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THEORETICAL OVERVIEW OF SUSTAINABILITY OF WASTEWATER MANAGEMENT IN THE ECO-CITIES SETTING

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1.0 BACKGROUND INFORMATION

Tanzania like other African countries is experiencing urbanization problems, urbanization has risen from 5.7 million in 1967 to 29.1 million in 2012 with the annual urban population growth rate of 5.2 percent *(NBS, 2012)*. The urban growth rate in Dar es Salaam city is higher than capacity of the responsible authorities to provide planned and serviced plots for shelter and urban development activities. An estimated 70% of Dar es Salaam's population lives in poor, unplanned settlements. These areas are associated with inadequate basic service levels including lack of water and wastewater services, poor health and environmental conditions *(The World Bank AFTU 1 & 2)*. To offset the urbanization problems for the Dar es Salaam city, the government is planning several new satellite cities.

In 2010, the government of Tanzania developed a new master plan of the eco-city at Kigamboni area in Dar es Salaam region. Reasons for proposing a new city were many, main one being to provide solutions that will mitigate urbanization problems of Dar es Salaam and its environment.

Currently in Tanzania, there are no much studies on sustainability of wastewater management in the eco-cities setting. Such studies if present could act as the guiding tools for selection of appropriate and sustainable wastewater management approaches in planned eco-cities of Tanzania. Therefore, this overview will help the Tanzanian planners in decision making during planning of wastewater management systems for the eco cities.

This paper presents the theoretical overview of sustainability of wastewater in the eco-cities setting. The review was based on documents. There are five major sections which are, Idea of sustainable cities or eco-cities; Different selected case studies of eco cities; Concept of wastewater Management; Sustainability of wastewater treatment technologies and Analytical Hierarchy Process (AHP) for decision making in wastewater management.

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1.1 The Idea of Sustainable Cities (Eco-cities)

The term "eco-city" is interchangeably expressed as "sustainable city," "low-carbon city," "eco-community," "green city". In recent years, eco–city as a sustainable urban model has gained increasing popularity and has been broadly discussed with researcher, policy makers, Politician's and other decision makers. Eco-city concept has progressively translated into concrete projects, strategies, and policies, mainstreaming urban sustainability and being replicated across the world. Idea of eco-city was first introduced in 1987 by Richard Register, a leading theorist and author in ecological city design and planning. According to the general feeling of an eco-city is that, the city should, be environmentally friendly, liveable, energy saving, promote integrated water and sanitation. The city should do strive to minimize air, water and soil pollution, congestion, flooding and the related incidence.

Eco-city development is also used as a new environmental model to fight global warming, ecological degradation and unsustainable resource exploitation (*van Dijk, 2015*). Economically, building eco-cities, including the green infrastructures has been new business opportunity, this also serving the objectives of economic sustainability. Since, the introduction of eco-city idea, eco-cites received great attention and promotion worldwide. The importance given to eco cities can be recorded from different governmental and non-governmental institutions. Some of the prominent organization that, hardly supported eco-cities ides includes, the World bank, UNHABITAT, UNDP, US Environmental Protection Agency, the Swedish Environmental Protection Agency, GIZ, etc. The interest in building more eco-cities has risen over the last 25 years. It was noted that, in china alone, eco cities projects that are in progress reached 250 in 2014.

The reasons behind the building new Eco-cities varies, but generally is to offset challenges related to environmental, socio-economic pressures, development etc. (*Mneimneh et al., 2014*) indicated some basics consideration to develop an eco-city to includes

- The scale, about project area, infrastructure and innovation
- The sectors, including housing, transport, energy, waste, water, and land; and
- Policy processes Dimensions of an eco-city

There are ten basic dimension used to evaluate the eco-city plan, these key dimension was developed by Kenworth in 1996. The ten eco-city dimensions are 1. Energy 2. Solid waste 3. Transport 4. Pollution 5. Water 6. Sanitation 7. Climate change 8. Housing 9. Sustainability 10. Integrated approach.

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Energy is an important for eco-city. An eco-city should aim to limit CO2 emissions, ensure proper energy management at the household level and less greenhouses gases emissions from transportation. It should promote public transport on liquefied Natural Gas (LNG), promote solar energy and use of wind energy etc.

Pollution issues are the key dimension for eco-city. It is related to the effort required to limit, air pollution from households, water pollution, soil pollution, industrial pollution, smog, noise pollution and other types of pollution. Regarding water resources issues, eco-cities should ensure, there are proper infrastructures to separate drainage and sanitation, promote rainwater harvesting, use sustainable urban drains, promoting urban agriculture.

Sanitation dimension is mainly related with effort required to, close the water cycle, deal with flooding, to promote eco sanitation, produce energy out of sewer (biogas), decentralized waste water treatment, use eco-friendly water technologies, appropriate sanitation solutions, developing sanitation value chain, reuse of grey water on the spot. The eco-city need to develop strategies for integrating different dimensions such as involvement of all stakeholders, promoting biodiversity, promote wildlife etc. it should also have a policy for climate mitigation, adaptation, leadership.

When it comes to wastewater management, the criteria are farther enlarged in the Table 1.1; the information from this table is adopted and adjusted based on listed sub-criteria.

Table 1.1: Wastewater Dimensions of an Eco-City

Main criteria (question)	Sub-criteria (you have to check)
How does the city deal with wastewater issues?	1. Produce energy out of sewer (biogas) 2. Decentralized waste water treatment 3. Use eco-friendly water technologies 4. Appropriate sanitation solutions 5. Developing sanitation value chain 6. Reuse of grey water on the spot 7. Efforts to close the water cycle 8. Measures to deal with flooding 9. Separate drainage and sanitation 10. Integrated water resource management 11. City promotes water demand management 12. Promoting rainwater harvesting (to conserve water resources and minimize the use of ground water)

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13. Using sustainable urban drains
14. Separate brown and grey water
15. Promoting urban agriculture
16. Efforts to limit water pollution from different sources
17. Efforts to promote eco sanitation

The criteria listed on table 1.1, have been used in different researches to evaluate whether a wastewater management qualify as an eco-city standard or not. As an example used these criteria to compare the cities of Rotterdam and Beijing on the compliance for eco-city (their comparison was not only for wastewater they compared for all ten dimensions of eco cities).

1.2 Different Selected Case Studies of Eco-Cities: A Focus on Wastewater Issues

There few cities that are planned in Africa that are designed to be eco cities. The cities that are in progress in Africa at different stages includes the Eko Atlantic in Nigeria, this is perhaps the most famous of them. Nevertheless, others include the Tatu City in Nairobi Kenya, Hope City in Accra Ghana, La Cité du Fleuve in Kinshasa Democratic Republic of Congo and Diamniadio Valley digital city project to be developed in Senegal. However, none of these cities put their plans on their website, about how planned to do with wastewater. Nevertheless, the section that follows contains case studies of eco cities from other developing countries and one from Sweden. The aim is the same that is to learning from experience gained from other countries.

1.1.1 Case studies

Case 1: Caofeidian Eco-City

The literature summary on Caofeidian Eco-City is based on (Millers-Dalsjö and Ullman, 2009, Wang and Shi, 2010, Y. Zhang, 2010). Caofeidian Eco-City is situated in China, close to Beijing about 220Kilometers. The areas earmarked for the Caofedian Eco-city was 150square kilometers. The scheduling and planning procedures were done in four phases.

Phase 1	November 2007-April 2008. This was the first round in which international tendering for planning the city was done.
Phase 2	April –June, 2008, the second call for the international completion for finding the right company to planning it
Phase 3	July 2008-February 2009. SWECO company from Sweden with a joint venture of Tsinghua company from China developed a concept plan

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Wastewater management for Caofeidian eco-city

Caofeidian eco-city is faced with challenge of freshwater supply, salinization and inadequate rain has affected most of its water sources. Effort has been made to ensure that, water resource use is as done in a closed cycle, flooding issues are controlled and rainwater is harvested. The key milestone set by the city is that, come year 2020 rate of recycling of water, and reuse of treated water to reach 100%. The city is designed to hybrid model of wastewater in which both decentralized and the centralized alternative.

With regard to centralized model, two-wastewater treatment plant designed, the first treatment plant holds the capacity of 85,000 m^3 of wastewater per day. Land allocated to this first plant is 16 hectares, located in north part of the city. The second plant also have a design capacity of treating maximum of 85,000m^3 of wastewater per day is situated in the 10heactres area in the northeast of the city. Based on the city plan, the demand of water is 120L/day for the resident, demand of other users such as tourist, small businesses, companies e.t.c. was estimated to be 150L/d (Millers-Dalsjö and Ullman, 2009)

On the other hand, on the decentralized option, wastewater from household is designed to be treated at community level. Since, the city faces short rainfall and flesh water supply, and rainwater collection and storage are measures implemented to reduce water shortage. To ensure the rainwater is properly collected in community areas, special channels with filtration were installed to collect rainwater and perform basic treatment such as filtration. The collected water is then treated in small treatment plants at community level and stored in small pond that is linked to the nearby water landscape. The water is fully utilized for flushing, irrigation, carwash etc.

In addition, appropriate system for separating grey and black was constructed some residential area. The grey water is collected in the same system of rainwater and other black wastewater is taken to the central sewage treatment plant, and is collected through gravity pipeline (Wang and Shi, 2010). The gravity pipeline is preferred because of minimizing the energy use from the pumps. The water, which is treated and reused, is monitored to ensure it meet national and international (WHO) standards (Millers-Dalsjö and Ullman, 2009). Meanwhile black water and treated sludge from the central treatment plant are used to generate biogas. The treated water itself is taken to the wetland for farther polishing and then is supplied back for reuse (Millers-Dalsjö and Ullman, 2009).

Case 2: Dongtan Eco-city

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Dongtan Eco-city is the second case of the eco-cities under review. The city is in china close to Shanghai on Chongming Island. The total area of the island is 1225 square kilometres, with an estimated population of 50,000. Implementation of the city design was done in several phases; the first phase was to be completed in 2010 by building residential areas to accommodate about 10,000 residents in an area of 1 km^2. The second phase was to extend up to 6.5 km^2 including the housing of 80,000 people and the completion is estimated to be year 2020 in which the eco-city will have to house 500,000 by 2050 and cover an area of 30 km^2. According to planners of the eco-city ensured that, city comply with most criteria such that, to be more ecologically friendly, minimum greenhouse emission, and self-sufficient water and energy.

The city ambitions are to collect 100% of the waste and wastewater and use 90% of waste to produce energy; the policy in place is to reach a zero waste in this city. Other by-products of waste will be used for generating organic fertilizers for the organic farms. There no plan for building the landfill in this city because all generated waste is managed in one way or other, and are re-used. Other strategies of the eco-city are to reduce its water consumption by 43% and water discharge by 88%. A dual piping system was designed for potable use and reclaimed water. Reclaimed water is mainly used for toilet flushing, farm irrigation and other uses away from drinking. On the other hand, the city uses green rooftops as other means of minimizing city’s water demand by collecting and storing rainwater, all Sewage is designed to be treated in biological/natural treatment systems.

Ecosystem in this eco-city is well maintained, the plan is to use the existing wetland for other ecosystem services like food provision and use as a buffer zone etc. on that case, the city created more than 3.5 km buffer zone between the city and the mudflats. Only around 40% of the land area of the Dongtan site developed to urban areas, with the rest dedicated to other uses. The city is designed with a separation of portable and grey water from each household; the overall aim is to minimize wastewater treatment and energy as well because the grey water is easy to be treated.

Case 3: Putrajaya Eco-City

This is the third case of the eco-cities in developing countries; the name of the city is Putrajaya. This was the first Malaysian known eco-city. The city was, developed as a Federal Government Administrative Centre. The development of this new city involved opening of a large land area of up to 4500 hectares. Putrajaya consist of government departments, commercial offices, residential premises and recreational parks as well as water bodies. Green space occupies 30% of the land area of the city.

The city is designed to use eco-friendly wastewater treatment technologies; it adopted an integrated environmental management approach whereby the Land use, sewerage, drainage, irrigation, lake and environment are linked. In this eco-city, constructed wetlands system is the main wastewater treatment technology applied. There are about 24 constructed wetlands built for wastewater treatment, wetlands act as a natural treatment system that filters most of the pollutants in the river water before it enters the lake. Putrajaya Wetlands aim for many goals, targeting for environmental, educational, and recreational. Under the environmental category, the design aims to create self-sustaining and balanced lake ecosystems, developing a natural habitat for conservation of wetland flora and fauna. The constructed wetland system is composed of six arms with twenty-four cells, these individual wetlands have different design, size, capacity, treatment load etc. In this eco-city, serious water monitoring is done to ensure that, wetland effluent meet WHO standards before are released in the receiving water bodies. So, the monitoring aim to investigate trends in pollution, identify potential threats and recommend preventive management measures, compliance to appropriate water quality objectives and standards.

Case 4: Tianjin Eco-City

This is the fourth case of eco-cities in developing countries under review. This eco-city, is Planned in such a way that, rain water harvesting is done through rooftops, porous pavement and drains from roadside. This water is collected and conveyed through the pipes installed underground, these pipes helps to minimize evaporation before transported to the main reservoir. Another source of water is the use of recycled water, grey water is used on sport at the household level, this has helped tom some extent to reduce water demand in the eco-city. Water conservation is one of the top priority agenda for this eco-city, it is projected that by year 2020 50% reclamation of water and/or recycling of domestic and industrial wastewater, rainwater harvesting, and desalination will be reached.

The daily water consumption is expected to be 120 litres per person per day by 2020, compared to the national average in China of 212 litres per person per day. The wastewater plant in this eco-city is centralized and is designed of treating about 100,000cubic meters per day. The size of the land used for this plant is 190,000m^2. The treated water is stored in a small lake which is used for recreation. The treated water in this lake conforms to quality required by authorities.

Case 5: Linkoping Eco-city

Linkoping Eco-City is another small case used in this review; it was selected because of its unique approach used for wastewater management. Linkoping eco-city is one of the only Swedish city in which public transportation system operated in circular model (*IEA, 2005*). The bus system is run on biogas obtained from wastewater treatment plants, landfill and a biogas production facility that uses agricultural crop residues and manure and the entire public bus fleet runs on bio methane (*IEA, 2005*). Fertilizer is also produced as a by-product, from nutrients such as phosphates and nitrogen that are contained in the wastewater. The project for building this eco-city received sufficient funding, strong political backing and cooperation between the city, Linkoping University, transit authorities and farmers' associations.

1.2.2 Lessons Learned and Challenges about Wastewater Management in Eco-Cities

Based on presented cases in the previous section and other literature, some wastewater issues in eco-cities are presented below.

1. Inconsistence conformity of the effluent of treated water

Treated wastewater does not conform to strict eco-city requirement; in some eco-cities performance of the treatment plants is not consistent in relation to required standard. Different reasons are stated including, inadequate funding, human resources, and other management issues. Eco-cities in developing countries are expected to face similar challenges, particularly those related to availability of qualified personnel to control/monitor the wastewater treatment activities. To run wastewater treatment process that will comply with modern eco-city, operators of the wastewater treatment systems need to be trained and certified. Even if the technology applied is more advanced operating under automation technology, still staff will be required for manual work such as fixing pipe leaks and valves, fixing electrical and instrumentation equipment.

2. When government introduces new wastewater standards (it need to upgrade the old systems)

Design of wastewater plant in some reviewed eco-cities are modular and static, it is difficult to upgrade the system in case of future changes in term of effluent standards. For, example when government introduces new wastewater stands it creates challenges, because the wastewater treatment infrastructure was designed to meet a certain standard. It requires some modification of the treatment system including changing of the technology to meet the required new standard. The rigid wastewater infrastructures are difficult to changes even in case of adapting to increased demand due to population increase.

3. Sludge management

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To maintain adequate sludge management has been also challenges among the existing eco-cities. Sludge is that, reside generated during physical, chemical and biological treatment, it containing a mixture of microorganism, suspended and dissolved organic matter and mineral reaching up to 99 percent of water. A major environmental challenge for wastewater treatment is disposal of excess sludge produced during the process. The most practiced option of dumping sludge is though disposing sludge in a landfill. However, disposing sludge in the landfill come with variety of negative impact the environment, including causing groundwater pollution. Although landfill might be considered as a cheap option, it comes with some associated long-term environmental, social and economic consequence. To solve, these problems, one of the solutions could be introducing the recycling of sludge, by extracting organic matter and nutrients for agriculture. Other solution is to generate electricity energy from sludge because sludge from WWTP produces various gases, mainly the methane gases.

4. The cost for energy in wastewater treatment is high and has implication on climate change

One of challenges for wastewater management in eco-cites is usage of energy. Energy consumption is one of the largest expenses in operating a wastewater treatment plants. Wastewater treatment, the largest proportion of energy is used in biological treatment, generally in the range of 50 - 60% of plant usage (http://www.oxymem.com/). Energy consumption is associated with greenhouse gas emissions. The target of most eco-cities is to reduce carbon footprint associated with energy, generally wastewater treatment is supposed to be an activity that prevent water pollution and not create other problems of air pollution. One of the solutions is to change the technology and select natural system such as constructed wetland.

5. Inadequate participation of private sectors to invest on wastewater management

Management of Wastewater infrastructure is affected by the inadequate sustainable funding. In most developing countries, wastewater infrastructures are owned and operated by government; Private sectors are not much interested in investing to this area. In some eco cities like the Tianjin eco-city in China, people were not attracted to live in the eco-city because of high cost of living, the cost of living was also contributed by the fact of outsourcing to private, most of the services. To solve this, several incentives were provided by government such as reduced educational fees and housing subsidies etc (*Changjie and Martin, 2017*).

6. Inadequate coordination between eco cities and the neighbouring towns

In adequate coordination between eco-cities and their neighbouring town or cities is a challenge noted to some eco cities. For, example, the eco-city of Putrajaya in Malaysia the activities

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undertaken outside Putrajaya boundary affect performance the constructed wetland system used for wastewater treatment. The authorities that monitor water quality in the eco-city do not have any mandate to control effect of neighbour activities. Therefore, there is a problem of coordination and integration between this eco-city and other cities. One of the solutions to this could include the establishment the regulatory oversight that will be able to monitor regulatory compliance to ensure the compliance of the effluent standard.

1.1 The Concept of Wastewater Management

This section presents overall basic information about wastewater management. It covers the existing wastewater treatment technologies in theory, approaches to wastewater management, Advantages and disadvantages of each approach, factors that influence the choice of wastewater treatment technology and approach.

1.1.1 Existing wastewater treatment technologies

The existing wastewater technologies in literature can be expressed in two distinctions, the first is based on the location and the second is based on treatment methods.

1.3.1.1 Classification of wastewater treatment technologies based on the location

When it comes to classify wastewater treatment technologies based on the location, there are mainly two categories which are common; these include onsite and offsite treatment technologies.

Locations of wastewater treatment plant are used to refer the treatment services such as whether the treatment is an onsite or offsite treatment.

Onsite treatment technologies

These are technologies by which treatment of wastewater and disposal is done at the site of wastewater generation. In most cases, the onsite wastewater treatment are operated either by anaerobic processes. Most commonly technologies used in developing countries are septic tank systems. Septic tank is a common and low cost technology applied worldwide.

Offsite treatment technologies

These are technologies by which, waste water is collected from different sources, transported to other place far from the source for treatment and disposal. Offsite can be done either as a centralized or decentralized wastewater treatment model. In most cases, the offsite wastewater

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treatment is operated either by anaerobic process techniques such as activated sludge process, trickling filters, Rotating Biological Contractor (RBC) etc. or as aerobic systems such as waste-stabilization ponds (aerated lagoons and oxidation ponds), up flow anaerobic stabilization blanket (UASB). On the other hand, Natural Treatment Processes (Constructed wetland) can also be centralized/decentralised.

1.3.1.2 Classification based on treatment methods

When it comes to classify wastewater treatment technologies based on the treatment methods applied, there are mainly two categories which are common, these include natural and conventional wastewater treatment technologies.

Natural Treatment Technologies

The natural treatment systems apply physical, chemical, and biological processes that occur naturally to provide treatment of wastewater. The physical, chemical, and biological processes include sedimentation, filtration, adsorption, chemical precipitation, sorption, oxidation and reduction, biological conversion and degradation. Examples of natural treatment systems commonly used in developing countries are pit latrines, septic tank system, waste stabilization ponds and constructed wetlands. In most circumstances, natural treatment systems remove almost all the major constituents in wastewater which are considered pollutants, such as, organic matter, nitrogen, phosphorus, trace elements, trace organic compounds, and micro-organisms. The removal process could be either aerobic or anaerobic or combination of both.

Biological processes can be classified to aerobic processes and anaerobic processes. Aerobic processes use microorganisms that use oxygen to degrade waste products while anaerobic processes use microorganisms that do not use oxygen to degrade waste products.

Due to the simplicity in operation and maintenance, natural treatment has become a popular approach in many developing countries.

***Conventional Treatment Technologies*:**

The natural treatment systems apply natural processes and chemicals or artificial energy to provide treatment of wastewater. Examples of technologies that are commonly used in developing countries are (1) the activated sludge process, (2) aerated lagoons, (3) trickling filters, and (4) rotating biological contractors (RBC)

1.1.2 Common Wastewater management approaches (models) in developing countries

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There are two main wastewater management approaches in most developing countries which are the centralized management and decentralized management approaches.

1.1.2.1 Centralized wastewater management approach

The centralized model of wastewater treatment is the most tradition way and has been existing for many years. In many cities centralized wastewater infrastructures are mainly owned by central government or municipal or water bodies/authorities, this model is a form of top down approach of wastewater management. Investment cost for putting the wastewater systems is borne by the government; users of service are required to pay fees. The cost recovery is depending on income of users, but it's more feasible in the high income countries than in low income countries. The centralized wastewater management consists of the following.

1) The centralized collection system (sewers) that collects wastewater from many wastewater producers: households, commercial areas, industrial plants and institutions, and transports it to the
2) Centralized wastewater treatment plant in an off-site location outside the settlement, and
3) Disposal/reuse of the treated effluent, usually far from the point of origin.

This type is also referred to as off-site management (see *figure 1.1*).

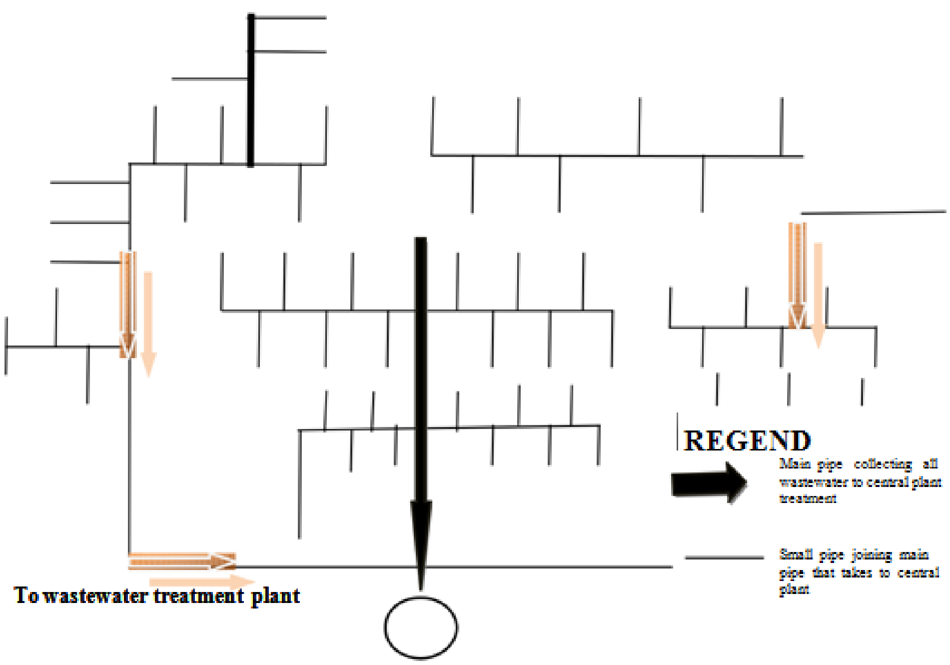

Figure 1.1: Schematic diagram of centralized wastewater management model

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The centralized wastewater treatment strategy or option is more common in developed countries. For example, In Germany, over 95% of the population is currently connected to sewer systems; In Israel 96% of the population is connected to sewer systems, etc. In developing countries effort has been made to adopt centralized way of wastewater treatment, however, show that in Mexico more than 90% of the centralized system were not functional due to various reasons associated with operational and maintenances.

1.3.2.1.1 Pros and cons of centralized

As summarized based on, the pros and cons of centralized wastewater management, includes: -

- The cost per unit volume of wastewater treatment is still competitive compared to decentralization where the waste- water collection system exists
- About 80-90% of the capital costs are mainly for system of wastewater collection with potential economies of scale in a more populated area
- The wastewater collection infrastructures are expensive and they have a life span of 50-60 years (need replacement). Also, the periodic maintenance causes some disturbances to other public utilities.
- Treatment of wastewater is more of sanitation improvement but nutrient recovery and other micro-pollutants are not much dealt with.
- Because large water is treated there is a possibility of eutrophication in the receiving end
- Diluted wastewater requires more expensive treatment approaches
- Heavy rainfall events may produce overflow phenomena
- Natural disasters such as earthquakes may cause disruptions to the system generating strong pollution phenomena in the receiving water body diseconomies of scale are possible where long distances have to be covered because of rainwater infiltration
- There is a strong dependency on electrical energy supply that might not be adequate due to an economic crisis
- Huge volumes of potable water are required to keep the sewage system clean

1.3.2.1.2 Use of membranes bioreactor for municipal wastewater management in a centralized model

Membrane Bioreactors (MBRs), a modern wastewater treatment technology is applied to most of new wastewater treatment plants (WWTPs), in some cases is used to retrofit or upgrade existing WWTPs. MBRs technologies involve a combination of the biological treatment with membrane filtration. MBRs have gained popularity in recent years because of its ability to maintain high concentration of mixed liquor suspended solid (MLSS) and good performance of wastewater treatment. The common recorded problems related to MBR in are plant maintenance and operating cost resulted duet to membranes biofouling.

Despite best performance of MBRs, higher energy need and fouling issues provide a major drawback of MBR demand in the market. The reported estimated energy demands for MBR in literature are in the range of 0.8 – 1.4 kWh/m^3. For example, energy use in kWh/m^3 for seven full-scale operated municipal wastewaters in German are 0.7, 0.8, 1.0, 1.2. Considering the MBR and other conversional wastewater treatment plants, MBR is estimated to demand three times more energy due to the intensive membrane aeration required to minimize clogging and membrane fouling.

- **Operation and maintenance issues of MBR**

MBR like any other wastewater treatment technology, its performance depends on flow and pressure of wastewater. Different operation and maintenance parameters need to be designed to ensure the designed capacity is maintained. The important design parameter is the flowrate of water per unit membrane (Lm^2h); this factor is the key determinant of controlling fouling rate that cause fouling problem to membranes. Knowing the fouling rate helps to understand the required frequency for membrane cleaning. In addition to membranes surface fouling; clogging of aerators and membranes channels was also mentioned by researchers and practitioners to be another common MBR problem. Therefore, an operator of MBR needs to understand well on how to maintain all these inherent problems. *Figure 1.2* shows the schematic diagram of the MBR process.

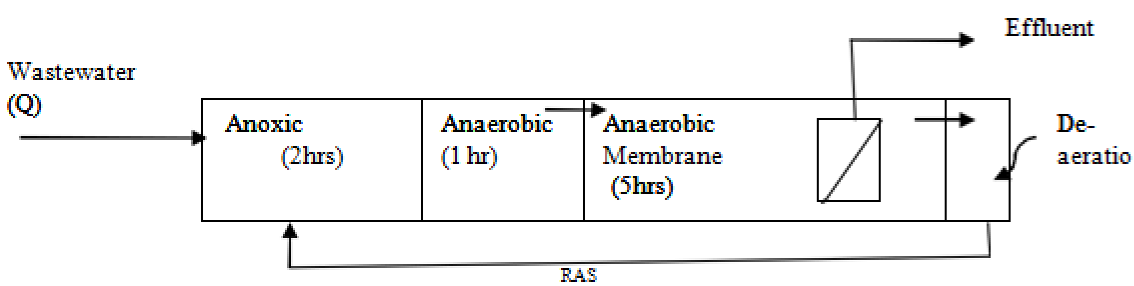

Figure 1.2: Schematic process diagram of anaerobic membrane bioreactors system process

The main factors affecting the treatment performance of MBR are divided in three types including those related to operation conditions, sludge management and the use of chemicals for treatment improvement *(Ahamed et al., 2015)*. The operation factors include the temperature, organic loading rate (OLR), Hydraulic Retention Time (HRT) and the upflow velocity. The

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effect of temperature in the wastewater treatment is that, when temperature decreases the microbial activities also decreases, this affect removal efficiency of the BOD and COD.

The Hydraulic Retention Time (HRT) is an important factor to almost all wastewater treatment technologies including the MBR, for MBR apart from influencing the treatment performance it also has an economic consequence, the shortest HRT the low capital cost (*Hahn & Figueroa, 2015)*. However, all together have shown that, removal efficiency is better for the longer HRT which means more size of the reactor and associated cost. HRT depends on the wastewater up flow velocity, and other factors such as characteristics of wastewater, properties of sludge and other hydraulic system *(Elyasi et al., 2015)*. Upflow velocity is an important criterion because it helps to determine an extent of wastewater mixing to improve substrate and biomass contact, but the velocity of wastewater need to be controlled because the higher the velocity may affect removal efficiency because of detachment of solid caused by friction and shear forces. Therefore, an optimum HRT need to be calculated based on those factors to attain the good performance.

Apart from MBR as treatment system, performance of the membrane depends on flow and pressure of water *(Ahamed et al., 2015)*. In addition to that, membranes type and configuration are also need to be considered while managing the MBR. Membranes can be configured as a flat sheet, hollow fiber, tabular membranes etc. *(Elyasi et al., 2015)*. These configurations can be put in form of submerged or emerged system. The most important operation condition for steady operation of membrane is the act of removing the cake layer deposited on the surface of the membrane. In the case, this is not done properly, the sediment concentrate on the surface of the membrane, then after longtime of operation, it becomes difficult to remove them. Whenever MBR operation is left without proper control of shear rate, the membranes pores tend to clog due to deposition of small particles *(Ahamed et al., 2015)*. To minimize the fouling problem, one of the measures is to control quantity of materials passing through the membrane; this is called membrane flux / filtration velocity. The critical flux for membranes in the municipal wastewater treating is 7L/m^2 with a biomass concentration of 14800mg/l. One of suggested method to reduce the fouling is to employ the backwash and relaxation approach, in which membranes can be cleaned (weekly or monthly). Cleaning of membranes can have done either ex-situ by applying water jet or in situ by using chemicals such as alkali, oxidant or acid cleaning agent.

Economic issues of MBR need to be carefully considered while selecting a technology for wastewater treatment. In areas where the standard wastewater treatment is required MBR technology can be more preferred, especially if the treated wastewater is intended to be reused for other purposes. Before procuring, the membranes a through feasibility study need to be done, the cost of membrane, energy and cleansing material have to be considered. The key main

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disadvantages of MBR are related to aspects of cost MBR from literature includes, relatively high investment cost for installation, limited membrane life caused by fouling, use of chemical for cleansing and high energy demand. On the other hand, key advantages of MBR include small land requirement (small spatial footprint) and high quality of treated wastewater. The performance of one of the MBR plant is shown in the *Table 1.2*.

Table 1.2: Performance of the MBR in Pollutants Removal

	BOD		COD		SS		TN		TP		Coli form (MPN/100ml)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
Total average	143.5	1.0	86.5	6.6	236.2	1.1	31.6	7.5	4.2	0.6	11228	no noted counts
Effluent standard	10		40		10		20		2		3000	

In Africa MBR technology is not widely used, according to (www.thembrsite.com), as of February 2015 there were only two countries that have MBR operating at a full-scale treatment of municipal wastewater. The status of MBR in Africa is shown in *Table 1.3*

Table 1.3: Status of MBR in Africa as of February 2015

	Location	Commissioned Date	Peak daily flow	Average daily flow (m^3 per day)	Costs
1.	Bellville, Cape Town- South Africa	2014	40	23,000	
2.	Khayelitsha, CapeTown, South Africa	2010	36	18,000	2009: (US$15M)
3.	Casablanca, Morocco	2013	8		US$17.7m

Table 1.3 is based on the http://www.thembrsite.com/about-mbrs/largest-mbr-plants/largest-mbr-plants-africa/ (As accessed on April, 2016)

1.1.2.2 The Decentralized wastewater management approach

The idea of decentralized wastewater management is realized when wastewater is collected, treated and disposed/reused at or near the point of generation. The decentralized systems can be applied on different scales. It can be applied to

- A cluster of homes;
- Individual households;
- A neighbourhood;
- Public facilities;
- Commercial area;
- Industrial parks; and
- Small portions of large communities

Figure 1.3 below show the schematic diagram of the on-site or decentralized wastewater management.

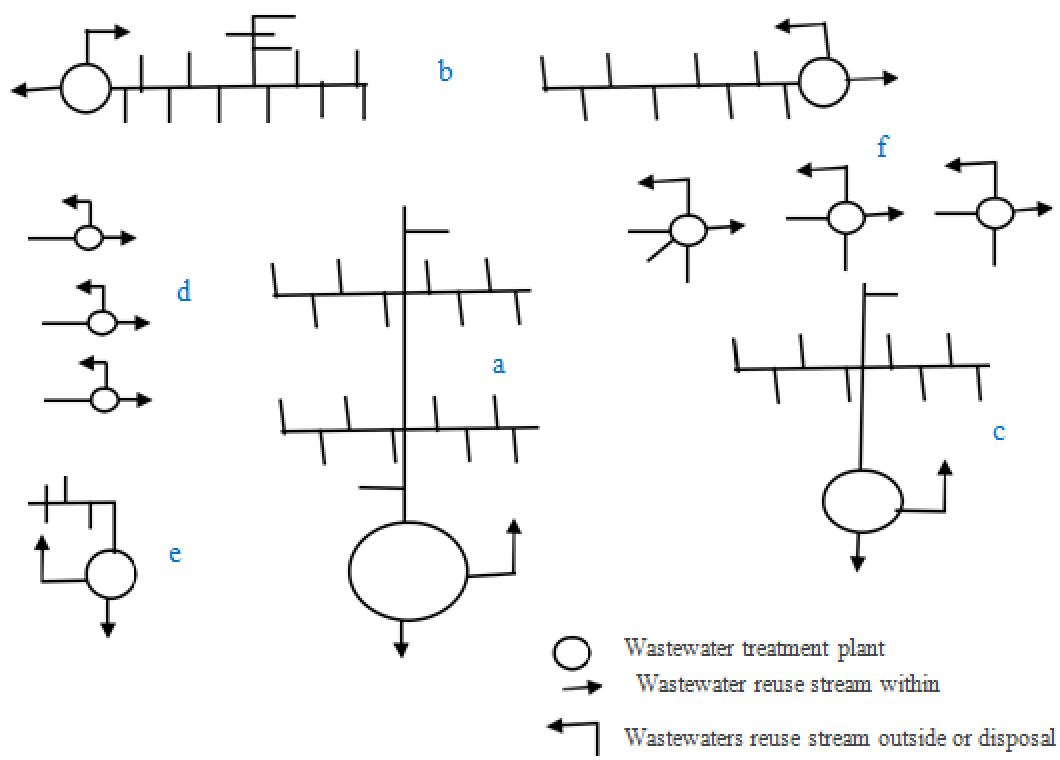

Figure 2.3: Schematic diagram of Decentralized Wastewater Model

Figure 1.3 above show the schematic diagram of the on-site or decentralized wastewater management. Six basic schemes of small subsystem for wastewater treatment can be de developed as shown in the fig 3 above; (a) is can be appropriate for commercial and residential areas; (b) is a subsystem for residential neighbours; (c) is more appropriate for industrial areas; is a system for single residence unit; (e) system for any new development; (f) system for cluster of homes.

For developing countries, decentralized wastewater treatment could better option because it has management that is more flexible. Not only that, but also decentralised system, are localized systems that, lend themselves to recycling and reuse of water and recycling of nutrients, and this offer possibility of closing the water resource loop. In addition to that, decentralized system is relatively affordable and demand less expertise for construction, operation and maintenance.

1.3.2.2.1 Advantages of decentralized wastewater management approach

- **Costs**

As stated in the earlier section, decentralized system of wastewater holds major fiscal advantage; cost issues are reduced first from the minimizing wastewater collection infrastructure. Even in case when wastewater collection is needed, small diameter pipes are used, as in some instances even tanks are used to do the preliminary treatment. In addition, no large interceptors and few, if any, lift stations, are needed. This results in less costly effluent collection system. In addition, in comparison with centralization decentralized can be adjusted to adopt future demand.

- **Environmental**

In comparison with the centralized system, decentralized systems use small volumes of wastewater for treatment, in the incidence of system failure, less environmental damage is expected. The decentralised system is less complicated and not made based on mechanical operation this also minimize the risk of frequent failure of the treatment plant. In case of few smaller treatment plants, chances of simultaneous failure for all of them are lower than that, of a failure of one central plant. The treatment and reuse can be tailored from separate subsystem, for example, industrial wastewater, can be treated separately and not be mixed with domestic wastewater.

- **Opportunities for reuse of effluent and nutrient**

Decentralized management increases reuse opportunities. Use of reclaimed water would become more cost-effective as effluent would be available near the potential points of use, thus decreasing the costs of reclaimed water distribution systems. On the other hand, nutrient collected for decentralised plant can be easily improves unlike for those nutrient collected from centralized system. This is because from centralized system the massive sludge load consists of concentrated toxic substances that are difficult to remove but for decentralized system sludge in a small quality can be pumped easily processed

- **Water Intensity**

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Decentralized system uses less fresh water for waste transportation and system cleaning; this is different from the mechanical system whereby freshwater is used to clean the plant and to dilute the wastewater.

- **Construction**

The decentralised system can be built on gradually because it is basically a modular system, in which different treatment unit can be constructed and operated at different times depending on the needs. Because of that, in decentralised system there is no need for instantaneous lump sum of money for construction of the entire system as compared to centralized where one central plant is required to treat all generated waste in the city. Apart from benefits explained above, also supported that, decentralization is more flexible can be applied to response need of any area, suburban or urban centres. Also, it applies in industrial and commercials centres.

1.1.2.2.1 Disadvantages of decentralized wastewater management approach

Treatment performance and cost issues are the main key issue discussed in the literature while addressing the drawback of decentralized system.

- **Performance**

Comparing to the supplicated technologies like membranes bioreactors (MBR), the decentralized natural based technologies have low performance in terms of the treatment performance. Reasons for inefficiency may not necessary be due to the design problems but also is associated by inappropriate operational and maintenance practices, especially in developing countries. People who are attending and managing most of these treatment plants are unprofessional, usually the household's owners and owners of small enterprises, in most cases; these people have not knowledge and lack motivation to maintain the system efficiently.

- **Cost**

According to, decentralized wastewater management plants can result to high cost like the centralized management system. By considering the economy of scale, building and managing several small on-site systems might cost much than one large central system. In addition, the operation and maintenance requirements of many small systems will be more than, those of one central system. However, management requirement for wastewater treatment systems are the same, whether is centralized or decentralized, both of them needs effective management during their operation and maintenance course. Both system needs to be managed by the by qualified people who are trained for the job. The following section presents Anaerobic Baffled reactors (ABR) as examples of the common technology run on decentralized mode.

1.1.2.2.2 Use of anaerobic baffled reactors for municipal wastewater management in a decentralized model

Attention to Anaerobic Baffled Reactors (ABR) technology has increased in recently years, among the researchers, practitioner, and decision makers prefer to opt ABR other than mechanical based systems. ABR technology is relatively low cost technology compared other aerobic treatment technologies. The Advantages listed by different authors for this anaerobic technologies includes (a) minimal energy requirement lead to low cost, no oxygen is required for this technology, there no energy is required (b) low sludge production(can also be reason for low cost of sludge handling) (c) can be good source of alternative fuel from produced biogas d) simple in designing and operation, e) can respond to high and low load (load variation is not big problem) because its good capacity to retain solids.

Anaerobic baffled reactors (ABRs) are designed in such a way that, it uses a vertical baffle, which are sequentially arranged in series *(Figure 3.9)*. The wastewater is forced through sequenced cells under upflow and downflow condition over the baffles containing sludge blanket as it moves from inlet to outlet. ABRs configuration allows microorganism to naturally perform, all the three steps required to convert the organic matter to methane, the steps include the hydrolysis, acidogenesis, and methanogenesis *ABR* has higher potential of handling large volumes of wastewater without clogging. In each compartment, existing bacteria responds to the flow of the waste within the reactor. This has been an additional advantage of ABR because through this process it vertically separates the acidogenesis and methanogenesis process, this is a two-phase operation occurring in the same reactor. ABR has no mechanical mixing or any moving part; this makes its construction to be less costly *(Krishna et al., 2009)*. The treatment performance of the ABR is mainly influenced by the reactor's hydrodynamics and microbial processes.

1.3.2.2.3 Use of constructed wetlands for municipal wastewater management in a decentralized model

The use of Constructed Wetlands (CWs) as a natural biological wastewater treatment process is recognized and accepted internationally. Constructed Wetland (CW) is the treatment system engineered and designed to use natural wetland vegetation, soil and microorganism contained in the wastewater in a controlled system *(Kimwaga et al., 2013)*. Wetland based technology, proved to be one of low cost technology for treating sewage, storm water, agriculture runoff, landfill leachate, and partially treated industrial wastewater. The efficiency of CWs in treating municipal

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wastewater is well reported by many scientists. The performance for removal of Biochemical Oxidation demand (BOD) and the Total Suspended Solids (TSS) has proved to reach above 90%. Depending on design of the CWs System, hybrid system in which CWs is combined with other treatment plant appeared to be more efficient in the removal of Chemical Oxygen Demand (COD), Ammonium-nitrogen, Nitrate-Nitrogen and TSS. Wetland designs depend on the quantity of water to be treated and nature of pollutants to be removed, many designs can be built to maximize this. Constructed wetland system (CWS) are of different types that are designed for different purpose.

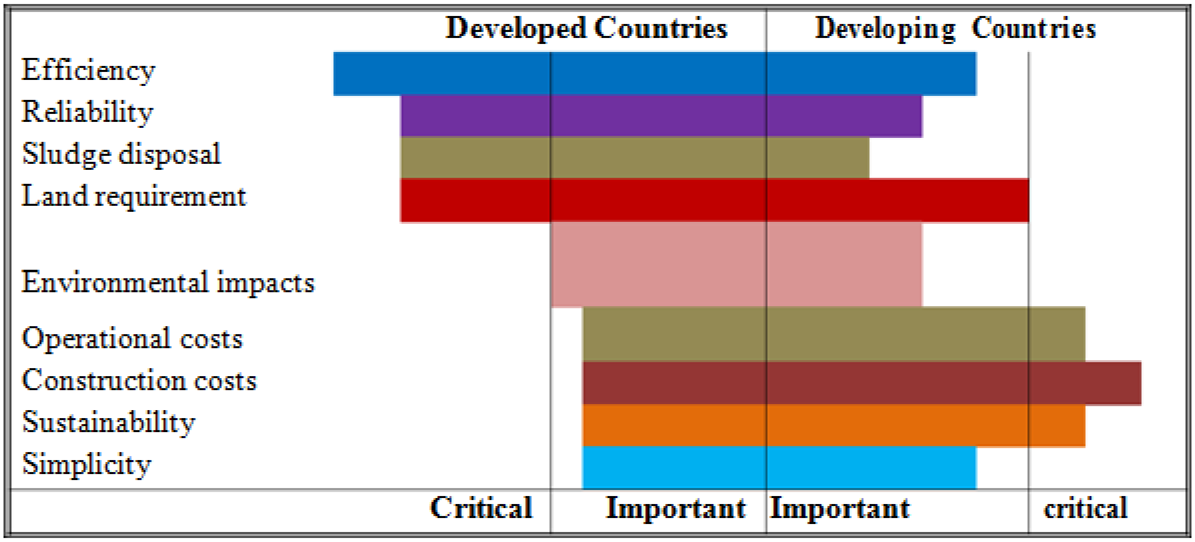
The wetland system is mainly divided into two main systems, free surface wetland and the subsurface flow wetland. With regard to constructed wetland system, two main branches of CWS are categorized the, Horizontal Flow system (HFS) and Vertical Flow System (VFS). The horizontal one is named so, because wastewater is fed at the inlet and allowed to flow horizontally through the bed to the outlet. While in Vertical Flow System, wastewater is allowed or fed intermittently and drains vertically through the bed via a network of drainage pipe.

1.1.3 Factors influencing the choice of strategy

There are nine key criteria considered in the process of selecting wastewater treatment technology which include; 1. Efficiency 2. Sludge disposal 3. Land requirement 4. Construction cost 5. Reliability 6. Sustainability 7. Environmental impacts 8. Operational costs 9. Simplicity

Based on these nine criteria have shown that, in practice these criteria are given different the weight when used as technology selection in different part of the world *(see table 1.5)*. In developing countries, critical issues are those related with simplicity, construction and operational cost. Other items such as efficiency, reliability, and environmental impact, seemed to be less critical. In contrast, developed countries' most critical items include system efficiency, reliability, and land requirement, while costs, sustainability and simplicity are considered less important. To select an appropriate wastewater treatment technology for developing countries, one needs to understand the current, local contextual situations.

Table 1.4: Priorities of Selection of Wastewater Strategy in Developed and Developing Countries



From *table 1.4* above, those factors can be formulated as criteria's while doing an evaluation. Those criteria can be used in combination with other engineering requirement used for designing, constructing, and operating the system the WWTP. Examples of engineering requirement can be influent wastewater characteristics (flow and quality), efficiency, land requirement, and process reliability. In developing countries, the issues of affordability of the technology, is important, it has to be given much attention. The target community's ability to afford the wastewater system is an important factor in selecting a strategy.

1.2 Sustainability of Wastewater Treatment Technologies

Sustainability of any chosen technology is the most important aspect in the eco-cites, sustainability assessment need to be done before choosing any technology (*Molinos-Senante et al., 2014).* Decision makers are no longer looking only for technical and investment cost of the WWTP but also they want to find out other aspects of social and environmental impacts (*Muga and Mihelcic, 2008).*

Sustainability assessment for WWTPs is normally done in two approaches of evaluation. The first approaches are by developing single indicator and integrate it with different criteria or develop a set of multidisciplinary indicators *(Muga and Mihelcic, 2008)*. The second approach is to base on the known three pillars of sustainability, the economic, environmental and social issues. Following second approach, different indicators can be developed. In literature, it was noted that, most studies dwell on evaluating performance of treatment process rather than comparing different treatment technologies. Most experts while assessing sustainability of WWT *(Muga and Mihelcic, 2008)* do not critically evaluate social issues. *Table 1.5* below indicates some common sustainability indicators used in theory.

Table 1.5: Sustainability Dimensions and Indicators for WWTP

Dimension	Indicator
Economic	Investment cost
	Operation and maintenance costs
	User cost
Environment	Organic matter efficiency removal
	Suspended solids efficiency removal
	Nitrogen efficiency removal
	Phosphorus efficiency removal
	Energy consumption
	Land area required
	Sewage sludge production
	Potential for water reuse
	Potential to recover products
	Reliability
Social	Odors
	Noise
	Visual impact
	Public acceptance
	Complexity

The above table of modified from the following sources (Molinos-Senante et al., 2014; Muga and Mihelcic, 2008; Murray, Ray, and Nelson, 2009)

1.2.1 Economic indicators

Economic indicators include initial investment cost and operation and maintenances cost of the wastewater treatment plants (WWTPs). In most cases the life cycle of the WWTs need to be evaluated including the cost and benefit analysis for each alternative of wastewater technology.

1.2.2 Environmental indicators

Environmental indicators can be grouped in the several categories such as those related to efficiency of the WWTP, focusing on quality of effluent by looking on its effectiveness on removal of organic matter, suspended solids (SS), nitrogen (N) and phosphorus (P), and other nutrients. On other hand, environmental indicators can be addressed in term of emissions of CO2 and other GHGs *(Foley et al., 2010)*. Spatial footprint is also an important indicators related to environmental issues, this the amount of land area required for the wastewater management or treatment process *(Molinos-Senante et al., 2014)*. Other aspect of the environmental indicators is the reliability of the treatment plant, the capacity of plant to operate over long period while maintaining the good performance, the treatment plant needs to have minimal mechanical failures *(Molinos-Senante et al., 2014)*.

1.2.3 Social indicators

The social indicators represent the impact of the WWT on society. Most of social indicators are qualitative, therefore often not addressed while assessing technologies or WWTPs *(Foley et al., 2010)*. However, it is essential to consider impact of implementation of technology on society as a whole. The key indicators in this category can include issues of odour, noise, visual impact, public acceptance e.t.c. It should be noted that, simplicity of the technology might be a key factor in selection of the WWT system, especially in developing regions.

1.3 Analytical Hierarchy Process (AHP) for decision making in wastewater management.

There are many methods used for supporting a decision making process for wastewater selections, in this thesis a simple Analytical Hierarchy Process (AHP) is discussed. However, choosing a technology alone does not lead to effective wastewater management, other administrative strategies need to be developed as well. SWOT analyses is the better tool used to in developing management strategies over the years. The next section presents more about SWOT analyses and Analytical Hierarchy Process (AHP). Using SWOT analyses and Analytical Hierarchy Process (AHP) in the process of selection for wastewater systems.

1.3.1 SWOT

SWOT is a common synonym of the words Strength, Weakness, Opportunities and Threat. When these words are scrutinized in a certain plan or any undertaking is referred as SWOT analysis. In particular, the Strength and Weakness are those factors that are within the control of the evaluated entity, while the opportunities and threat are those which are outside the control of the evaluated entity. SWOT analysis has been popular for many years and it has gained acceptance because of its assumed simplicity and build a framework with focus in developing strategies. *Table 1.6* below shows briefly the SWOT idea or framework.

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Table 1.6: SWOT Concept

Internal Factors	STRENGTHS e.g. capacity and resources available to meet the desired objective	OPPORTUNITIES Conducive external environment/factors to favour completion of the objective	**external Factors**
	WEAKNESSES Challenge and key limit that cause or bring difficulties to achieve the goal	THREATS Negative external factors or situation thatwill hinder performance of the objective	

Sources: Information in this table was adopted and modified from (*Barrella, 2012), (Alshomrani and Qamar, 2012), (Andouhjerdi et al., 2014)*

Strength and Weakness factors mainly internal thing within the organisation, examples of internal factors include resources (financial, human, equipment etc.), natural and man-made assets, information strategy of city, administration, Policy consensus within city council. Also, the ability and capacity of the city administration to put into practice the policies; and, level of autonomous funding.

Opportunity and threats factors mainly external thing outside the organisation, examples of external factors include resource constraints, such as availability of energy at affordable prices, forces such as the political balance of power at provincial or national levels. Other can be, institutional arrangements outside the control of city administration, public support or opposition, and, legal mandates.

The important aspects after identifying the SWOT factors are to develop alternative strategies. The best way of developing the strategies is to make a TOWS matrix. TOWS matrix shown in *table 1.7* below depict basic frame of developing strategies by using combination of strength and weakness and the opportunity and threat.

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Table 1.7: TOWS Matrix

	Strengths(S)	**Weaknesses(W)**
Opportunities(O)	SO strategy Maxi-Maxi Usestrength toMaximize opportunity	**WO strategy** Mini Maxi Minimize weakness by taking optimizing the opportunities
Threats(T)	**ST strategy** Maxi Mini use strength to minimize threat	**WT strategy** Mini Mini Minimize weakness and reduce the treats to minimal

Table was adopted with modification from (*Alptekin, 2013*)

As noted earlier in this section, SWOT analysis has been considered more effective for identifying different strategic factors during planning process. However, a couple of authors challenged this SWOT analysis/process that, it is more qualitative and does not measure the intensities of each identified factor. They explained that the main disadvantages of SWOT are based on its inability to quantify effects of weight and strategic factors on alternatives. Farther comments on SWOT weakness noted in literature, that SWOT can be oversimplified. Therefore, they proposed that, SWOT should not be used alone but it need to be combined with other methods which are capable of quantifying the SWOT factors. To support this idea, other authors also commended that, if results of SWOT analysis are solely used for decision making, the chances for getting good and comprehensive assessment of proposed strategies are low. They concluded that, since the planning process is associated with number of indicators and criteria that are not depended to each other, using SWOT alone is inadequate.

1.3.2 Analytical hierarchy process

Analytical Hierarchy Process (AHP) is one of the most popular methods of decision-making based on Multi criteria and multi objective. AHP structure performs the decision making and monitoring the decision process by defining goals, criteria and options, comparing the criteria and options dually and determining alternative priorities. Currently, the AHP structure is one of the most popular approaches used for multi-criteria decision making to solve the real problems developed by Saaty in 1977.

AHP applied for investigation of qualitative issues, which do not have a criterion for measurement and always appear with quantitative issues that arise in decision-making. This method also, solves complexes decisions, as it apply multiple criteria. The drawback of this method is that, it lacks specificity in composing the hierarchy and forming evaluation factors.

However, in case of this study, factors that will be used for AHP those that came from SWOT analysis.

1.3.3 Combing SWOT factors and analytical hierarchy process

The main purpose for combing two processing is enhancing SWOT factors, so, they can be quantified and qualified. This will help to equate them and determine their weight and priority. The approach of combining (AHP) and SWOT is not new, it has been used widely over the years. These methods were applied for evaluation of different management strategies including of natural resource management like forest, fisheries, energy, mining and mineral etc. Also it was used on marketing, Industries, urban planning etc. The basic steps employed to use this method is threefold, firstly, carry out the SWOT analysis by listing the important Strength, Weakness, Opportunities and threats. Then, second, calculate the weight of each SWOT group through paring the factors within each SWOT group. Then finally, the third step will be the uses the AHP to develop relative priorities of each factor within SWOT. Then calculate the overall factor weight and rank them through multiplying the factors of each local group by the specific group weight.

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