calculated according to equation 5

$$CWQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (5)$$

The choice of the final method for determining the quality of the water stream from the point of view of the physical-chemical water quality indexes depends on their nature and complexity, as well as on the purpose of their calculation.

2.8 Application of Multiple Criteria Decision Making (MCDM) of Wastewater Treatment Technology

The review of Multiple Criteria Decision Making (MCDM) methods suggests that Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are the competing and most widely used methods. TOPSIS method was firstly proposed by (Hwang and Yoon 1981). According to this technique, the best alternative would be the one that is nearest to the positive ideal solution and furthest from the negative ideal solution. Normalization is the practice of eliminating redundant data from crisp data in order to improve data integrity and scalability. In other ways, normalization helps to convert all fuzzified data into the range '0' to '1'. This also helps to equalize the units of all the characterization parameters. On the other hand, the AHP is important tool in determining the final decision based on mathematics of any multi criteria decision whose units are different and requires pairwise comparison among criteria (Anaokar et al., 2018). In AHP procedures, Eigen vector is also called priority vector important factor since it is normalized, the sum of all elements in priority vector is 1. The priority vector shows relative weights among the

factor that have compared. Consistency since judgments may lack a minimum level of consistency, mechanisms to improve consistency are necessary. Considering the consistency ratio (CR) and consistency index (CI). A CR value that is lower than 0.10 is generally acceptable; if not, the pair-wise comparison needs to be revised (Abid & Bahloul, 2011).

Table 3 Saaty's nine point scale for pair-wise comparison for AHP preference (Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong Importance	Experience and judgment strongly favor one activity over another
7	Demonstrated Importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

3 MATERIALS AND METHODS

There were 37 municipal decentralized wastewater treatment technologies under AAWSA including all treatment systems like wetland and sand filtration. However, in this study only three types of technologies were studied. The number of treatment plants for each technology were 3 MBR, 2 ABR and 1 WSP selected based on 30% of fully operating plants from 11 MBR, 8 ABR and 3 WSP plants.

3.1 Description of the study area

The wastewater treatment plants are located at Gelan WSP, Asko ABR, Repi ABR, Mekanisa Kotari MBR, Bole Bulbula MBR and Kilinto MBR in Addis Ababa, Ethiopia.

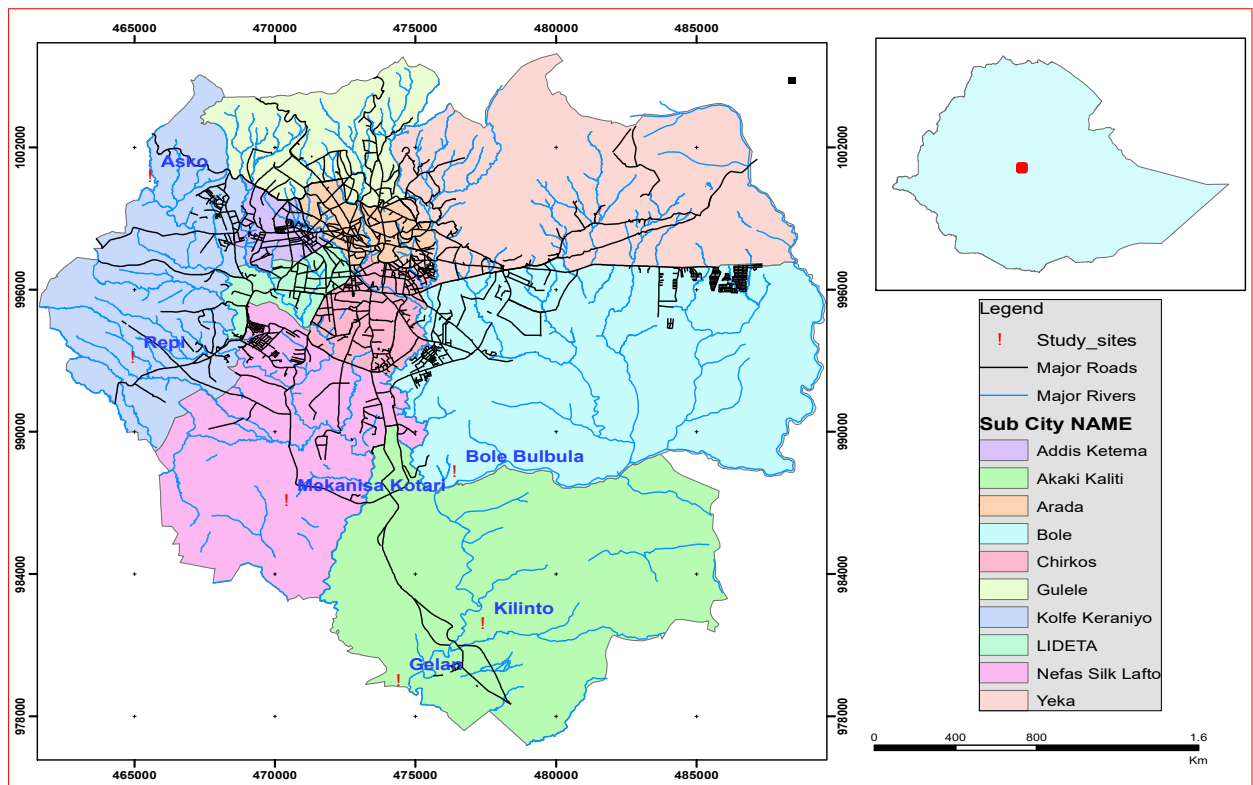


Figure 4 Location maps of wastewater treatment plants

The description of each wastewater treatment plants, their capacity and locations are given in Table 4.

Table 4 Wastewater treatment plants description with locations

WWTP	Technology	Sub city	Coordinate	Design (m ³ /day)	Actual (m ³ /day)	Design population service
Asko	ABR	Addis Ketema	N09°03'12.31", E038°41'16.71"	500	500	5600
Repi	ABR	Kolfe Keranio	N08°59'03.4", E038°40'56.52"	500	350	6200
Gelan	WSP	Akaki-Kality	N08°51'40.98", E038°46'06.43"	6640	2600	78,130
Mekanisa Kotari	MBR	Nifas silk Lafto	N08°55'47.25", E038°43'55.65"	1700	1700	15,000
Bole Bulbula	MBR	Bole	N08°56'35", E038°47'15"	3000	600	25,000
Kilinto	MBR	Akaki-Kality	N08°53'04", E038°47'41"	4000	1500	26,000

3.2 Sampling procedure

The setting up of a proper sampling was the first step into characterizing the constituents of wastewater. Several factors were considered to meet a representative sampling strategy. These factors included number of and selection of sampling locations, type of samples (grab or composite samples), sample sizes, time intervals between samples and total number of samples needed to achieve statistically representative output values from the analyses. The details of the sampling procedure are listed as follows:

3.2.1 Sampling points

The selection of critical points throughout the treatment plants was designed to achieve a better overview of the plant's performance as a whole. Samples were collected for MBR at inlet point of the treatment plant at the main pumping station where in the gutter between the screening unit and the pump house and at outlet of the treatment plants from the wastewater treated tank. At WSP, samples were taken at inlet where significant turbulence occurs at the distribution channel and at outlet where the discharge of polishing ponds to the receiving

water body. At ABR, samples were taken at inlet of the discharge of manhole and at outlet point of treatment plants. The sampling type was grab sampling through the study periods.

3.2.2 Types, size and scope of sampling regime

In this study, samples were taken from two sampling points (inlet and outlet). For each sites 6 monthly samples including influent and effluent for three months were taken. During the entire study period, a total of 36 samples were collected and analyzed for the required water quality parameters in the period of December 2021 to February 2022. Sampling was carried out between 10:00 and 12:00 each morning during the sampling period. Sample containers were selected as per the standard sampling requirements and the quality assurances were made by using quality control methods such as following standard protocol, washing plastic bottles, calibration of the instruments, standard solution and duplicate analysis were done according to (EPA, 2007). For physicochemical measurement samples were collected with one-liter clean plastic container and samples for bacteriological analysis were collected using glass bottles.

All collected samples were analyzed for pH, Electrical Conductivity (EC), Turbidity, Total Suspended Solid (TSS), Total Dissolved Solids (TDS), Dissolved oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Sulfate, Ammonia, Nitrate, Phosphate and Coliform (total and E. coli). Heavy metals were excluded as a result of the source of wastewater is domestic where heavy metals are considered low concentration.

3.2.3 Laboratory analysis

Parameters such as dissolved oxygen (DO), turbidity and pH of the wastewater would have been measured onsite but it was measured at laboratory in less than 4 hours, because of difficulty to take the instrument to the site in some reasons. The laboratory analysis was taken at AAWSA and 5 Kilo university at Biochemical Engineering department laboratories.

DO

The readings of the dissolved oxygen in the wastewater samples were performed using a handheld HI9146 dissolved oxygen meter. The sensor was cleaned with distilled water between every measurement.

pH and Electrical Conductivity

The pH and EC readings were measured using a handheld HACH HQ30D portable pH and Conductivity meter. After the calibration the pH probe held in the sample until the pH-value was stabilized to read the results. For conductivity the EC probe held in the sample and read the results. In between every reading of the sensor was cleaned with distilled water.

Turbidity

The measurements were made using HACH 2100N laboratory Turbidimeter, EPA, 115 Vac. After calibration, the samples held in and read the results very quick.

TDS and TSS

The total dissolved solid and total suspended solids were undertaken according to APHA Standard Methods for the Examination of Water and Wastewater -Method 2540 C and 2540 D. A well-mixed sample was filtered through a standard glass fiber filter, and the filtrate was evaporated to dryness in a weighed dish and dried to constant weight at 179-181⁰C. The increase in dish weight represents the total dissolved solids. A well-mixed sample was filtered through a weighed standard glass fiber filter and the residue retained on the filter was dried to a constant weight at 103-105⁰C. The increase weight of the filter represents the total suspended solids. If the suspended material clogs the filter and prolongs filtration, the difference between the total solids and total dissolved solids may provide an estimate of the total suspended solids. The value of TDS and TSS can compute by using equation 6 and 7 Metcalf & Eddy (2004)

$$\text{Total dissolved solids (mg/L)} = \left[\left(\frac{TDSA - TDSB}{\text{Sample(ml)}} \right) \times 1000 \right] \quad (6)$$

Where TDSA = weight of dried residue + dish in milligrams and
TDSB = weight of dish in milligram

And

$$\text{Total suspended solids (mg/L)} = \left[\left(\frac{TSSA - TSSB}{\text{Sample(ml)}} \right) \times 1000 \right] \quad (7)$$

Where TSSA = weight of dish and filter paper + dried residue
TSSB = weight of dish and filter paper in milligram

COD

The sample analysis was done by according to the standard ISO 6060-1989 DIR 38409 H41-H44 by using dichromate method with spectrometer DR 5000. The re-agent vial was selected according to the expected COD range of the sample, 2 ml of sample and deionized water for blank was transferred to the reagent vial and inserted in COD reactor for 2 hrs in 150⁰C. Finally after cooling the vials, blank vial inserted into spectrometer until the reading results zero after that the sample vial inserted into spectrometer and read the results.

BOD

The sample analysis was done by manometric method. The sample volume has taken from 50 % of COD mg/l and the sample pH was adjusted at 6.5 to 7.5. A clean magnetic stir bar added to each test dark bottle. For the suppression of nitrification, nitrification inhibitor was added after filled the dry seal cup with 3 drops of sodium hydroxide then it placed the manometric cup with BOD sensors on the test bottle and the sample was incubated at 20⁰C. After 5 days in the incubator, the measurements of manometric caps were taken and calculated BOD₅ by equation 8

$$\text{BOD}_5 = \text{Value} \times \text{Factor} \quad (8)$$

Where: The factor values are from the standard table for specific sample volume where taken.

Ammonia

The sample analysis was done by Nessler method 8038 using spectrometer DR 5000. The sample was filled at mixing cylinder to the 25ml and the blank was filled at mixing cylinder to the 25ml with deionized water. Reagents like mineral stabilizer and polyvinyl alcohol dispersing agent were used and measurement was done according to test procedure of the method.

Sulfate

The sample analysis of sulfate in the wastewater was done by SulfaVer 4 method 8051 by using spectrometer DR 5000. The sample and the bank were filled at sample cell with 10ml

for each. SulfaVer 4 powder pillow reagent was used and measurement was done according to test procedure of the method.

Phosphate (Orthophosphate)

The sample analysis of Phosphate (Orthophosphate) was done by PhosVer3 (Ascorbic acid) by method 8048 by using spectrometer DR 5000. The sample with 5 ml was added to a reactive Phosphorus test (N tube Vial). PhosVer 3 phosphate powder pillow reagent was used and the measurement was done according to test procedure of the method.

Total Coliform and E. coli

Total coliforms and Escherichia coli (E.coli) were measured by using EPA (2002) method 1604, water by membrane filtration using a simultaneous detection technique (MI Medium). A 10 mL wastewater sample was filtered through a 47-mm, 0.45- μm pore size cellulose ester membrane filter that retains the bacteria present in the sample. The filter was placed on a 5-mL plate of MI agar, and the plate was incubated at 35°C for up to 24 hours. The bacterial colonies that grow on the plate were inspected for the presence of blue color from the breakdown of (Indoxyl- β -D-glucuronide) IBDG by the E. coli enzyme β -glucuronidase and fluorescence under long-wave ultraviolet light (366 nm) from the breakdown of MUGal by the TC enzyme β -galactosidase. The following formulas in equation 9 and 10 were used to determine the final value

$$\text{E. coli/100 mL} \quad \frac{\text{Number of blue colonies}}{\text{Volume of sample filtered (mL)}} \times 100 \quad (9)$$

$$\text{TC/100 mL} \quad \frac{\text{Number of fluorescent colonies} + \text{Number of blue, non-fluorescent colonies}}{\text{Volume of sample filtered (mL)}} \times 100 \quad (10)$$

For general counting rules, USEPA Microbiology Manual, Part II, Section C, 3.5, was used.

3.3 Data Analysis

The raw data were coded and entered into a Microsoft excel spreadsheet for descriptive analysis, the mean and standard deviations were calculated. The data were exported to SPSS (version-23) for correlation analysis. The data were analyzed using one-way ANOVA to declare a statistically significant difference between the treatment plants. Prior to conducting

the ANOVA, the assumption of normality was evaluated and determined to be satisfied as the six groups were associated with skew and kurtosis less than [2.0] and [9.0] respectively.

3.4 Removal Efficiency

The removal efficiency of each wastewater treatment plants were calculated by using equation 11 described as

$$\%RE = \left(\frac{a - b}{a} \right) \times 100 \quad (11)$$

Where: a represent parameter concentration in influent (mg/L) while b is represent parameter concentration in effluent (mg/L).

3.5 Wastewater Quality Index

The wastewater quality index determined by the weighted arithmetic water quality index method (WAWQIM) and the rating with their corresponding grade of the treated wastewater are determined by using equation 12.

$$WQI = \frac{\sum q_i w_i}{\sum W_i} \quad (12)$$

Where: WQI has a value between 0 and 100 which indicates the quality of the water; q_i represents a relative value of the water quality, specific to each parameter; i represents the number of parameters taken into consideration; W_i is a factor which measures the importance of a parameter in the calculation of the WQI index (relative weight); q_i is calculated by equation 13.

$$q_i = 100 \times \frac{V_i - V_0}{S_i - V_0} \quad (13)$$

where: V_i represents the value experimentally determined of the i analyzed parameter; V_0 represents the ideal value of that parameter; S_i represents the standard, legally accepted, value for the water category in which the analyzed water sample was included. W_i factor is computed by using equation 14.

$$W_i = \frac{K}{S_i} \text{ and } K = \frac{1}{\sum \frac{1}{S_i}} \quad (14)$$

Where: K is constant of proportionality

3.6 Multiple Criteria Decision Making

The MCDM were done on basis of environmental criteria that includes the removal of pollutants which is the removal efficiencies of TSS, BOD₅ and COD, which are the important characteristics that indicate the pollution strength of the wastewater (Alali et al., 2011). The values of removal efficiency are taken from this study.

The step-by-step exposition of the TOPSIS methodology for selection of appropriate wastewater treatment alternatives were done in this study according to (Yoon and Hwang, 1995) and (Upadhyay, 2015).

Step 1: Normalization

The normalized score matrix (r_{ij}) is determined by equation 15.

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^m (X_{ij}^2)}}, i=1, \dots, m; j=1, \dots, n \quad (15)$$

Where: x_{ij} is the score of j^{th} indicator for i^{th} alternative, and there are n indicators (or attributes) and m alternatives.

Alternative	Technology	Removal efficiency								
		BOD	X_{ij}^2	r_{ij}	COD	X_{ij}^2	r_{ij}	TSS	X_{ij}^2	r_{ij}
Asko	ABR	31.70	1004.89	0.16	38.65	1493.82	0.20	52.66	2773.08	0.26
Repi	ABR	6.72	45.16	0.03	3.67	13.47	0.02	-14.92	222.61	-0.07
Gelan	WSP	85.19	7257.34	0.44	84.52	7143.63	0.44	89.44	7999.51	0.44
Bole Bulbula	MBR	99.09	9818.83	0.51	97.21	9449.78	0.50	99.20	9840.64	0.49
Mekanisa Kotari	MBR	98.26	9655.03	0.51	97.97	9598.12	0.51	99.89	9978.01	0.49
Kilinto	MBR	99.67	9934.11	0.51	98.06	9615.76	0.51	99.66	9932.12	0.49

Step 2: Calculate the weighted normalized ratings.

The weighted normalized ratings were calculated, the weighted normalization matrices are given in equation 16.

The weighted normalization matrices (a_{ij}) are calculated as follows

$$a_{ij} = W_j r_{ij} \quad (16)$$

Where: w_j is the weight of the j^{th} attribute

To find weight elicitation (W_j), AHP approach was used.

Pair wise comparison judgmental matrix

	BOD	COD	TSS
BOD	1	3	7
COD	0.33	1	5
TSS	0.14	0.2	1
Sum	1.47	4.20	13.00

Calculate weight criteria, weight criteria is determined weight of intensity divided by the sum of intensity i.e $1/1.47=0.68$, as shown below

	BOD	COD	TSS	W_j
BOD	0.68	0.71	0.54	0.64
COD	0.23	0.24	0.38	0.28
TSS	0.10	0.05	0.08	0.07

Weighted value= weight* weight criteria, i.e $1*0.64=0.64$ for BOD, $0.33*0.28=0.21$

Alternative	Technology	The weighted normalization matrices					
		BOD	W_j*r_{ij}	COD	W_j*r_{ij}	TSS	W_j*r_{ij}
Asko	ABR	0.16	0.11	0.20	0.06	0.26	0.02
Repi	ABR	0.03	0.02	0.02	0.01	-0.07	-0.01
Gelan	WSP	0.44	0.28	0.44	0.12	0.44	0.03
Bole Bulbula	MBR	0.51	0.33	0.50	0.14	0.49	0.04
Mekanisa	MBR	0.51	0.33	0.51	0.14	0.49	0.04
Kilinto	MBR	0.51	0.33	0.51	0.14	0.49	0.04

Step 3: Calculate TOPSIS

TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution, and the longest geometric distance from the negative ideal solution. Using equations 17 and 18, the corresponding distances from the ideal solutions can be calculated.

$$A_w = \{(\max_{t_{ij}: i = 1, 2, \dots, m; j \in J^-}), (\min_{t_{ij}: i = 1, 2, \dots, m; j \in J^+})\} = t_{w_j}: j = 1, 2, \dots, n \quad (17)$$

$$A_b = \{(\min_{t_{ij}} : i = 1, 2, \dots, m; j \in J^-), (\max_{t_{ij}} : i = 1, 2, \dots, m): j \in J^+\} = t_{bj} : j = 1, 2, \dots, n \quad (18)$$

Step 4: Identification of best ideal and worst ideal Solutions

It is possible to analyze the best and worst ideal solutions. The best option can be obtained by considering the positive ideal solutions; the worst one by considering the negative ideal solutions. Using the measure of separation, the best and worst options can be calculated using equations 19 and 20.

$$S_{ib} = \sqrt{\sum_{j=1}^n (t_{ij} - t_{wj})^2}, i=1,2,3,\dots,m \quad (19)$$

$$S_{iw} = \sqrt{\sum_{j=1}^n (t_{ij} - t_{bj})^2}, i=1,2,3,\dots,m \quad (20)$$

Where: S_{ib} gives the best ideal solution and S_{iw} gives the worst ideal solution and t_{ij} means the measure of separation of each alternative solution. The concept of best and worst ideal solution is the measure of separation for the best and worst options.

Step 5: Calculate separation measures and ranks

The ranking process was achieved using the closeness coefficient, which is the number close to the best option. This coefficient can be obtained using equation 21.

$$R_{iw} = \left[\frac{S_{iw}}{(S_{iw} + S_{ib})} \right] \leq I_{iw} \leq 1, i = 1, 2, \dots, m \quad (21)$$

Alternative	S_i^+	S_i^-	$S_i^+ + S_i^-$	Ranking
Asko	0.2421	0.1004	0.3425	0.2932
Repi	0.3402	0.0000	0.3402	0.0000
Gelan	0.0520	0.2883	0.3404	0.8472
Bole Bulbula	0.0000	0.3380	0.3380	1.0000
Mekanisa Kotari	0.0000	0.3361	0.3361	1.0000
Kilinto	0.0000	0.3403	0.3403	1.0000

4 RESULTS AND DISCUSSION

This chapter provides a descriptive analysis of the influent and effluent wastewater quality of the six wastewater treatment technologies. The results of concentration and the removal efficiency of the physicochemical and bacteriological are discussed below

4.1 Characteristic of Influent and Effluent of WWTPs

The results of concentration and the removal efficiency of the physicochemical and bacteriological are given in Table 5.

4.1.1 pH of wastewater

The mean values of pH concentration of effluent results are given in Table 5, all the pH value in the effluent of the treatment plants was within the permissible range 6-9 (EEPA, 2003). A statistically significant difference ($p < 0.05$) in pH effluent between treatment plants were recorded. Relatively higher effluent pH value of 8.15 was measured at Gelan WSP wastewater treatment; it might be due to increased algal activity in facultative and maturation ponds as CO_2 is consumed during photosynthesis by algae or due to high ammonia concentrations in the effluent (Butler et.al, 2017). Similar findings were reported on a case study WSP at Jimma, Gondar and Hawassa, Ethiopia (Belay et al., 2022).

4.1.2 Electrical conductivity

The mean values of EC concentration of effluent decreased as compared to the influent for all wastewater treatment plants except for Repi ABR wastewater treatment plant where relatively higher EC value of $1966.17 \mu\text{S}/\text{cm}$ was measured. A statistically significant difference ($p < 0.05$) in EC effluent between treatment plants were recorded. However, all the value of EC effluent concentration of the treatment plants does not meet the permissible range of EEPA which is $< 1000 \mu\text{S}/\text{cm}$. This might be as a result of degradation and freeing of the ions from the matrices of the wastewater (Tanko et al., 2018). The variation of conductivity in the wastewater can be caused by variation of the ion content. Ions that cause conductivity are hydrogen H^+ , hydroxide OH^- and nutrients such as phosphate and nitrate and a conductivity (1000 to $10,000 \mu\text{S}/\text{cm}$) is an indicator of saline conditions (USEPA, 2018).

4.1.3 Total suspended solids (TSS) and Total dissolved solid (TDS)

The mean values of total suspended solids of effluent decreased as compared to influent for all wastewater treatment plants. A statistically significant difference ($p < 0.05$) in TSS effluent concentration and in removal efficiency between treatment plants were recorded. As per the standard set by (EEPA, 2003), the TSS level of all treatment plants except Asko and Repi (ABR) meet the standard limit which is 50 mg/l.

The mean values of TDS effluent concentration decreased as compared to influent for all wastewater treatment plants and the effluent was within the standard limit which is 2000mg/l. There was also statistically significant difference ($p < 0.05$) in TDS effluent between treatment plants.

4.1.4 Dissolved oxygen (DO)

All the DO mean values of the effluent of the treatment plants was lower than the permissible range of EEPA which is the level of dissolved oxygen in effluent of wastewater treatment plant should be greater than 5mg/l. Even though, the dissolved oxygen level of effluent at MBR and WSP showed increment than influent along the treatment plants. Statistically significant difference ($p < 0.05$) in effluent between treatment plants were recorded. As per Mara (2003), DO concentration is not a reliable parameter for assessment of treatment performance as there will be oxygen replacement. In MBR treatment, it is known that aerobic biological treatment is dependent of the access of oxygen to perform well, and this is provided for through the aid of aeration of the filter media.

The rise in DO at the outlet could be a result of the wastewater being exposed to free oxygen after leaving the filter media, streaming through the aerated under drain (Kvernberg, 2012). At Gelan treatment the value of 2.24 mg/l was relatively higher than (0.675 mg/L) reported in Hawassa, Ethiopia and a value of 0.22 mg/L reported in Sebeta and 2.12 mg/l reported in Jimma (Belay et al., 2022), Butler et al. (2017) mentioned the possible reason for this variation might be due to the nature of the raw wastewater, the type of oxidation pond, the environment. They also stated a DO saturation level lower than 5 mg/L, can lead to undue stress to the fish and levels reaching below 2 mg/L may result in death. This is an indication that the rate of oxygen production through photosynthesis was lower than the rate of oxygen consumption through respiration and decomposition of organic matter. This is fall in DO concentration indicates that the pond is becoming anoxic and some management strategies

like aeration with mechanical aerators need to be implemented. In anaerobic conditions which also the reason why smaller DO found in ABR treatment system were unable to enter oxygen into the system.

4.1.5 Nitrate (N-NO₃⁻)

The nitrate of effluent concentration value was within the permissible range of EEPA (< 50mg/l) except Kilinto MBR a value of 52.14mg/l. NO₃⁻N accumulated in the effluent and their concentration was high as compared to the influent in MBR and WSP, it might be due to domestic sources and its concentration in treated effluents is high because of oxidation of NH₃⁻N into NO₃⁻N by microbes (Morrison et al., 2001). It is important to note that nitrate level in the treated final effluent could be a source of eutrophication for receiving water as the obtained values exceeded the recommended limit.

4.1.6 Ammonia (N-NH₃)

The effluent decreased as compared to influent for all treatment plants except at Repi and Gelan. The discharges of ammonia for all treatment plants did not meet the standard set by EEPA which is 10mg/l except Kilinto with a value of 4.69 mg/l. A statistically significant difference (p<0.05) in ammonia effluent concentration and in removal efficiency between treatment plants were recorded.

4.1.7 Orthophosphate

High phosphate concentration effluent were found than the standard requirement set by EEPA which is < 0.02 mg/l even if the effluent decreased as compared to influent for all treatment plants except Repi. A statistically significant difference (p<0.05) in orthophosphate effluent concentration and in removal efficiency between treatment plants were recorded. High relative effluent with a value of 59.10mg/l were found at Repi ABR.

Table 5 Mean influent, effluent and removal efficiency of wastewater treatment plants.

Parameter	Asko			Repi			Gelan		
	In	out	% RE	In	out	% RE	In	out	% RE
pH	6.91	6.81	1.24	7.28	7.05	2.53	7.32	8.15	*
EC	2248.66	1667.67	26.17	1555.5	1966.17	*	1522.83	1300.33	12.04
TSS	836.33	407.75	52.66	807.58	737.37	*	484.57	50.00	89.44
TDS	962.91	836.25	12.66	842.66	759.22	6.58	675.01	547.33	18.60
DO	1.07	0.93	*	0.89	0.85	4.80	0.73	2.24	*
Nitrate	29.27	27.07	19.11	26.44	19.74	36.26	8.72	18.91	*
Ammonia	112.68	78.84	28.36	77.31	108.36	*	39.08	39.61	*
OrthoPhosphate	54.89	35.58	33.20	42.24	59.10	*	25.24	17.08	33.53
Sulfate	57.93	21.72	62.41	48.37	28.37	40.65	29.19	35.70	*
COD	3343.67	1991.53	38.65	2544	2270.85	3.67	1261.17	190.17	84.52
BOD ₅	1444	1008.17	31.70	1772	1311.33	6.72	674	97.33	85.19
Turbidity	1082.83	346.50	69.33	713.83	851.17	*	455	31.08	93.14
Total Coliform	6.05*10 ⁶	496.67	99.99	4.98*10 ⁶	4566.67	99.89	6*10 ⁶	1483.33	99.98
E.Coli	3.07*10 ⁶	265.00	99.99	2.29*10 ⁶	2222.50	99.83	3.4*10 ⁶	140.67	99.99

Parameter	Bole Bulbula			Mekanisa Kotari			Kilinto		
	In	out	% RE	In	out	% RE	In	out	% RE
pH	7.31	7.93	*	7.26	7.93	*	7.31	7.73	*
EC	1552.33	1320.67	14.96	1745.50	1564.33	5.47	1288.33	1008.00	19.91
TSS	302.64	1.50	99.20	1581.58	0.97	99.89	739.08	2.61	99.66
TDS	864.94	569.00	34.20	953.08	577.98	32.81	664.25	407.14	38.79
DO	0.56	2.51	*	0.62	1.98	*	0.84	2.20	*
Nitrate	14.67	24.97	*	14.83	21.54	*	17.80	52.14	*
Ammonia	60.86	18.12	63.70	67.42	44.70	42.64	56.09	4.69	90.24
OrthoPhosphate	35.94	10.18	71.93	38.59	7.64	81.00	37.66	17.89	52.15
Sulfate	36.23	58.93	*	43.18	63.80	*	33.25	60.28	*
COD	1450.35	40.16	97.21	2367.38	41.17	97.97	1809.83	34.52	98.06
BOD ₅	666.67	6.33	99.09	975.33	12.67	98.26	739.67	2.17	99.67
Turbidity	415.5	0.60	99.86	1102.5	0.72	99.89	804.33	1.30	99.85
Total Coliform	4.40*10 ⁶	808.00	99.98	6.14*10 ⁶	3451.33	99.94	4.88*10 ⁶	83.67	99.99
E.Coli	2.58*10 ⁶	825.33	99.96	3.44*10 ⁶	1837.33	99.93	2.39*10 ⁶	29.67	99.99

* indicate the removal efficiency is less than zero

4.1.8 Sulfate

The effluent concentration decreased as compared to influent at only Asko and Repi. However as per standard limit, sulfate levels were recorded within the standard requirement set by EEPA which is <200 mg/l. A statistically significant difference ($p < 0.05$) in sulfate effluent concentration between treatment plants were recorded.

4.1.9 Turbidity

The mean values of turbidity effluent were decreased than influent for all treatment plants except Repi. There was a statistically significant difference ($p < 0.05$) in turbidity effluent concentration and in removal efficiency between treatment plants. As per standard limit of turbidity effluent of WSP and MBR treatment plants were within the standard EEPA which is <300 mg/l.

4.1.10 COD and BOD

The effluent of COD and BOD was decreased as compared to influent for all treatment plants and as per standard limit, effluent of COD in all MBR were within the standard limit EEPA which is <125 mg/l while ABR and Gelan WSP did not meet the EEPA standard. Effluent of BOD in all MBR treatment plants were within the standard while ABR and WSP did not meet the standard <25 mg/l.

There was a statistically significant difference ($p < 0.05$) in COD/BOD effluent concentration and removal efficiency between treatment plants. MBR has high removal efficiency and lower concentration of organic matter in the effluent than WSP and ABR. For WSP, the reason might be BOD_5/COD might raise capability of bio-degradation of a wide range of contamination or it might be the effect of anaerobic pretreatment might clear by lower BOD_5/COD ratio in the ponds.

The Ratio of BOD_5/COD is referred to as biodegradability index and ranges from 0.4 to 0.8 for domestic wastewater. Ratio > 0.6 implies biodegradable quality of waste which can be treated biologically. Ratio varying from 0.3 to 0.6 implies that seeding has to be done in order to treat it. Ratio < 0.3 indicates that it cannot be treated biologically (Rukeh and Agbozu, 2013). In this study, BOD_5/COD ratio of influent was found the biodegradable nature of wastes and can be treated biologically except at Asko (0.43) that indicate seeding has to be

done. The possible influential factors on the BOD₅/COD ratio may include: local industrial types, the input from food-processing, catering and service industries can contribute to a high BOD/COD ratio of wastewater.

The finding of Gelan WSP was the same as similar study at Hawassa, Jimma and Kotebe in Ethiopia (Belay et al., 2020) that they did not meet limit standard. The higher values of organic loading in the effluent of the pond might indicate the total area of the facultative pond is not sufficient to handle the BOD₅ concentration of wastewater and a short retention period that should be removed at the preliminary treatment unit (Mara et al., 1992.). Effluent which has high concentration of BOD₅ and COD can cause depletion of oxygen in the aquatic environment or in the receiving water bodies. Therefore, the BOD₅/COD removal and the consequent quality of the effluent depend on the amount of oxygen present, retention time and temperature of ponds.

4.1.11 Total and E. coli Coliform

The influent concentration was high because the treatments receives human sewage that commonly accepted as being a suitable indicator of reduction of bacterial pathogens in wastewater treatment plant (Bitton G., 2005). The effluent of TC was decreased as compared to influent for all treatment plants.

For total coliform and E.coli, all treatments performed with an average percent removal was 99.99%. Statistically significant difference ($p < 0.05$) in total coliform and E.coli effluent concentration and total coliform of removal efficiency between treatment plants were recorded. However, the effluent contains a large number of bacteria which was beyond standard set by EEPA to be 50MPN/100mL. The effluent of E.coli was contains a high number of E.coli which was beyond standard set by EEPA < 10 MPN/100 mL in all treatment plants. Therefore, an additional treatment is needed (disinfection) to achieve the microbial quality required for water reuse purpose.

A significant proportion of the bacteria were retained mostly due to the fact that microbial reduction depends upon bacterial activity, suspended solids' settlement, inactivity due to sunlight and environment factors and turbid water hinders the disinfection process and is often associated with microbial on (Umara Q. et al., 2021).

4.2 Removal Efficiency and Performance Comparison with Other Studies

4.2.1 Asko and Repi ABR

Relatively smaller removal efficiency of ammonia was attained at Asko ABR a value of 28%. The finding of removal efficiency for ABR wastewater treatment was less than Nepal (70%) and Indonesia (35%). The reduction percent of phosphate in this study indicated at Asko ABR was 33% and greater than the reported result at two treatment plants in Palestine with value of 1.73% and 28% (Mohammed, 2010) and no removal of phosphate was found at Repi ABR, that might be attributed to phosphorus in runoff from domestic wastes and detergents. The percent removal of sulfate was attained at ABR Asko (62%) and Repi (40%) treatment plant.

Asko ABR had removal efficiency of 69% and there was no removal efficiency of turbidity at Repi and does not comply with the standard, this might be due to observed problems during the study period that manhole cover is damaged that could be the results of many grits might interred to the treatment plant, runoff that pass over the red-ash or low retention times because if the particles are relatively large they will settle down to the bottom over time as long as there is no or very little motion in the treatment. Small removal of TC and E.coli was obtained. However, the finding result showed E. coli for ABR was greater than the reported result in Nepal 98% (Singh S. et al. 2008), 68% and 61% were obtained respectively in E. coli and total coliform in South Africa (Foxon et.al, 2004).

Table 6 Comparison of mean removal efficiency of ABR wastewater treatment plants

Parameters	Asko	Repi	Iran, Moradghol (2019)	Nepal, Singh et al. (2008)
BOD ₅	31%	7%	71%	90%
COD	38%	4%	75%	90%
TSS	52%	No removal	79%	96%
NH ₄ ⁺ -N	-		23%	70%
NH ₃ ⁺ -N	28%	NR	-	-
TC	99%	99%	-	26%
FC	99%	99%	-	98%

The performance of ABR treatment plant with wetland was determined with some parameters such as TSS, BOD₅, COD, NH₄-N, Total Phosphorus (TP) and Fecal coliform (FC). The average removal efficiencies of the treatment plant was 96% TSS, 90% BOD₅, 90% COD, 70% NH₄-N, 26% (TP) and 98% (FC). Moradghol (2019) found that ABR operation at hydraulic retention time (HRT) =24 hours, the average removal efficiency of BOD₅, COD, TSS, Total Kjeldahl Nitrogen, Total Phosphorus were obtained to 71%, 75%, 79%, 23% and 30.3% respectively. In this study the Asko ABR treatment plant performed in average removal of TSS 52.66%, COD 38.65% and BOD₅ 31.70% and Repi ABR performed with removal efficiency of 3.67% of COD, 6.72% of BOD₅ and no removal of TSS.

The overall finding results were lower than to the expected performance comparing with the study in Iran and Nepal, ABR treatment was less than the reported result in Iran 75% COD and 71% BOD (Moradghol, 2019). Lower removal efficiency of COD and BOD found in ABR units might be a result of poor operation and maintenance activities, due to design criteria implemented according to previous quality standards that allowed a maximum BOD concentration in the effluent of wastewater treatment systems (Yulistyorini et al., 2019). The overall performance might be influenced by pH, organic loading rate (OLR), hydraulic retention time because the bacteria did not get enough time to consume the substrate and limit time for reaction (Ramandeep, 2016) or this might be as result of high salinity as well as high mineral content, due to oxidative degradation of dissolved solids during treatment (Singh and Varshney, 2013). During the study, an accumulated red-ash at outlet of treatment which is used as wet land but there is no collection channel at the end that the treated sewage pass over the red-ash to the downstream and having the scarcity of water for sanitation in the sites were observed (Bwapwa, 2012).

4.2.2 Mekanisa Kotari, Bole Bulbula and Kilinto MBR

Higher removal efficiency of ammonia was attained at Kilinto MBR a value of 90% and removal reduction for MBR was less than with Belli et al. (2014) report which was the removal of ammonia of 99% when MBR was operated in a sequential batch. The removal efficiency of phosphate at Mekanisa (81%) and Bole Bulbula (71%) MBR were greater than the reported result by Singh and Reghu, (2015) which was 61% of reduction. To remove phosphorus in MBR, addition of metal salt, alum or ferric chloride directly to the pre-aeration tank, precipitate soluble phosphorous can be used (Mahlet, 2017). There are other methods

like application of Absorptive media, Ion exchange, Biological removal, especially enhanced biological phosphorus removal and Algae-based and Hybrid treatment options (Bunce et al., 2018).

High percent reduction of turbidity about 99% were recorded, which was most satisfied removal efficiency in the advantage of a preservation of the sludge in the reactor by filtration and the effluents from the MBR systems produced high-quality of treated water that can be suitable for water reuse. Also high bacteria removal was obtained upto 99.99% for three MBRs, it might be due to pretreatment anaerobic unit that reduce microbial contamination.

Table 7 Comparison of mean removal efficiency of MBR wastewater treatment plants

Parameters	Mekanisa Kotari	Bole Bulbula	Kilinto	Kitanou et al. (2021)	Magdalena et al. (2019)
BOD ₅	98.26%	99.09%	99.67%	93.8%	96%
COD	97.97%	97.21%	98.06%	93.5%	94%
TSS	99.89%	99.2%	99.66%	99.2%	93%
TN	-	-	-	91%	82%
NH ₃ -N	42.64%	63.70%	90.24%	-	-
TC	99.94%	99.98%	99.99%	-	-
FC	99.93%	99.96%	99.99%	-	-

Relatively Mekanisa Kotari MBR had lower performance than the other two MBRs. The study were done on Mekanisa MBR by Mahlet at 2017 on filtration performance of the treatment plant was evaluated using permeate flux, transmembrane pressure (TMP) and permeability as performance indicators and the finding results were, TMP was maintained below 20mbar in all operation period this was done by compromising the design flow rate. (1) The permeate flow or the flux was declining below 10LMH, this affected the permeability capacity of the plant; the permeability was only 60LMH/bar. This value is very low compared to the standard for average operation of MBRs (150LMH/bar-250LMH/bar). (2) Installing primary clarifier is not feasible for the treatment site as it is located close to the residential area and available land is limited, if primary clarifier installed, it can remove fibers that cause problem in the membrane inside out filtration process and it could be a solution. (3) The low nitrogen removal efficiency is related with poor denitrification capacity of the plant (Mahlet, 2017).

Most of the time, COD and BOD₅ reduction were in the range of 86–94% and 90–97% successively. The TSS in the MBR effluent was completely removed and could not be detected as indication of efficient membrane filtration (Abdel-Shafy and El-Khateeb, 2011). In conventional wastewater treatment processes like activated sludge process removal of COD and BOD₅ varies from 80-95 % while in MBR process can reach upto 96-99 % depending upon the quality and pore size of membranes (Singh and Reghu, 2015). In this study, The three MBRs have a higher removal of BOD₅ (98%), COD (97%), the finding results were within the expected removal capacity and also greater than in Morocco 93% and TSS removed upto 99%, the same as similar study in Morocco 99% (Kitanoua et.al, 2021), a main reason can be preservation of the sludge in the reactor by the integrity of the membrane filtration. The overall reduction of all MBRs in this study meet the expected removal capacity ranges and the performance was better than comparing to other studies.

4.2.3 Gelan WSP

Good removal efficiency of TSS observed (89.44%) at Gelan was higher than with similar study conducted in Kotebe 56% (Biniam, 2018), Jimma 66% (Belay, 2022), Ghana 87% (Emmanuel et al. (2015)). The overall removal efficiency of ammonia was less than zero and extremely smaller than Jimma, Ethiopia (53%), Mikililand (34%), Ethiopia and Ghana (52%). Ammonia can be removed by desorption or incorporation into the aquatic biomass or transformed to nitrite or nitrate in the nitrification process and subsequently be converted into nitrogen gas by heterotrophic or autotrophic denitrification (Santos and Haandel, 2021) or removal mechanisms for nitrogen control in WSP could include: (a) ammonia volatilisation, (b) biological nitrogen uptake, and (c) sedimentation of dead biomass and accumulation in the sludge layer in maturation pond (Camargo et al., 2010).

In this study, COD (84.52%) was less than the reported result in Ghana (89%) and greater than the reported results in Jimma 56% (Belay et al., 2022), Mikililand 64% (Metadel and Mekibib, 2012) and Kotebe 75% (Biniam, 2018), Ethiopia and BOD₅ at Kotebe (74%) and Jimma (75%) and less than Ghana (93%). The finding of orthophosphate at Gelan WSP treatment percent reduction, a value of 33% was less than (71%) at Jimma, Ethiopia (Belay, 2022). The possible reason could be a consequence of dilution effect. However, the level of phosphate in water systems will reduce the likelihood of algal and other plant growth. The presence of high levels of phosphate in the effluent of the pond may cause undesirable

phytoplankton growth (eutrophication) in receiving water bodies, which results in algal bloom formation (Belay, 2022). High removal efficiency of bacteria were found and the finding results were the same as a similar case study reported results in Jimma (99.99%) and greater than E.coli (94.3%).

Table 8 Comparison of mean removal efficiency of WSP wastewater treatment plants

Parameters	Gelan	Mikililand (Metadel & Mekibib, 2012)	Jimma, (Belay, 2022).
BOD ₅	85.19%	71.28%	75.3%
COD	84.52%	64.41%	56.5%
TSS	89.44%	58.82%	65.8%
Nitrate	-	40.02%	70.7%
NH ₃ ⁺ -N	No Removal	34.48%	52.8%
TC	99.98%	61.44%	99.99%
FC	99.99%	62.70%	94.3%

4.3 Data Analysis of Influent and Effluent Parameters

There was no statistical difference between the wastewater treatment plants influent in all parameter even if there was a difference in concentration in each parameters between six treatment plants. This might be due to all effluent have the same characteristics as result of a discharge is municipal sewage. There was statistical significance difference effluent between the wastewater treatment plants except nitrate($p < 0.05$, two tailed), in pH [$F(5,12) = 16.96$, $P = 4.49E-05$], EC [$F(5,12) = 3.566$, $P = 0.03$], TSS [$F(5,12) = 12.077$, $P = 0.0002$], TDS [$F(5,12) = 4.655$, $P = 0.014$], DO [$F(5,12) = 7.596$, $P = 0.002$], ammonia [$F(5,12) = 6.310$, $P = 0.004$], phosphate [$F(5,12) = 27.641$, $P = 3.43E-06$], sulfur [$F(5,12) = 7.807$, $P = 0.002$], COD [$F(5,12) = 71.583$, $P = 1.64E-08$], BOD [$F(5,12) = 35.482$, $P = 8.72E-07$], turbidity [$F(5,12) = 70.747$, $P = 1.75E-08$], TC [$F(5,12) = 6.828$, $P = 0.003$] and E.coli [$F(5,12) = 3.385$, $P = 0.039$]. The reasons what might be are discussed in above sections 4.1. In order to find out exactly which groups are different from each other, post-hoc test Fisher's least significant difference test was done and the results are given in Table 9.

Table 9 Variations of physico-chemical and bacteriological parameters.

Site	Technology	pH	EC	TSS	TDS	DO	Ammonia
Asko	ABR	6.8±0.12 ^a	1.67±0.31 ^a	407.75±226.22 ^b	836±208.46 ^b	0.93±0.11 ^a	78.835±6.08 ^b
Repi	ABR	7.0±0.24 ^a	1.97±0.40 ^a	737.37±299.30 ^b	759±94.66 ^b	0.85±0.16 ^a	108.36±50.43 ^b
Gelan	WSP	8.145±0.29 ^b	1.30±0.10 ^a	50±7.21 ^a	547±56.10 ^a	2.24±0.07 ^b	39.61±7.16 ^a
Bulbula	MBR	7.9±0.2 ^b	1.3±0.26 ^b	1.5±0.43 ^a	569±64.08 ^a	2.51±0.62 ^b	18.12±16.98 ^a
Mekanisa	MBR	7.9±0.29 ^b	1.56±0.46 ^b	0.97±0.40 ^a	578±141.92 ^a	1.98±0.27 ^b	44.70±36.04 ^a
Kilinto	MBR	7.7±0.15 ^b	1.01±0.10 ^b	2.61±1.75 ^a	407±117.4 ^a	2.20±0.84 ^b	4.69±4.99 ^a
LSD		0.40	0.544	272.66	222.31	0.8	47.34

The same letter indicates there is no different between each other while different letters indicate there is a different between each other

Site	Technology	Phosphate	Sulfate	COD	BOD	Turbidity	TC	E.coli
Asko	ABR	35.58±10.85 ^b	21.72±2.08 ^a	1991.53±531.01 ^b	1008.17±418.41 ^b	346.5±164.19 ^b	496.67±55.08 ^a	265±70.89 ^a
Repi	ABR	59.1±4.65 ^b	28.37±17.60 ^a	2270.85±59.89 ^b	1311.33±53.7 ^b	851.17±56.25 ^b	4566.67±2074.13 ^b	2222.5±1869.82 ^b
Gelan	WSP	17.08±6.01 ^a	35.7±16.59 ^a	190.17±17.61 ^a	97.33±9.29 ^a	31.08±6.43 ^a	1483.33±845.95 ^a	140.67±71.28 ^a
Bole Bulbula	MBR	10.18±3.76 ^a	58.93±8.93 ^b	40.16±3.97 ^a	6.33±4.91 ^a	0.6±0.05 ^a	808±739.86 ^a	825.33±665.81 ^a
Mekanisa	MBR	7.64±4.37 ^a	63.8±6.20 ^b	41.17±5.49 ^a	12.67±0.29 ^a	0.72±0.36 ^a	3451.33±1708.91 ^b	1837.33±833.98 ^b
Kilinto	MBR	17.89±6.30 ^a	60.28±8.36 ^b	34.52±2.65 ^a	2.17±0.29 ^a	1.3±0.77 ^a	83.67±72.50 ^b	29.67±34.82 ^a
LSD		11.46	20.26	388.56	306.64	126.21	2117.80	1566.37

4.4 Data Analysis of Removal Efficiency

The variation of parameters for treatment plants were determined by using one-way ANOVA ($p < 0.05$, two tailed). There was a statistically significance difference between treatment plants and in order to find out exactly which groups are differ from each other, post-hoc test Fisher's least significant difference test was also done and the results are given in Table 10.

Table 10 Variation of removal efficiency of physicochemical and bacteriological parameters

Treatment	Technology	TSS	Ammonia	Orthophosphate	COD	BOD	Turbidity	TC
Asko	ABR	52.66 ^a	28.36 ^a	33.20 ^a	38.65 ^b	31.70 ^b	69.33 ^b	99.99 ^b
Repi	ABR	-14.92 ^a	-150.80 ^a	-85.98 ^b	3.67 ^a	6.72 ^a	-44.92 ^a	99.89 ^b
Gelan	WSP	89.44 ^b	-16.10 ^b	33.53 ^a	84.52 ^b	85.19 ^b	93.14 ^b	99.98 ^b
Bulbula	MBR	99.20 ^b	63.70 ^b	71.93 ^a	97.21 ^b	99.09 ^b	99.86 ^b	99.98 ^b
Mekanisa	MBR	99.89 ^b	42.64 ^b	81.00 ^a	97.97 ^b	98.26 ^b	99.89 ^b	99.94 ^b
Kilinto	MBR	99.66 ^b	90.24 ^b	52.15 ^a	98.06 ^b	99.67 ^b	99.85 ^b	99.99 ^a
Average		70.99	9.67	30.97	70.01	70.10	69.52	99.96
LSD		70.42	201.27	91.85	26.20	45.56	56.40	0.07

4.5 Correlation of Effluent Physicochemical and Bacteriological Parameters

The correlations among the effluent of physicochemical and bacteriological properties for six wastewater treatment plants were studied and the values of the correlation coefficients (r) are given in Table 11. The correlation coefficient (r) has a value between +1 and -1. Correlation is characterized as strong, when it is in the range of +0.8 to 1.0 and -0.8 to -1.0, moderate if it is in the range of +0.5 to 0.8 and -0.5 to -0.8 and weak when it is in the range of +0.0 to 0.5 and -0.0 to -0.5.

There was a strong negative significant correlation between TSS and pH, EC ($r = -0.842$, $r = -0.847$) at ($P < 0.05$) respectively, TDS with pH exhibited a strong negative significant correlation ($r = -0.823$, $P < 0.05$). This shows that with increase or decrease in the values of pH EC, TSS and TDS also exhibit decrease or increase in their values. TDS with EC indicated a strong positive significance correlation ($r = 0.870$, $P < 0.05$) as similar to the study Arutchelvan et al. (2004). They studied a significant linear relationship between EC-TDS and concluded that these two parameters are indicators of salinity level which make them very useful as one way in studying water quality (Arutchelvan et al., 2004).

There was a strong positive significant correlation between DO and pH ($r = 0.932$, $p < 0.01$), DO with TSS, EC and TDS were a strong negative significant correlation ($r = -0.932$, $p < 0.01$), ($r = -0.831$, $r = -0.867$ at $p < 0.05$) respectively. There was a strong positive significant correlation between Ammonia with EC, TSS, TDS and Phosphate ($r = 0.956$, 0.932 at $P < 0.01$ and $r = 0.886$ at $P < 0.05$) respectively and a strong negative significant correlation with DO ($r = -0.922$ at $P < 0.01$). A strong positive correlation may be due to inter-molecular association between ammonia and water influencing the EC (Shcherbakov et al., 2009).

COD had a strong positive significant correlation with EC, TDS, TSS, ammonia and phosphate ($r = 0.822$ at $P < 0.05$, $r = 0.891$ at $P < 0.05$, $r = 0.966$ at $P < 0.01$, $r = 0.920$ at $P < 0.01$, $r = 0.935$ at $P < 0.01$) respectively and a strong negative significant correlation with pH, DO and sulfate ($r = -0.933$ at $P < 0.01$, $r = -0.969$ at $P < 0.01$ and $r = -0.849$ at $P < 0.05$) respectively. There was a strong positive significant correlation between BOD with EC, TDS, TSS, ammonia, phosphate and COD ($r = 0.838$ at $P < 0.05$, $r = 0.871$ at $P < 0.05$, $r = 0.983$ at $P < 0.01$, $r = 0.932$ at $P < 0.01$, $r = 0.956$ at $P < 0.01$ and $r = 0.977$ at $P < 0.01$) respectively and negative significant correlation with pH, DO and sulfate ($r = -0.911$ at $P < 0.05$, $r = -0.963$ at $P < 0.01$ and

r= -0.833 at P<0.05) respectively. These associations indicate that organic pollutants, suspended solid and dissolved solids may originate from common sources such as domestic, sewerage, municipal and industrial wastes (Melaku et al., 2007).

Turbidity had a strong positive significant correlation with EC, TSS, ammonia, phosphate, COD and BOD (r=0.840 at P<0.05, r=0.990 at P<0.01, r=0.910 at P<0.05, r= 0.979 at P<0.01, r=0.921 at P<0.01 and r=0.949 at P<0.01) respectively and a strong negative significant correlation with DO (r=- 0.876 at P<0.05). At high ammonia at concentrations can cause nitrification in the water distribution system, leading to many problems including corrosion, which in turn affects turbidity (Gezahegn et al., 2021). Also E.coli had a strong positive significant correlation with TC (r= 0.935 at P<0.05). High positive correlations between Turbidity, TSS, BOD, COD and EC were also observed similar work done by (Venkatesh et al., 2009) and this result implies that the organic matter, TSS, TDS constituent of water samples may directly influence water turbidity (Deshu Mamo et al., 2021).

Table 11 Effluent correlation of physicochemical and bacteriological parameters in treatment plants

		pH	EC	TSS	TDS	DO	Nitrate	Ammonia	Phosphate	Sulfate	COD	BOD	Turbidity	TC	E.coli
pH	Pearson Correlation	1													
	Sig. (2-tailed)														
EC	Pearson Correlation	-0.665	1												
	Sig. (2-tailed)	0.150													
TSS	Pearson Correlation	-.842*	.847*	1											
	Sig. (2-tailed)	0.035	0.033												
TDS	Pearson Correlation	-.823*	.870*	0.799	1										
	Sig. (2-tailed)	0.044	0.024	0.056											
DO	Pearson Correlation	.932**	-.831*	-.923**	-.867*	1									
	Sig. (2-tailed)	0.007	0.040	0.009	0.025										
Nitrate	Pearson Correlation	0.011	-0.671	-0.320	-0.556	0.245	1								
	Sig. (2-tailed)	0.984	0.144	0.537	0.252	0.639									
Ammonia	Pearson Correlation	-0.757	.956**	.932**	.886*	-.922**	-0.572	1							
	Sig. (2-tailed)	0.082	0.003	0.007	0.019	0.009	0.235								
Phosphate	Pearson Correlation	-.816*	0.742	.983**	0.698	-.884*	-0.193	.866*	1						
	Sig. (2-tailed)	0.048	0.091	0.000	0.123	0.019	0.714	0.026							
Sulfate	Pearson Correlation	0.713	-0.607	-0.776	-0.800	0.784	0.390	-0.786	-0.770	1					
	Sig. (2-tailed)	0.112	0.201	0.070	0.056	0.065	0.445	0.064	0.073						
COD	Pearson Correlation	-.933**	.822*	.966**	.891*	-.969**	-0.287	.920**	.935**	-.849*	1				
	Sig. (2-tailed)	0.007	0.045	0.002	0.017	0.001	0.582	0.009	0.006	0.032					
BOD	Pearson Correlation	-.911*	.838*	.983**	.871*	-.963**	-0.303	.932**	.956**	-.833*	.997**	1			
	Sig. (2-tailed)	0.012	0.037	0.000	0.024	0.002	0.560	0.007	0.003	0.039	0.000				
Turbidity	Pearson Correlation	-0.778	.840*	.990**	0.730	-.876*	-0.319	.910*	.979**	-0.703	.921**	.949**	1		
	Sig. (2-tailed)	0.068	0.036	0.000	0.099	0.022	0.538	0.012	0.001	0.119	0.009	0.004			
TC	Pearson Correlation	-0.138	0.755	0.533	0.339	-0.426	-0.604	0.658	0.464	-0.132	0.369	0.425	0.606	1	
	Sig. (2-tailed)	0.794	0.083	0.276	0.511	0.400	0.205	0.155	0.354	0.804	0.472	0.401	0.202		
E.coli	Pearson Correlation	-0.184	0.743	0.482	0.346	-0.381	-0.518	0.574	0.388	0.036	0.333	0.383	0.558	.935**	1
	Sig. (2-tailed)	0.727	0.090	0.333	0.502	0.456	0.292	0.233	0.448	0.946	0.519	0.453	0.250	0.006	

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

4.6 Wastewater Quality Index

Wastewater quality index of the six treatment plants was determined using the weighted arithmetic method based on the average of three months of ten parameters as shown in table 14, compared with the WHO and Iraq standards of effluent disposal to water bodies. The rating and grading of wastewater quality with their possible uses are listed in Table 12 and 13.

Table 12 Table Rating and grading of the wastewater quality for corresponding levels of WWQI (Chaterjee and Raziuddin 2002).

WWQI Value	Water Quality	Possible Uses
0-25	Excellent	Drinking, irrigation and industrial
26-50	Good	Domestic, irrigation and industrial
51-75	Poor	Irrigation and industrial
76-100	Very Poor	Irrigation
>100	Unsuitable	Proper treatment required before irrigation

Table 13 Water Quality Classification based on WWQI value (Basim Hussein et al., 2018)

WWQI Value	Water Quality
<50	Excellent
50 – 100	Good
100 – 200	Poor
200 – 300	Very poor
300 – 400	Polluted
>400	Very Polluted

The finding results indicated that the treated effluent wastewater of Asko is very poor to Iraq and unsuitable under the WHO, Repi is very polluted to Iraq and unsuitable under the WHO, Gelan is poor to Iraq and unsuitable under WHO the finding implies that the effluent of the WSP system is inappropriate for discharge to the receiving water bodies and the environment. Similar findings were reported on a case study WSP at Jimma, Ethiopia that water quality of the treatment was unsuitable for the discharge into the environment and concluded that it might be due to inadequate preliminary treatment to reduce the incoming organic loading, poor maintenance and monitoring system of the treatment plant (Belay et al., 2022).

Table 14 Wastewater quality index results and classification of water quality

Treatments	Calculated WWQI	WHO Standard	Iraq, (Basim et al., 2018)
Asko ABR	540.73	Unsuitable	Very poor
Repi ABR	721.96	Unsuitable	Very Polluted
Gelan WSP	151.48	Unsuitable	Poor
Bole Bulbula MBR	74.60	Poor	Good
Mekanisa MBR	124.32	Unsuitable	Poor
Kilinto MBR	43.40	Good	Excellent

Bole Bulbula is good to Iraq and poor under WHO, it indicate that the effluents of this MBR is appropriate for irrigation and industrial uses, Mekanisa is poor to Iraq and unsuitable under the WHO that implies the effluent is inappropriate for discharge to the receiving water bodies and requires proper treatment before irrigation as a result the use of water with poor quality for agricultural activities can affect crop yield and cause food insecurity. Kilinto is excellent to Iraq and good under WHO, implies that the effluents is appropriate for domestic like flushing toilets, irrigation and industrial purposes like cooling water for power plants.

In general, the finding results of MBR are relatively better than WSP and ABR. However, it has poor quality as compared to the reported in Egypt which had a good quality referring to the classification of WWQI levels (Mohamed and Ahmend, 2021). The quality of effluent for all technology in this study were unsatisfied, this might be due to the incomplete treatment of wastewater at the primary and biological stages for this reason most of the values of organic and inorganic indicators are high (Basim H. et al., 2018). For decision making and conclusion, the WWQI classification under the WHO is more accurate and realistic in terms of the effluent quality receiving sources (Basim H. et al., 2018).

4.7 Multiple Criteria Decision Making

A key concept of TOPSIS is to measure each alternative's distance from the positive and negative ideal solutions separately. The best alternative should be very close to the ideal solution and furthest from the negative one. In this study, to calculate weighted normalization rating, the AHP decision analysis tool has been proven to be a suitable approach. AHP is preferred when the information on attributes is available on Saaty's scale, which results in comparison of alternatives in the form of priority. TOPSIS is the algorithm can easily be implemented computationally and can be made available as a decision support tool for the

end users. In the case of municipal wastewater treatment plants, Anaokar et al (2017) applied TOPSIS to compare the activated sludge process and extended aeration because it was difficult to rank the plants, as their capacity and working approaches are different and the rankings were found to be realistic and matched their BOD and COD removal efficiency. Weights indicate the importance of each criterion in context to output. Satty's nine-point scale provides a better judgmental base to that of the experts and helps to simplify the complex process of pair-wise comparison. Considering all these factors and concerning the approach to applying weights to the criteria, the ranking was obtained and worst score which indicates rank R_{iw} ; is the proportion of the best ideal solution to the worst ideal solution scale, with reference to the worst ideal solution. This will give an idea for further ranking procedures, the ranking was calculated in the case of the performance evaluation of WWTPs and it can be interpreted that the lower the rank, the higher the removal efficiency, the results are given in Table 15.

Table 15 Wastewater technologies ranking

Alternative	Technology	Relative closeness	Ranks
Asko	ABR	0.29	5
Repi	ABR	0.00	6
Gelan	WSP	0.85	4
Bole Bulbula	MBR	1.00	1
Mekanisa Kotari	MBR	1.00	1
Kilinto	MBR	1.00	1

The results showed that Bole bulbula, Mekanisa Kotari and Kilinto MBR wastewater treatment technology were ranked 1, which indicates the best removal efficiency with a score relative closeness 1.00, Gelan WSP wastewater treatment technology were ranked 4 with 0.85 score and Asko and Repi ABR technology were ranked 5 and 6 with 0.29 and 0.00 score respectively. Use of MCDM in different environmental activities promotes resource optimization, cost reduction, and better control over the performance of the activities (Ghatak & Mahanta, 2017). Applying TOPSIS to the performance evaluation process confirms that the three MBR wastewater treatment technologies have high score which indicate the better removal performance and ABR wastewater treatment technology has low score which indicate the least removal performance.

5 CONCLUSION AND RECOMMENDATION

CONCLUSION

In this research, performances of three technologies (MBR, ABR and WSP) in six decentralized wastewater treatment plants found in Addis Ababa were evaluated. Different water quality parameters were tested and their removal efficiency was determined. The removal efficiency was relatively high in MBR that reduce the main parameters like BOD by 98%, COD by 97% and TSS by 99%, WSP reduced BOD by 85%, COD by 84% and TSS by 89%, and ABR recorded relatively low reduction in BOD by 30%, COD by 38% and TSS by 51%. Total coliform and E. coli were removed up to 99% in all treatment technologies but most treated effluent parameters including BOD, COD and coliforms did not meet the standard limit set by EEPA in all treatment plants. However, based on the results, it can be concluded that relatively MBR has better and ABR has the lower removal efficiency during the study period. The finding results of wastewater quality index was 540.73 at Asko, 721.96 at Repi, 151.48 at Gelan and 124.32 at Mekanisa which indicate unsuitable for discharge into the environment. A value of 74.60 determined at Bole bulbula indicates poor quality which is inappropriate for discharge to the receiving water bodies and requires proper treatment before irrigation. A value of 43.40 at kilinto indicates good quality which is safe for disposal and reuse for irrigation according to WHO. The three technologies were also compared and the finding found to be BoleBulbula, Mekanisa and Kilinto MBR technology with a score of 1, ranked 1, indicating higher removal efficiency as compared with WSP and ABR, whereas Gelan WSP with a score of 0.85, Asko ABR with a score 0.29 and Repi ABR with a score 0.00 were ranked 4,5 and 6 respectively.

RECOMMENDATION

To adequately treat wastewater and make it suitable for disposal in the environment, general recommendation for all technologies are given below

- Low nitrogen removal efficiency is related with poor de-nitrification capacity of the MBR plant. In order to enhance this, alternate anoxic/oxic process is proposed. As the process require only minimal, if any, additional configuration reform it is the most cost effective solution to meet the effluent standard limit and ammonia volatilization and biological nitrogen uptake can be used for WSP treatment plant.

- Remove sedimentation of dead biomass, accumulation in the sludge layer in maturation pond and sufficient monitoring and maintenance activities are proposed for WSP
- To remove phosphorus in MBR, addition of metal salt, alum or ferric chloride directly to the pre-aeration tank, precipitate soluble phosphorous can be used.
- ABR could not be used as secondary treatment unit for treating domestic wastewater. A post-treatment is needed
- Desludging should be carried out regularly so that the wastewater will have more detention time to be treated in each units of the treatment plant
- Maintenance work should be done for damaged structures in time
- Microbiological analysis as part of quality control should be incorporated in the treatment plant quality control protocol for all treatment plants.

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7 ANNEX

Annex 1 Design wastewater loads and effluent limits

Parameters	Unit	Bole Bulbula	Mekanisa	Kilinto	Effluent limit
Chemical oxygen demand	kg/day	1275	750	2250	<50
Biochemical oxygen demand	kg/day	900	510	1200	<5
Total suspended solids	kg/day	1050	595	1400	<5
Total nitrogen	kg/day	126	71.40	168	10
Total phosphorous	kg/day	66	37.40	88	5
pH	-	7-7.5	7-7.5	7-7.5	6.5-8
Fecal coliform	n ^o /100 ml	10 ⁸	-	-	<100

Annex 2. Site pictures of wastewater treatment plants



Membrane bioreactor wastewater treatment: Aeration tank



Bulbula, Mekanisa and Kilinto MBR wastewater treatment plant



Repi Anaerobic baffle reactors treatment



Asko Anaerobic baffle reactors treatment



Annex 3. Guideline Surface Water Quality Standards for Ethiopia (EEPA, 2003)

Parameter	EEPA (2003) & Belay et al.(2022)
pH	6-9
EC (mg/l)	≤1000
TSS (mg/l)	≤50
TDS (mg/l)	≤2000
DO (mg/l)	≥5
Nitrate(mg/l)	≤50
Ammonia(mg/l)	≤10
Phosphate(mg/)	≤0.02
Sulfate (mg/l)	≤200

COD (mg/l)	≤ 125
BOD (mg/l)	≤ 25
Turbidity(NTU)	≤ 300
TC (CFU)	≤ 50
E.coli (CFU)	≤ 10

Annex 4. Wastewater quality index calculation results

Asko wastewater quality index

	STANDARD(SN)	1/SN	$\sum 1/SN$	$K=1/(\sum 1/SN)$	$W_i= K/SN$	IDEAL VALUE(VO)	MEAN.CON VALUE(VN)	VN/SN	$VN/SN*100=QN$	$W_i.QN$
pH	8.5	0.118	0.51	1.95	0.23	7	6.81	0.13	13.00	2.99
EC(μ s/cm)	1000	0.001	0.51	1.96	0.00	0	1667.67	1.67	166.77	0.33
TSS(mg/l)	50	0.020	0.51	1.96	0.04	0	407.75	8.16	815.50	31.98
TDS(mg/l)	2000	0.001	0.51	1.96	0.00	0	836.25	0.42	41.81	0.04
DO(mg/l)	5	0.200	0.51	1.96	0.39	0	0.93	0.19	18.60	7.29
Nitrate(mg/l)	50	0.020	0.51	1.96	0.04	0	27.07	0.54	54.14	2.12
Ammonia(mg/l)	10	0.100	0.51	1.96	0.20	0	78.84	7.88	788.40	154.59
Sulfate(mg/l)	200	0.005	0.51	1.96	0.01	0	21.72	0.11	10.86	0.11
COD(mg/l)	125	0.008	0.51	1.96	0.02	0	1991.53	15.93	1593.22	24.99
BOD(mg/l)	25	0.040	0.51	1.96	0.08	0	1008.17	40.33	4032.68	316.29
Sum		0.51			1.00					540.73
									overall quality	540.73

Repi wastewater quality index

	STANDARD(SN)	1/SN	$\sum 1/SN$	$K=1/(\sum 1/SN)$	$W_i= K/SN$	IDEAL VALUE(VO)	MEAN.CON VALUE(VN)	VN/SN	$VN/SN*100=QN$	$W_i.QN$
pH	8.5	0.118	0.51	1.95	0.23	7	6.81	0.13	13.00	2.99
EC(μ s/cm)	1000	0.001	0.51	1.96	0.00	0	1966.17	1.97	196.62	0.39
TSS(mg/l)	50	0.020	0.51	1.96	0.04	0	737.37	14.75	1474.74	57.83
TDS(mg/l)	2000	0.001	0.51	1.96	0.00	0	759.22	0.38	37.96	0.04
DO(mg/l)	5	0.200	0.51	1.96	0.39	0	0.85	0.17	17.00	6.67
Nitrate(mg/l)	50	0.020	0.51	1.96	0.04	0	19.74	0.39	39.48	1.55
Ammonia(mg/l)	10	0.100	0.51	1.96	0.20	0	108.36	10.84	1083.60	212.47
Sulfate(mg/l)	200	0.005	0.51	1.96	0.01	0	28.37	0.14	14.19	0.14
COD(mg/l)	125	0.008	0.51	1.96	0.02	0	2270.85	18.17	1816.68	28.50
BOD(mg/l)	25	0.040	0.51	1.96	0.08	0	1311.33	52.45	5245.32	411.40
Sum		0.51			1.00					721.96
									overall quality	721.96

Gelan wastewater quality index

	STANDARD(SN)	1/SN	$\sum 1/SN$	$K=1/(\sum 1/SN)$	$W_i= K/SN$	IDEAL VALUE(VO)	MEAN.CON VALUE(VN)	VN/SN	VN/SN*100=QN	W _i .QN
pH	8.5	0.118	0.51	1.95	0.23	7	8.15	0.76	76.00	17.46
EC(μ s/cm)	1000	0.001	0.51	1.96	0.00	0	1300.33	1.30	130.03	0.25
TSS(mg/l)	50	0.020	0.51	1.96	0.04	0	50	1.00	100.00	3.92
TDS(mg/l)	2000	0.001	0.51	1.96	0.00	0	547.33	0.27	27.37	0.03
DO(mg/l)	5	0.200	0.51	1.96	0.39	0	2.24	0.45	44.80	17.57
Nitrate(mg/l)	50	0.020	0.51	1.96	0.04	0	18.91	0.38	37.82	1.48
Ammonia(mg/l)	10	0.100	0.51	1.96	0.20	0	39.61	3.96	396.10	77.67
Sulfate(mg/l)	200	0.005	0.51	1.96	0.01	0	35.7	0.18	17.85	0.18
COD(mg/l)	125	0.008	0.51	1.96	0.02	0	190.17	1.52	152.14	2.39
BOD(mg/l)	25	0.040	0.51	1.96	0.08	0	97.33	3.89	389.32	30.53
Sum		0.51			1.00					151.48
									overall quality	151.48

Bole Bulbula wastewater quality index

	STANDARD(SN)	1/SN	$\sum 1/SN$	$K=1/(\sum 1/SN)$	$W_i= K/SN$	IDEAL VALUE(VO)	MEAN.CON VALUE(VN)	VN/SN	VN/SN*100=QN	W _i .QN
pH	8.5	0.118	0.51	1.95	0.23	7	7.93	0.62	62.00	14.24
EC(μ s/cm)	1000	0.001	0.51	1.96	0.00	0	1320.67	1.32	132.07	0.26
TSS(mg/l)	50	0.020	0.51	1.96	0.04	0	1.5	0.03	3.00	0.12
TDS(mg/l)	2000	0.001	0.51	1.96	0.00	0	569	0.28	28.45	0.03
DO(mg/l)	5	0.200	0.51	1.96	0.39	0	2.51	0.50	50.20	19.69
Nitrate(mg/l)	50	0.020	0.51	1.96	0.04	0	24.97	0.50	49.94	1.96
Ammonia(mg/l)	10	0.100	0.51	1.96	0.20	0	18.12	1.81	181.20	35.53
Sulfate(mg/l)	200	0.005	0.51	1.96	0.01	0	58.93	0.29	29.47	0.29
COD(mg/l)	125	0.008	0.51	1.96	0.02	0	40.16	0.32	32.13	0.50
BOD(mg/l)	25	0.040	0.51	1.96	0.08	0	6.33	0.25	25.32	1.99
Sum		0.51			1.00					74.60
									overall quality	74.60

Mekanisa Kotari wastewater quality index

	STANDARD(SN)	1/SN	$\sum 1/SN$	$K=1/(\sum 1/SN)$	$W_i= K/SN$	IDEAL VALUE(VO)	MEAN.CON VALUE(VN)	VN/SN	$VN/SN*100=QN$	Wi.QN
pH	8.5	0.118	0.51	1.95	0.23	7	7.93	0.62	62.00	14.24
EC(μ s/cm)	1000	0.001	0.51	1.96	0.00	0	1564.33	1.56	156.43	0.31
TSS(mg/l)	50	0.020	0.51	1.96	0.04	0	0.97	0.02	1.94	0.08
TDS(mg/l)	2000	0.001	0.51	1.96	0.00	0	577.98	0.29	28.90	0.03
DO(mg/l)	5	0.200	0.51	1.96	0.39	0	1.98	0.40	39.60	15.53
Nitrate(mg/l)	50	0.020	0.51	1.96	0.04	0	21.54	0.43	43.08	1.69
Ammonia(mg/l)	10	0.100	0.51	1.96	0.20	0	44.7	4.47	447.00	87.65
Sulfate(mg/l)	200	0.005	0.51	1.96	0.01	0	63.8	0.32	31.90	0.31
COD(mg/l)	125	0.008	0.51	1.96	0.02	0	41.17	0.33	32.94	0.52
BOD(mg/l)	25	0.040	0.51	1.96	0.08	0	12.67	0.51	50.68	3.97
Sum		0.51			1.00					124.32
									overall quality	124.32

Kilinto wastewater quality index

	STANDARD(SN)	1/SN	$\sum 1/SN$	$K=1/(\sum 1/SN)$	$W_i= K/SN$	IDEAL VALUE(VO)	MEAN.CON VALUE(VN)	VN/SN	$VN/SN*100=QN$	Wi.QN
pH	8.5	0.118	0.51	1.95	0.23	7	7.73	0.48	48.00	11.03
EC(μ s/cm)	1000	0.001	0.51	1.96	0.00	0	1008	1.01	100.80	0.20
TSS(mg/l)	50	0.020	0.51	1.96	0.04	0	2.61	0.05	5.22	0.20
TDS(mg/l)	2000	0.001	0.51	1.96	0.00	0	407.14	0.20	20.36	0.02
DO(mg/l)	5	0.200	0.51	1.96	0.39	0	2.2	0.44	44.00	17.25
Nitrate(mg/l)	50	0.020	0.51	1.96	0.04	0	52.14	1.04	104.28	4.09
Ammonia(mg/l)	10	0.100	0.51	1.96	0.20	0	4.69	0.47	46.90	9.20
Sulfate(mg/l)	200	0.005	0.51	1.96	0.01	0	60.28	0.30	30.14	0.30
COD(mg/l)	125	0.008	0.51	1.96	0.02	0	34.52	0.28	27.62	0.43
BOD(mg/l)	25	0.040	0.51	1.96	0.08	0	2.17	0.09	8.68	0.68
Sum		0.51			1.00					43.40
									overall quality	43.40