Fuzzy Based Decision Support Method for Selection of Sustainable Wastewater Treatment Technologies

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DECLARATION

This thesis is my original work and has not been presented for degree in any other University.

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This thesis is submitted for examination with our approval as University supervisors.

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DEDICATION

This work is dedicated to my late father, Dominic Kamami, who always encouraged and inspired me to aim high.

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especially at times when I seemed to waver, and I will forever be grateful. May our Almighty God bless you all abundantly.

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LIST OF ABBREVIATIONS

ASP	Activated sludge process
BOD	Biochemical oxygen demand
CBR	Case based reasoning
CFU	Colony forming units
COD	Chemical oxygen demand
CWs	Constructed wetlands
DBPs	Disinfection by products
EDCs	Endocrine disrupting compounds
FS	Faecal sludge
HRT	Hydraulic retention time
MPN	Most probable number
NGO	Non- governmental organization
NTU	Nephelometric turbidity unit
O & M	Operation and maintenance
PhACs	Pharmaceutically active compounds
TC	Total coliform
TDS	Total dissolved solids
TF	Trickling filter
TOC	Total organic carbon

TOD	Total oxygen demand
TSS	Total suspended solids
UASB	Up flow anaerobic sludge blanket
USEPA	United States Environmental Protection Agency
WHO	World health organization
WSPs	Waste stabilization ponds
WWTP	Wastewater treatment plant

ABSTRACT

Inadequate decision support tools have lead to selection of inappropriate and unsustainable wastewater treatment technologies. There is therefore the need to develop tools that would improve decision making process in selection of appropriate wastewater treatment technologies. The broad objective of this research work was to develop a decision support method for selection of sustainable wastewater treatment technologies. The specific objectives were to investigate performance data for wastewater treatment technologies, develop a decision support method (DSM) for evaluating performance of technologies, and to validate the method. The decision support method was developed through evaluation of performance of wastewater treatment technologies against environmental and economic indicators. Fuzzy logic techniques were used in order to support decision making under uncertainty. The method was validated through a training tool in wastewater treatment known as ED-WAVE which was developed by a consortium of European and Asian countries. Also, independently collected data from three wastewater treatment plants in Kenya were used in the validation process. The Decision Support Method (DSM) relied on performance evaluation in order to rate wastewater treatment technologies. This was an improvement on existing decision support tools such as ED-WAVE that relied on retrieval of past performance data in order to arrive at a solution when a new treatment case was presented. Decision support method enabled performance of a single treatment unit within a treatment sequence to be rated. Also the overall performance of a treatment sequence could be rated through DSM hence allowing for any required improvements on performance to be incorporated in design. Through application of DSM, the performances of wastewater treatment plants in Nairobi, Nakuru and Thika were rated as “Good”. Using DSM analysis, additional technologies that could improve the rating of treatments plants in Nairobi, Nakuru and Thika from “Good” to “Excellent” were investigated. The Decision Support Method provided a more reliable method for wastewater treatment technology performance rating and hence selection as compared to ED-WAVE. Further improvements on the tool could be achieved through testing and validating more case studies and treatment sequences.

CHAPTER 1

1.0 INTRODUCTION

1.1 Background

The production and discharge of domestic wastewater is rapidly increasing especially in developing countries due to population growth, urbanization, and economic development. There is, however, a lack of investing capacity worldwide for construction and operation of adequate treatment facilities (Van Lier and Lettinga, 1999). This is threatening the quality of surface waters, soils and groundwater to which wastewater is discharged. At the same time, there has been a rapid increase in water demand in urban and peri-urban areas, for production of food, particularly fresh vegetables (Cofie et al., 2003).

These two trends cause an increasing use of partially treated and untreated wastewater in irrigated agriculture in and downstream of urban centers. It has been recognized that such use has additional beneficial effects, as the used water often contains important nutrients. However, unbalanced application of these nutrients, as well as the presence of pollutants in wastewater, has also been identified as a threat to resources (van der Zee and Shaviv, 2002; van der Zee et al., 2004).

The technical problem to be resolved for protecting resources is complex and broad. This is due to the large variety of pollutants and nutrient concentrations, of soil and geohydrological conditions, crops, and agricultural management (Van Asten et al., 2003). The management question in wastewater reuse involves socio-economic and cultural factors. These are related to among others policy regulations and the degree to which these are enforced, costs, benefits, and public acceptance of wastewater use in irrigated agriculture. These will differ between countries and often within countries.

In view of commonly regional setting of watershed hydrology, the development of concepts for sustainable wastewater use, and their implementation in sustainable practice are an optimization problem (Huibers et al., 2004). At present, the lack of a methodology for integrated interdisciplinary problem solution, prevent development of truly sustainable strategies (Kaledhonkar et al., 2001).Hence, both scientifically and in practice the increasing wastewater production and growing water scarcity form an opportunity as well as an environmental conflict (van Lier and Huibers, 2004).

Simple, affordable, and efficient sewage treatment systems are urgently needed, especially in developing countries, where most of the conventional technologies currently in use in industrialized nations are too expensive and complex (Grau, 1996). Sustainable sewage treatment technologies will help to preserve water ecosystems and their biodiversity, indispensable for the provision of clean water, flood control, and other vital services.

The conventional centralized system flushes pathogenic bacteria out of the residential area, using large amounts of water and often combines the domestic wastewater with rainwater, causing the flow of large volumes of pathogenic wastewater. In turn, the wastewater must be treated where the cost of treatment increases as the flow increases. On the other hand, conventional systems may even be technologically inadequate to handle the locally produced sewage. For example, in comparison to the United States and Europe, domestic wastewater in arid areas like the Middle East are up to five times more concentrated in the amount of oxygen demand per volume of sewage. This is extremely high and may cause a large amount of sludge production (Bdour et al., 2007).

1.2 Problem Statement

Growing water scarcity threatens economic development, sustainable human livelihoods, environmental quality, and a host of other societal goals in countries and regions around the world. Urban population growth, particularly in developing countries, places immense pressure on water and land resources. It also results in the release of growing volumes of wastewater, most of it untreated and which is increasingly being used for irrigation in urban and peri-urban agriculture.

The diminishing supply of fresh water sources is placing increasing pressure on the agricultural sector to produce more food with less water. One way to achieve this is by making irrigation more efficient and by using recycled water (Jensen et al., 2001). Rapid urbanization in developing countries' cities has resulted in generation of huge volumes of municipal and industrial wastewater requiring treatment and safe disposal (Bruins, 1997; Mensah et al., 2001).

Using treated wastewater for agriculture provides a means through which wastewater can safely be reused and managed thereby reducing demand on fresh water sources (Rose, 1999). The potential for wastewater use for irrigation can best be realized in an enabling environment that ensures adequate wastewater treatment and management. However, in most developing countries, wastewater used for agriculture is largely not treated raising public health concerns (Kilelu, 2004). To ensure sustainable and safe wastewater use for food production in urban and peri-urban areas, there is need to implement safe wastewater use and management options (Mara et al., 2005).

The process of evaluating and selecting appropriate wastewater treatment technology should consider the life cycle cost of such a system including design, construction, operation, maintenance, repair and replacement (Massoud et al., 2008). Simple, affordable, and efficient sewage treatment systems are urgently needed. This is especially so in developing countries where most of the conventional technologies currently in use in industrialized nations are too expensive and complex (Grau, 1996).

There exists treatment technologies to achieve any desired water quality. But in most regions of the world, especially in the developing countries, inadequate resources, including qualified personnel and poor technology selection methods, are major impediments to sustainable wastewater management (Volkman, 2003; Bradford et al., 2002; von Sperling and Chernicharo, 2001). Hence the need to develop appropriate decision support methods to assist decision making process during selection of wastewater treatment technologies. This would ensure selection of economically and environmentally appropriate technologies.

1.3 Objectives

1.3.1 Broad Objective

To develop a decision support method that will improve selection process of wastewater treatment technologies through evaluating their performance against environmental and economic indicators.

1.3.2 Specific Objectives

1. To document performance data on wastewater treatment technologies against economic and environmental indicators.
2. To develop a decision support method for evaluating performance of wastewater treatment technologies against economic and environmental indicators.
3. To validate the decision support method through the ED-WAVE tool and field collected data.

1.4 Justification

Wastewater reuse has drawn increasing attention worldwide as an integral part of water resources management. Such a move is driven by two major forces, i.e. diminishing freshwater sources due to rising demand, and heightened environmental concerns (Toze, 2005). Agriculture is by far the biggest consumer of available fresh water supplies. Presently about seventy percent (70%) of today's global fresh water consumption feeds agriculture (Koehler, 2008).In many water scarce countries and regions of the developing world, wastewater is often used directly for irrigation, causing health concerns (Toze, 2005). For these countries and regions, improving wastewater treatment capacity through appropriate technologies and encouraging the reuse of reclaimed wastewater are of importance for alleviating water scarcity and reducing environmental and health risks.

For most developing countries, the lack of adequate and appropriate technologies for wastewater treatment has been a major constraint for safe wastewater use. This inadequacy is made more challenging by limited financial, institutional and poor technology selection methods (Massoud et al., 2008; von Sperling and Chernicharo, 2001).

The development of efficient wastewater treatment systems is a complicated task. It requires significant engineering experience as well as deep theoretical knowledge of the designers. Usually the task facing an engineer is to determine the levels of treatment that must be achieved and a sequence of methods that can be used to remove or to modify the components found in wastewater in order to reduce the environmental impact and to meet ecological requirements. The solution of this task requires the detailed analyses of local conditions and needs, application of scientific knowledge and engineering judgment based on past experience (Avramenko and Kraslawski, 2008).

A decision support method that facilitates performance comparison of treatment technologies against set criteria would improve selection process of wastewater treatment technologies. Existing decision support tools like ED-WAVE have limitations in that they rely on past experiences in order to solve new problems (Avramenko and Kraslawski, 2008). The decision support method relied on evaluation of technology performance against wastewater characteristics like biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS). Then on the basis of evaluation results, a decision would be made on which treatment technologies best suited the case at hand.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Categories of wastewater

Wastewater is categorized according to its origin. The categories include:-

1. Grey water – composed of domestic water without urine and faeces.
2. Black water- composed of domestic water that is mixed with faeces and urine.
3. Industrial wastewater- composed of water from industrial processes, which may contain varying concentration of heavy metals.

In many developing urban centers, wastewater is generally a mixture of the three different categories and its use is mainly informal. The uncontrolled and varied nature of sources of wastewater used for irrigation makes it difficult to define, monitor and control the practice (Cornish et al., 1999).

A typical household in developed countries discharges approximately 35 litres of blackwater, and 105 litres of greywater per person per day (USEPA, 2000). The potential for on-site treatment and reuse will depend on the quality of discharged wastewater. Greywater contributes about 65% of the volume of domestic wastewater, 70% of the phosphorus, and 63% of the BOD (biochemical oxygen demand), whilst blackwater contributes about 35% of the volume of wastewater, 61% of suspended solids, 82% of nitrogen and 37% of BOD (USEPA, 2000). The potential presence of pathogens in greywater is substantially lower than in blackwater. However, several authors have shown that greywater may contain pathogens. Thus, both greywater and blackwater require adequate treatment before onsite reuse.

2.2 Nature of wastewater

Municipal wastewater is a combination of water and carried wastes removed from residential, institutional and commercial establishments together with infiltration of water, surface water and runoff water (Al-Enezi et al., 2004). The methods of wastewater treatment were first developed in response to the concern for public health and the adverse conditions caused by the discharge of wastewater to the environment (Jamrah, 1998).

The nature of wastewater is described by its flow and quality characteristics. In addition, wastewater discharges are classified based on whether they are from municipalities or industries. Flow rates and quality characteristics of industrial wastewater are more variable than those for municipal wastewater (Metcalf and Eddy, 2003).

Municipal wastewater is comprised of domestic (or sanitary) wastewater, industrial wastewater, infiltration and inflow into sewer lines, and storm water runoff. Domestic wastewater refers to wastewater discharged from residences and from commercial and institutional facilities (Metcalf and Eddy, 2003). Domestic water usage, and the resultant wastewater, is affected by climate, community size, density of development, community affluence, dependability and quality of water supply (Metcalf and Eddy, 2003).

2.2.1 Wastewater Characteristics

Wastewater quality may be defined by its physical, chemical, and biological characteristics. Physical parameters include colour, odour, temperature, and turbidity. Insoluble contents such as solids, oil and grease, also fall into this category. Solids may be further subdivided into suspended and dissolved solids as well as organic (volatile) and inorganic (fixed) fractions. Chemical parameters associated with the organic content of wastewater include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and total oxygen demand (TOD). Inorganic chemical parameters include salinity, hardness, pH, acidity and alkalinity, as well as concentrations of ionized metals such as iron and manganese, and anionic entities such as chlorides, sulfates, sulfides, nitrates and phosphates (Metcalf and Eddy, 2003).

Bacteriological parameters include fecal coliforms, specific pathogens, and viruses. Both constituents and concentrations vary with time and local conditions. It should be emphasized that these properties are interrelated. For example, temperature, which is a physical property, affects both the biological activity of the wastewater and the amount of oxygen dissolved in the wastewater. The effects of the discharge of untreated wastewater into the environment are manifold and depend on the types and concentrations of pollutants.

2.3 Wastewater contaminants and their importance

i) *Suspended solids (SS)* can lead to development of sludge deposits and anaerobic conditions when untreated wastewater is discharged to the aquatic environment.

ii) *Biodegradable organics* are principally made up of proteins, carbohydrates and fats. They are commonly measured in terms of BOD and COD. If discharged into inland rivers, streams or lakes, their biological stabilization can deplete natural oxygen resources and cause septic conditions that are detrimental to aquatic species.

iii) *Pathogenic organisms* found in waste-water can cause infectious diseases.

iv) *Priority pollutants*, including organic and inorganic compounds, may be highly toxic, carcinogenic, mutagenic or teratogenic.

v) *Refractory organics* that tend to resist conventional wastewater treatment include surfactants, phenols and agricultural pesticides.

vi) *Heavy metals* usually added by commercial and industrial activities must be removed for reuse of the wastewater.

vii) *Dissolved inorganic constituents* such as calcium, sodium and sulfate are often initially added to domestic water supplies, and may have to be removed for wastewater reuse.

Source: Adapted from Metcalf and Eddy, 2003; *Wastewater Engineering*, 4th edition.

2.4 Wastewater treatment

2.4.1 Methods and selection factors

When selecting a system to treat municipal wastewater, initially all processes are theoretically competitive (Tsagarakis et al., 2002). The selection of a process scheme for the design and operation of a municipal wastewater treatment plant is made based on several factors, such as:-

i) Land availability
ii) Climate
iii) Environmental considerations
iv) Costs
v) Wastewater characteristics
vi) Performance, reliability, compatibility, and flexibility of the processes selected
vii) Transportation and disposal of sludge and effluent discharge

Finally, a cost-effectiveness analysis is carried out to determine the optimum economically viable solution as the selection criterion.

Methods of wastewater treatment were first developed in response to the concern for public health and the adverse conditions caused by the discharge of wastewater to the environment (Metcalf and Eddy, 2003). The treatment objectives were concerned with the removal of suspended and floatable material, the treatment of biodegradable organics, and the elimination of pathogenic organisms. Because of the increased scientific knowledge and an expanded information base, wastewater treatment began to focus on the health effects related to toxic and potentially toxic chemicals released to the environment, in addition to the early treatment objectives

2.4.2 Wastewater treatment goals

Wastewater treatment implies the purification of a given wastewater until its characteristics achieve a certain objective, generally related to health, environmental, or economic matters. Several research studies have shown that, treated wastewater, if appropriately managed, is viewed as a major component of the water resources supply to meet the needs of a growing economy (Wisaam et al., 2007; Amann et al., 1997).

The greatest challenge in implementing this strategy is the adoption of low cost wastewater treatment technologies. These will maximize the efficiency of utilizing limited water resources, and ensuring compliance with all health and safety standards regarding reuse of treated wastewater effluents (Gijzen, 2001). It is crucial that sanitation systems have high levels of hygienic standards to prevent the spread of diseases. Other treatment goals include the recovery of nutrient and water resources for reuse in agricultural production and to reduce the overall user-demand for fresh water resources. Innovative and appropriate technologies can contribute to urban wastewater treatment and reuse.

2.4.3 Wastewater collection and treatment requirements

Wastewater collection systems (i.e., sewer networks) and centralized and decentralized treatment systems are designed and managed primarily to protect human and environmental health. Though their benefits are widely recognized, there are other aspects of this infrastructure and associated technologies that are not so obvious and hence less acknowledged, yet they impact communities and the surrounding environment (Massoud et al., 2008; von Sperling and Chernicharo, 2001). For example a positive aspect of the sewer network is the collection and transport of wastewater to appropriate treatment facilities. Here pathogens and chemical constituents such as oxygen depleting organic matter and phosphorus are removed before the treated water is returned to the environment. A negative aspect of such a network is that it can create an imbalance in water and nutrient fluxes and therefore distort natural hydrological and ecological regimes (Rose, 1999). For instance the discharge of large volumes of treated wastewater that contains low concentrations of chemical constituents may still lead to an excessive input of nutrients in a receiving water body, thus, leading to a water quality problem.

In an era where there is growing concern of the local and global impact of our current environmental management strategies, and the need to reduce sanitation problems, disease, and poverty, there is a greater need to develop more environmentally responsible, appropriate wastewater treatment technologies whose performance is balanced by environmental, economic, and societal sustainability (Muga, 2007;

Volkman, 2003). Thus in light of the main aspects of sustainability, questions that deserve further analysis are how selection of a particular wastewater treatment technology affects overall sustainability.

The increasing scarcity of water in the world along with rapid population increase in urban areas gives reason for concern and the need for appropriate water management practices. According to the World Bank, the greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes (Looker, 1998).

Agriculture consumes between 70% and 90% of abstracted fresh water resource in developing countries (Seckler et al., 1998). With the present population growth, more food will have to be produced. At the same time, the water requirements of urban areas, industries, and the environment are increasing rapidly. There is therefore an increasing pressure on the irrigation sector to produce more food with less water by making irrigation more efficient and by using recycled water.

2.5 Wastewater Treatment Technologies

2.5.1 Treatment technologies

Wastewater treatment is a process of increasing importance in a world with an ever growing human population. Wastewater treatment processes that can achieve an effluent standard at minimal cost are generally preferred by any country, especially developing countries (von Sperling and Chernicharo, 2001). The main economic considerations are capital cost, operation and maintenance (O&M) costs, energy consumption and the procurement of land, which are important parameters for selecting an appropriate treatment system.

A comparison between different treatment processes based on available, reliable sources could simplify the selection procedure. The cost of a sewage treatment process varies significantly depending on the time frame and location. Moreover, the configuration of any similar type of treatment process may vary according to the size of the local community or climatic conditions of the area, which in turn affects cost. These factors considerably affect the task of standardizing the cost of any process (Koning et al., 2008; Gijzen, 2001).

2.5.2 Organisms involved in wastewater treatment

The group of organisms most directly involved in wastewater treatment are the bacteria. They dominate, both in numbers and biomass, all other groups and dominate the processes of mineralization and elimination of organic and inorganic nutrients (Toze, 2005). They are favored, in traditional high load plants that operate with short sludge retention times, by their low generation times. Modern low load systems have high retention times and also allow for the presence of more slowly growing bacteria and of organisms with a more complex organization such as flagellates, amoebae, ciliates or even worms and insect larvae (Kamizoulis, 2008). The protozoa and metazoa are able to feed on particulates, such as those coming in with the sewage or bacterial flocs. It is generally assumed that their primary role in the wastewater treatment is the clarification of the effluent.

2.5.3 Selection of wastewater treatment technology

Selection of a particular wastewater treatment technology should not be based primarily on technical insight, but should also integrate the human and environmental activities that surround it. There exists a large array of technological and process options to achieve pathogen attenuation in faecal sludges and wastewater (Kilelu, 2004).

The conventional centralized system flushes pathogenic bacteria out of the residential area, using large amounts of water and often combines the domestic wastewater with rainwater, causing the flow of large volumes of pathogenic wastewater (Volkman, 2003). In fact, the conventional sanitary system transfers a concentrated domestic health problem into a diffuse health problem for the entire settlement and/or region. In turn, the wastewater must be treated where the cost of treatment increases as the flow increases. Another reason many treatment systems in developing countries are not successful and therefore unsustainable are that they were simply copied from Western treatment systems without considering the appropriateness of the technology for the culture, land, and climate. Many of the implemented installations were abandoned due to the high cost of running the system and repairs (van Leir and Lettinga, 1999).

On the other hand, conventional systems may even be technologically inadequate to handle the locally produced sewage. For example, in comparison to the United States and Europe, domestic wastewater in arid areas like the Middle East are up to five times more concentrated in the amount of oxygen demand per volume of sewage. This is extremely high and may cause a large amount of sludge production (Bdour et al., 2007). Non-centralized systems are more flexible and can adapt easily to the local conditions of the urban area as well as grow with the community as its population increases. This approach leads to treatment and reuse of water, nutrients, and byproducts of the technology (i.e. energy, sludge, and mineralized nutrients) in the direct location of the settlement.

The choice of a particular treatment option depends on various factors, namely, the objective of treatment (reuse or discharge into the environment), hence, the desired or legally stipulated quality of liquid effluents and of bio-solids produced by the process; the simplicity and sturdiness of the plant and its operation; the financial and economic cost; the land requirements; the type of cultivation envisaged or being practiced; the market opportunities for the sale of treatment products; the farmers' ability to pay and lastly, the need or otherwise to devise options which may be managed by rather unskilled persons on a decentralized, community-based scale(Rose, 1999; Orona et al.,1998).

Numerous small and large systems have been implemented throughout the world in the past decades, the effluents of which are largely used for irrigation. They may, if properly designed and operated, produce effluent meeting stringent hygienic quality standards.

Variants of this option allow effluent either for so-called restricted irrigation as well as for unrestricted irrigation, i.e. irrigation of crops eaten uncooked. Pond systems may also prove suitable to treat faecal sludges (FS) if particular precautions are taken with respect to solids separation and handling and to excessive ammonia levels in fresh, rather undigested FS (Heinss et al., 1998).

2.5.4 Wastewater treatment technology alternatives

i) Waste stabilization ponds

Care must be exerted when comparing various treatment options as to their pathogen removal performance versus land use and cost. Conclusive comparisons can only be made for options, which have been conceived and designed to achieve comparable levels of pathogens in the effluent or bio-solids. A planted soil filter, for instance, requires less land than a waste stabilization pond (WSP) scheme. But then, WSP, whether including maturation ponds or not, would normally produce higher removal efficiencies for bacteria and viruses due mainly to the longer system retention time [10-28 days in WSP schemes in warm climate versus 1-2 days in a planted soil filter] (Massoud et al., 2008; Metcalf and Eddy, 1991).Waste stabilization ponds, Fig.1, are commonly used as efficient means of wastewater treatment relying on little technology and minimal, albeit regular, maintenance. Their low capital and operating costs and capability to handle fluctuating organic and hydraulic loads have been valued for years in rural regions and in many countries wherever suitable land is available at reasonable cost (Volkman, 2003).

The major limitation of this type of treatment is the high effluent suspended solids (SS) concentrations mainly due to high concentrations of algal cells in the finished effluent (≥150mg/l) (Mara, 2000). The presence of such algae can impose serious constraints on effluent reuse potential, which is particularly important in water-scarce regions.

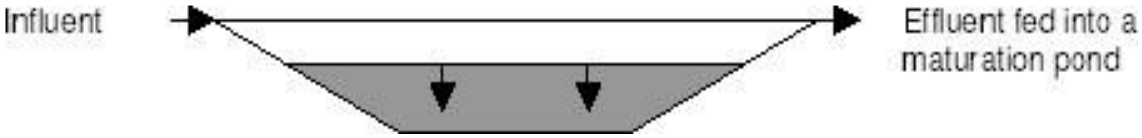


Figure 1. **Waste stabilization pond.**

ii) Sand filters

An intermittent sand filter is a down flow, gravity filtration unit employing sand as the filtration medium. The wastewater to be treated is applied periodically hence the term intermittent (Crites and Tchobanoglous, 1988). Intermittent sand filter units consist of a sand bed placed on a mesh or a gravel bed, a flow distribution system located at the top of the unit, and an under drain-collecting system for the produced effluent. Wastewater applied on the surface of the filters percolates through the sand grains and is cleaned by two mechanisms, namely, physical exclusion depending on particle size and biological degradation by micro-organisms. Intermittent sand filters effectively remove suspended solids, BOD and ammonia, their efficiency primarily depending on sand depth, organic loading rates and the size of sand used. The finer the sand grains, the better the removal efficiency of the filter (Metcalf and Eddy, 1991).

The total filter area is given by equation 1.

$$A = \frac{Q}{HLR} \qquad (1)$$

where,

A = total filter area (m^2)

Q = influent flow (m^3/day)

HLR = hydraulic loading rate (m^3/m^2/day)

Figure 2 presents a schematic diagram of a sand filter showing the cross-section and plan views.

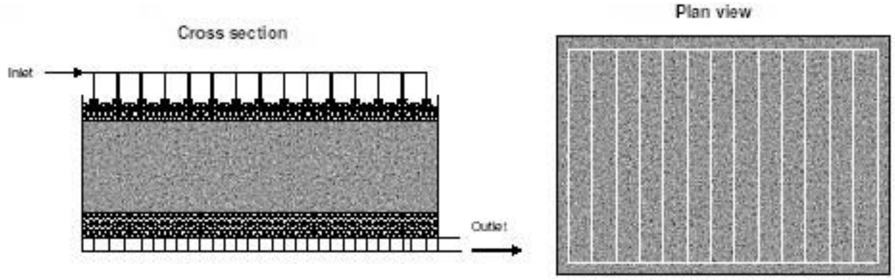


Figure 2. Cross section and plan views of sand filters.

iii) Trickling filters

An additional, promising alternative for the removal of algae from waste stabilization pond effluents could be the trickling filter (TF) Fig. 3, which couples biological and mechanical filtration to effectively reduce BOD and TSS in the effluents. Trickling filters are capable of achieving BOD and TSS removal efficiencies greater than 80%, producing an effluent suitable for reclamation [landscape irrigation and soil conditioning] (Koning et al., 2008; Metcalf and Eddy, 1991). At an incremental cost, addition of other treatment components (e.g. wetlands, ponds and sand filters) boosts overall removal rates of BOD and TSS to more than 90%, creating a water source acceptable for human contact (Koning et al., 2008; Geary, 1998).

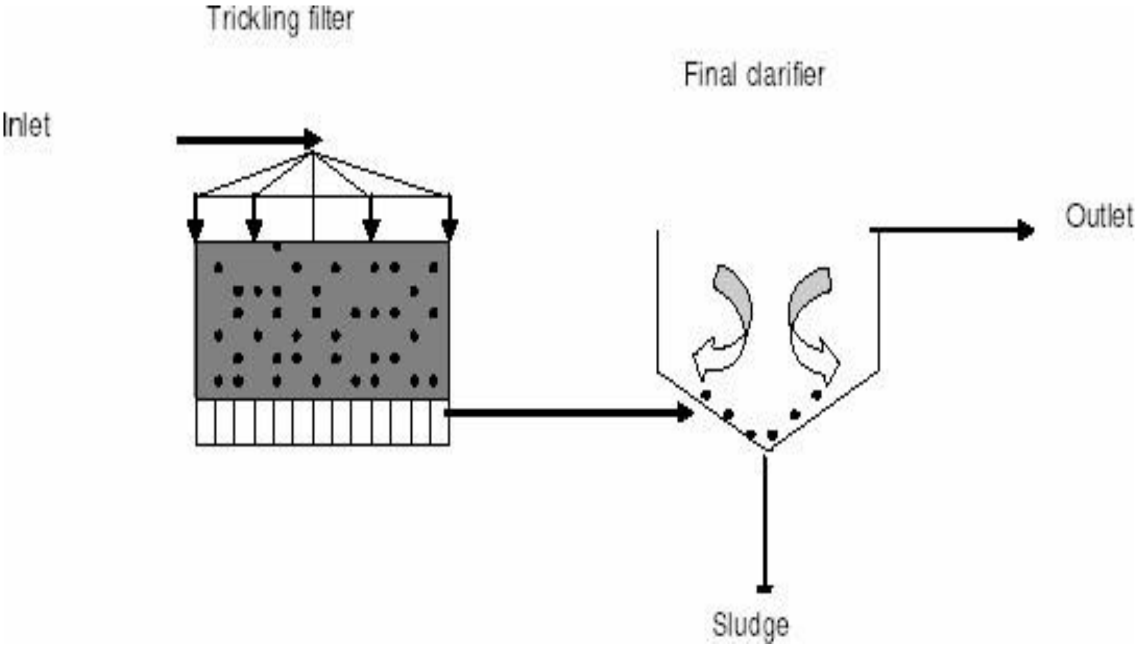


Figure 3. Trickling filter with final clarifier.

iv) Septic tank

Septic tanks, Fig.4, remove most settleable and floatable material and function as an anaerobic bioreactor that promotes partial digestion of retained organic matter (Montangero and Belevi, 2006). Septic tank effluent, which contains significant concentrations of pathogens and nutrients, has traditionally been discharged to soil, sand, or other media absorption fields for further treatment through biological processes, adsorption, filtration, and infiltration into underlying soils. Conventional systems work well if they are installed in areas with appropriate soils and hydraulic capacities; designed to treat the incoming waste load to meet public health, ground water, and surface water performance standards; installed properly; and maintained to ensure long-term performance (USEPA, 2000).

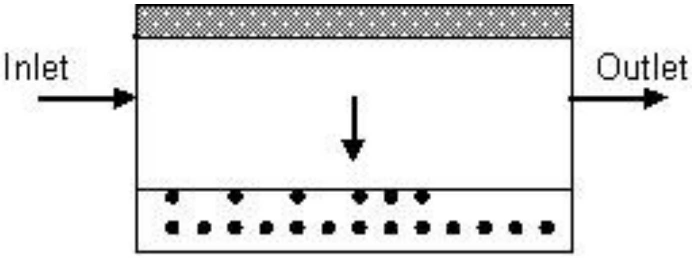


Figure 4. Septic tank.

v) Constructed wetland

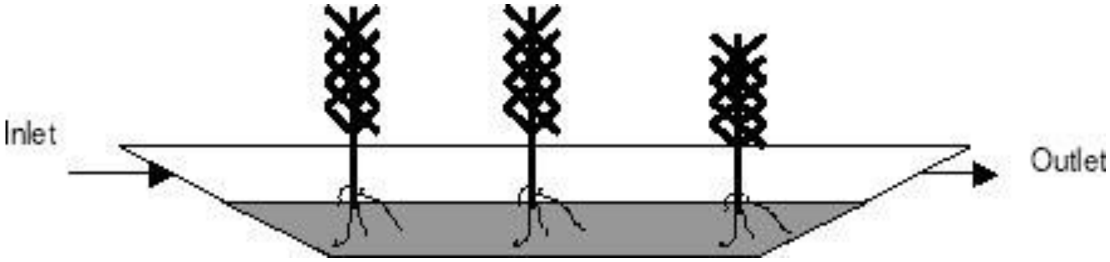


Figure 5. Constructed wetland.

Constructed wetlands (CWs), Fig. 5, are an attached-growth biological treatment process. CWs are shallow earthen basins usually lined with an impermeable liner in order to prevent seepage. The basin is then filled with a suitable soil layer where plants can root and grow. Organic removal takes place through sedimentation and aerobic decomposition brought about by microorganisms (Mbuligwe, 2004; Kivaisi, 2001).

Based on the flow pattern employed, there are two types of wetlands:-

1. The free water surface (FWS) wetlands where wastewater flows through an open basin and the flow resembles open channel flow. The wastewater flows in direct contact with the atmosphere.

2. Subsurface flow (SF) wetlands where wastewater flows underneath the surface of the wetland (Rousseau, 2005).

Advantages of constructed wetlands include low operational and maintenance costs, low surplus sludge and great tolerance in flow variations. A major disadvantage is the high requirement in land (Rousseau, 2005; Mashauri et al., 1999).

There are other centralized wastewater treatment systems. But the high capital costs, operational and maintenance requirements render them inappropriate for developing countries. Other important factor for consideration in wastewater treatment is the hydraulic and organic loading of wastewater. Two important treatment technologies in this category are the activated sludge process, Fig.6 and the membrane bioreactor, Fig.7.

vi) Activated sludge process

The process of activated sludge is a suspended growth biological treatment process. Degradation of waste is brought about by microorganisms, which oxidize organic matter aerobically, producing oxidation end-products (such as carbon dioxide, ammonia, etc.) and new microbial cells (Keller et al., 2002). The main principle of the method is that wastewater (termed substrate) and microorganisms (together termed mixed liquor) enter the reactor (usually termed oxidation tank) and remain in suspension, while air or oxygen is provided by diffusion or mechanical agitation. It is during this contact time that oxidation reactions and microbial culture growth take place. After the lapse of an adequate retention time, the treated wastewater and microorganisms are driven into a sedimentation tank where microorganisms settle at the bottom forming the sludge while the clarified wastewater is removed from the top (Metcalf and Eddy, 2003).

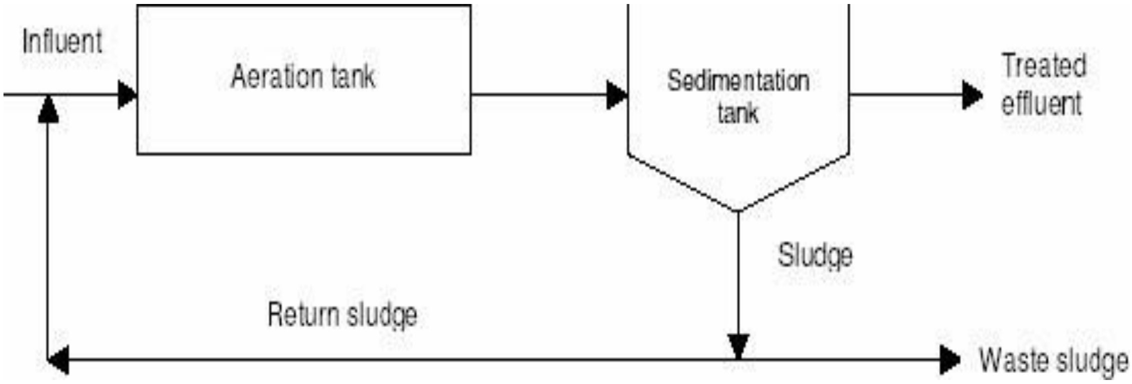


Figure 6. Activated sludge process.

vii) Membrane bioreactor

Membrane bioreactor (MBR) integrates biological treatment with membrane filtration. This results in a single stage degradation of organic components and removal of suspended and colloidal matter without a separate sedimentation/clarification step. The system consists of a suspended growth aerobic or anaerobic bioreactor with microfiltration (MF) or ultrafiltration (UF) membranes (Oron et al., 2008; Metcalf and Eddy, 2003).

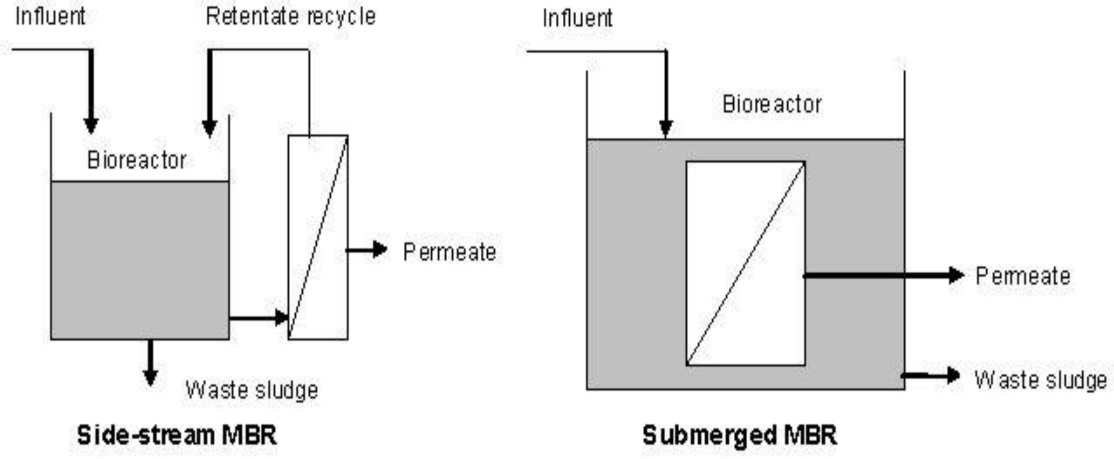


Figure 7. **Membrane bioreactor.**

2.5.5 Categories of technologies

The technologies used in municipal wastewater treatment can be separated into three categories depending on the principle they are based on, namely physical, chemical and biological methods (Metcalf and Eddy, 2003).

2.5.5.1 Physical methods

These use the physical properties of wastewater such as specific gravity, solubility, and particle size for contaminant removal. Examples of such processes are screen bars, grit removal chambers, and filtration units based on physical exclusion, sedimentation, and floatation tanks based on gravitational settling or floating respectively.

2.5.5.2 Chemical methods

These processes involve the addition of a chemical to react with or adsorb the contaminant or assist in the formation of flocs. Examples of such processes are coagulant addition, activated carbon adsorption, and chlorine or ozone for the disinfection of effluents. Usually, a chemical method is followed by a physical one, such as sedimentation or filtration for the removal of the contaminant.

2.5.5.3 Biological methods

In these processes, removal of the contaminant is achieved by microorganisms which use wastewater as feed to produce gases and biological cell tissue. Usually such processes are followed by a physical sedimentation process for removal of the biological cell tissue.

2.6 Levels of wastewater treatment

Wastewater treatment can be roughly classified in the following levels:-

a) Preliminary treatment - Aims at the elimination of coarse material like bottles, rugs, dead animals, stones, and so on, as well as the sand that comes with sewage. The removal is mainly due to physical actions like screening, flotation and settling. The objective of preliminary treatment is to protect pumps and pipes, protect further treatment units, and protect water bodies. The main treatment units are screens and sand traps.

b) Primary treatment - Intends to remove most of the remaining suspended solids through physical processes like flotation and settling. The objective is to protect further treatment units and protect water bodies from receiving these solids. The main units are sedimentation tanks (settlers), but also systems like septic tanks can be classified as mainly primary treatment units.

c) Secondary treatment - Aims to the elimination of organic matter through biological action (by means of bacteria, fungi, algae, protozoa, etc.). The main objective is to protect water bodies, although the production of a usable effluent is also increasingly important. Biological treatment can be accomplished either with aerobic (so as ponds) or anaerobic treatment systems (so as UASB reactors).

d) Tertiary treatment - Sometimes also called post-treatment, it intends to remove pathogens and nutrients from sewage, via chemical, photochemical, and biological action (pH, light, bacteria, algae, and fungi). The objective is to protect public health, water bodies, and to produce a usable effluent for more stringent purposes. Biological systems are mainly aerobic.

Source: Adapted from Huibers et al., (2002). *Wastewater and Irrigated Agriculture.*

2.7 Appropriate Treatment Technology

Based on experience from past mistakes in sewage treatment technology, the definition of what is appropriate and sustainable treatment technology should be clear. Developers should base the selection of technology upon specific site conditions and financial resources of individual communities. Appropriate treatment is defined as one that fulfils the quality standards set for discharge or reuse of wastewater.

Although site-specific properties must be taken into account, there are core parts of sustainable treatment that should be met in each case (van Leir et al., 1999). The criteria for sustainable technology are summarized below.

i) No dilution of high strength wastes with clean water
ii) Maximum recovery and reuse of treated water and by products obtained from the pollution substances i.e. irrigation, fertilization
iii) Application of efficient, robust and reliable treatment technologies, which are low cost and which have a long life-time and are plain in operation and maintenance
iv) Applicable at any scale, very small and very big as well
v) Leading to a high self sufficiency in all respects
vi) Acceptable for the local population

One approach to sustainability is through decentralization of the wastewater management system. This system consists of several smaller units serving individual houses, clusters of houses or small communities. Grey water can be treated or reused separately from the hygienically, more dangerous black and industrial wastewater. Non-centralized systems are more flexible and can adapt easily to the local conditions of the urban area as well as grow with the community as its population increases (Schertenlieb, 2000). This approach leads to treatment and reuse of water, nutrients, and byproducts of the technology (i.e. energy, sludge, and mineralized nutrients) in the direct location of the settlement. Communities must take great care when reusing wastewater; both chemical substances and biological pathogens threaten public health as well as accumulate in the food chain when used to irrigate crops or in aquaculture (Kamizoulis, 2008).

Among the various wastewater treatment processes, filtration is one of the effective and attractive processes to improve effluent water quality. Several filter media are eligible for such a purpose. Activated carbon (powdered or granular), Fig.8, is the most widely used adsorbent because it has excellent adsorption efficiency for organic compounds (Keller et al., 2002). However, the activated carbon is considered an expensive adsorbent, which makes the wastewater treatment a prohibitive cost step.

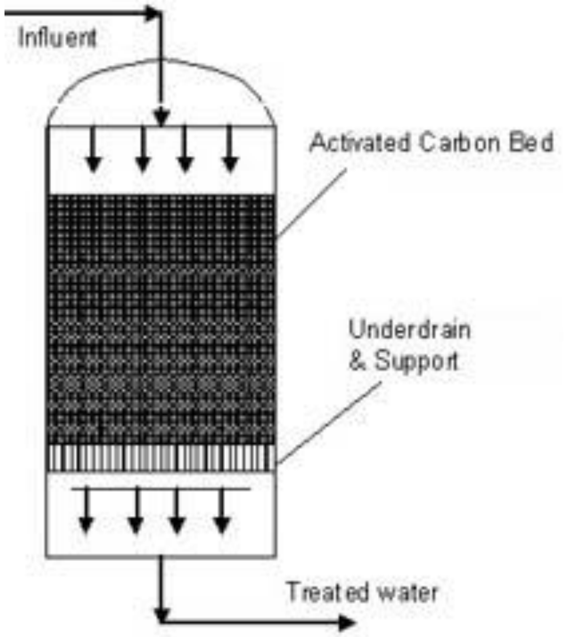


Figure 8. Activated carbon filter.

Several studies have tried to replace the activated carbon with less expensive materials. Therefore, there is a growing interest in using low-cost, easily available materials for the adsorption of organics and nutrients (P, N.). Consequently, a number of low-cost, easily available materials are being studied for the removal of metals, dyes and nutrients from domestic or industrial wastewater at different operating conditions (Van Lier and Lettinga, 1999). Many studies have been conducted on the wastewater treatment or potable water treatment with depth filters, in which the packing material is an ensemble of fibers. Results have demonstrated that these filters are effective in removing organics, nutrients, particulate, and high metal species. In a study carried out in Tunisia(Riahi et al., 2008), results indicated that date palm fibers filtration removed 55% of turbidity, 80% of COD, 58% of phosphorous and 98% of helminth eggs. The date palm fibers filter could thus be a potential technology for tertiary domestic wastewater treatment.

2.7.1 Choosing a Technology

Choosing the most appropriate technology is not an easy task but it could reduce the risk of future problems and failures. The two key issues in choosing a treatment technology are affordability and appropriateness (Grau, 1996). Affordability relates to the economic conditions of the community while appropriateness relates to the environmental and social conditions. As such, the most appropriate technology is the technology that is economically affordable, environmentally sustainable and socially acceptable. The reasons for success or failure most often depend on the appropriateness of the implemented technology. At the present time, it is recognized that even in the developed world complete sewerage and treatment systems covering 100% of the population may never be possible to be implemented unless wastewater management is based on selecting the cost-effective technologies. Therefore, it is clear that cost for construction, operation and maintenance of a wastewater treatment plant will play a great role in wastewater management strategies in most parts of the world (Tsagarakis et al., 2002).

Environmentally sound development requires appreciation of local cultures, active participation of local peoples in development projects and the choice of appropriate technologies. Many factors fall under the economic aspect and are used to decide on the affordability of a system. The community should be fully involved in the implementation of the system, the operation and maintenance including the sourcing of capital improvement needed in the future, and the necessary long-term repairs and replacements (Bradley et al., 2002; Green et al., 2005). Hence, population density, location and the efficiency of the technology as compared to its cost should be considered. Reasonably, in sparsely populated areas decentralized systems may provide cost-effective solutions (Parkinson and Tayler, 2003). The affordability of centralized systems in such areas may be doubtful due to the high cost of the conventional sewer lines. Among the different components of a centralized wastewater treatment system, collection, which is the least important in terms of treatment, costs the most. An assessment of the cost effectiveness of the selected system should be undertaken taking into consideration the capital cost for planning, design and construction, the costs of operation and maintenance and the value of the land used.

For a system to be environmentally sustainable, it should ensure the protection of environmental quality, the conservation of resources, and the reuse of water as well as the recycling of nutrients (Green and Ho, 2005). Understanding the receiving environment is crucial for technology selection and should be accomplished by conducting a comprehensive site evaluation process (Jantrania, 1998). This evaluation determines the carrying capacity of the receiving environment. Various environmental components should be evaluated including but not limited to:-

- Surface and groundwater quality,
- Aquatic and land-based ecosystems, soil and air quality,

- Energy use.

2.8 Environmental and economic impact of wastewater reuse

Increasing efficiencies in crop management and the continuing increases in crop yields has increased demands on water resources for irrigation purposes. Effluents are reused for irrigation purposes in many countries around the world on all of the populated continents (USEPA, 2000). There are ranges of mechanisms that can be used to reduce the pressure on fresh water resources for irrigation use. One possible mechanism is the recycling of wastewaters and drainage water that can be used in the place of other fresh water sources for irrigation. Types of wastewaters used for recycling include treated and untreated sewage effluent (Shereif et al., 1995; Asano et al., 1996; Haarhoff and Van der Merwe, 1996), storm water runoff (Dillon et al., 1994; Asano et al., 1996,), domestic greywater (Anderson, 2003), and industrial wastewater (Asano and Levine, 1996; Guillaume and Xanthoulis, 1996). These different water types, however, can vary in quality and in the contaminants that could be potentially present. The quality and contaminants present will impact on the level of treatment required. This will in turn impact on the economic viability of reusing the various wastewaters.

The reuse of water is just one source of water that has potential for use in an agricultural setting. Reused water does, however, have a major advantage in that it is usually a constant and reliable supply, particularly with sources such as treated sewage effluent or industrial discharges. As well as being a constant source of water, many waters suitable for reuse are produced in large volumes, which if not used would be merely discharged into the environment. It is well known that discharge of effluents, treated or un-treated, into the environment, particularly natural water bodies such as lakes, rivers and the coastal marine environments can cause severe degradation of these water ways. The degradation is often related to the presence of organic and inorganic nutrients, which can cause problems such as eutrophication and algal blooms. Reusing these discharged effluents can have a significant impact on reducing or completely removing the impact of these effluents from receiving environments. In addition, the reuse of wastewaters for purposes such as agricultural irrigation reduces the amount of water that needs to be extracted from environmental water sources (USEPA, 2000; Gregory, 2000).

2.8.1 Risks associated with Wastewater Reuse

There have been a number of risk factors identified for using reused waters for purposes such as agricultural irrigation. Some risk factors are short term and vary in severity depending on the potential for human, animal or environmental contact (e.g., microbial pathogens) while others have longer term impacts which increase with continued use of recycled water (e.g., salinity effects on soil). Heavy metals are easily and efficiently removed during common treatment processes and the majority of heavy metal concentrations in raw sewage end up in the bio-solid fraction of the treatment process with very low heavy metal concentrations present in the treated effluents (Sheikh et al., 1987). Thus, heavy metals are of little concern for irrigation of crops when using treated effluents as a source of recycled water.

If the source for the recycled water is from an industrial source or is less treated than normal then the influence of heavy metals would need to be considered. Heavy metals that are present in effluents used for irrigation tend to accumulate in the soils where there is a potential that they could become bio-available for crops. Angelova et al. (2004) observed that fibre crops such as flax and cotton did take up heavy metals when grown in heavily contaminated soils, however the concentrations detected in the leaves and seeds were only a small percentage of the concentration present in the soil. Apart from heavy metals, most of the concern and public comments regarding trace contaminants revolve around pharmaceutically-active compounds (PhACs), endocrine disrupting compounds (EDCs) and disinfection-byproducts (DBPs). These PhACs and EDCs originate either from industrial or domestic sources while DBPs e.g. trihalomethanes, are byproducts usually formed from the chlorination during and post treatment of reused water.

While wastewater reuse for agriculture has many benefits, it should be carried out using good management practices to reduce negative human health impacts. The WHO initially published Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture in 1989 and later revised it as “Guidelines for the safe use of wastewater, excreta and grey water, volume 2: Wastewater Use in Agriculture” (WHO, 2006). The Guidelines are set to minimize exposure to workers, crop handlers, field workers and consumers, and recommend treatment options to meet the guideline values (WHO, 2006). The Guidelines are focused on health-based targets and provide procedures to calculate the risks and related guideline values for wastewater reuse in agriculture.

The ideal solution is to ensure full treatment of the wastewater to meet WHO (1989) guidelines, or any other relevant governmental regulations in force, prior to use. However, in practice, most cities in low income countries are not able to treat more than a modest percentage of the wastewater produced in the city, due to low financial, technical and/or managerial capacity. The rapid and unplanned growth of cities with multiple and dispersed wastewater sources makes the management more complex. In many cities a large part of the wastewater is disposed off untreated into rivers and seas, with all the related environmental consequences and health risks. For instance, the Nairobi sewage network covered 65% of the total area by 1995, but this had shrunk to about 55% by 2004 because of the rapid development of the city. In terms of population, only about 25% of the population in the city was serviced by the sewerage network with the rest of the population either using septic tanks or having no sewage facilities at all (Kilelu,2004). The perspectives regarding the increase in wastewater treatment capacity in these cities are bleak. It may safely be assumed that urban and peri-urban farmers increasingly will use wastewater for irrigation, irrespective of the municipal regulations and quality standards for irrigation water (Cofie et al., 2003).

Studies conducted in several developing countries have demonstrated the clear livelihood implications of wastewater irrigation while highlighting the human health and environmental impacts. Thus appropriate strategies for minimizing the risks and maximizing the benefits will contribute to the general well being of the farmers as well as the consumers of the farm products (Huibers et al., 2004; Geary, 1998). Some of the management options identified with partners and stakeholders include improved health safeguards, cropping restrictions, blending wastewater with freshwater, appropriate irrigation techniques, primary stabilization or other low-cost alternatives, and pollutant source management.

Wastewater reuse must meet certain controls. First, wastewater treatment to reduce pathogen concentrations must meet the WHO (1989) guidelines. Second, crop restrictions must be specified to prevent direct exposure to those consuming uncooked crops as well as defining application (irrigation) methods that reduce the contact of wastewater with edible crops. Finally, control of human exposure is needed for workers, crop-handlers and final consumers (Rose, 1999). Table 1 presents World Health Organization (WHO) guidelines on wastewater reuse in agriculture.

Table 1. WHO Guidelines for treated wastewater reuse in agricultural irrigation.

Reuse process	Intestinal nematodes (arithmetic mean no. of eggs per litre)	Fecal coliforms (geometric mean no. per 100ml)
Restricted irrigation	≤ 1	N/A
Unrestricted irrigation	≤ 1	≤ 1000

Source: WHO (1989).

The WHO guidelines give the allowable concentrations of pathogens in wastewater in order to use it for either restricted or unrestricted irrigation. Restricted irrigation refers to irrigation of crops not directly consumed by humans (*e.g.*, trees, fodder crops).Unrestricted irrigation refers to irrigation of vegetable crops eaten directly by humans, including those eaten raw, and also to irrigation of sports fields, public parks, hotel lawns, and tourist areas (Mara and Cairncross, 1989).

2.8.2 Irrigation with wastewater

Wastewater is often associated with environmental and health risks. As a consequence, its acceptability to replace other water resources for irrigation is highly dependent on whether the health risks and environmental impacts entailed are acceptable. It is therefore necessary to take precautions before reusing wastewater. As a result, although the irrigation of crops or landscapes with sewage effluents is in itself an effective wastewater treatment method, a more effective treatment is necessary for some pollutants and adequate water storage and distribution system must be provided before sewage is used for agricultural or landscape irrigation (Asano et al., 1996).

Recycled water has successfully irrigated a wide array of crops with a reported increase in crop yields from 10 to 30%. Studies done in Mexico showed yield increases of up to 150% for corn as shown in Table 2 (Jimenez, 2005). Other studies done in southern Italy with partially treated wastewater showed a yield increase of 50% with citrus (Lopez et al., 2005). It is worth noting, however, that the suitability of recycled water for a given type of reuse depends on water quality and the specific use requirements. Indeed, water reuse for irrigation conveys some risks for health and environment, depending on recycled water quality, recycled water application, soil characteristics, climate conditions, and agronomic practices.

Table 2. Increased productivity through wastewater irrigation in the Mezquital Valley.

Productivity(tones/ha)			
Crop	**Wastewater**	**Freshwater**	**Increase (%)**
Corn	5	2	150
Barley	4	2	100
Tomato	35	18	94
Forage Oats	22	12	83
Alfalfa	120	70	71
Chile	12	7	70
Wheat	3	1.8	67

Source: Jimenez (2005).

The main water quality factors that determine the suitability of recycled water for irrigation are pathogen content, salinity, sodicity (levels of sodium that affect soil stability), specific ion toxicity, trace elements, and nutrients(Lazarova and Bahri, 2004). All modes of irrigation may be applied depending on the specific situation. If applicable, drip irrigation provides the highest level of health protection, as well as water conservation potential (Capra and Scicolone, 2006). Technologies such as drip irrigation and zero tillage substantially reduce water needs and health risks and are suited for the urban environment and can indeed be found in many cities.

Wastewater intended for reuse should be treated adequately and monitored to ensure that it is suitable for the projected applications. If wastewater streams come from industrial sources and urban run-off, toxic chemicals, salts, or heavy metals in the wastewater may restrict agricultural reuse. Such materials may change soil properties, interfere with crop growth, and cause bioaccumulation of toxic materials in food crops (Jensen et al., 2001). While separating household wastewater and runoff from industrial effluent is preferable, this may not be feasible. Thus proper treatment and monitoring should be practiced.

2.9 Decision Support Methods

Decision support techniques are rational processes for applying critical thinking to information, data, and experience in order to make a balanced decision when the choice between alternatives is unclear. They provide organized ways of applying critical thinking skills developed around accumulating answers to questions about the problem. Steps include clarifying purpose, evaluating alternatives, assessing risks and benefits, and making a decision. These steps usually involve scoring criteria and alternatives. This scoring provides a common language and approach that removes decision making from the realm of personal preference or idiosyncratic behavior (Avramenko and Kraslawski, 2008).

Previous research work in decision support tools has mainly focused on tools that help in recognition of similar past design situations. The support systems are aimed at facilitation of wastewater treatment design process in order to reduce on the development time through reusing and modifying past similar cases (Avramenko et al., 2009; Gutierrez et al., 2003; Brennecke et al., 2002).

Depending on type of information used and way of achieving result (decision-making), the design supporting methods can be distinguished on three major approaches, namely, Algorithmic, Knowledge-based inductive reasoning, and Case-based reasoning. First approach relies on specific procedure that transforms input to certain output; second method deals with generalized domain knowledge to make a decision; third approach considers exemplary knowledge of designs.

2.9.1 The ED –WAVE Tool

ED-WAVE is an educational tool for training on wastewater treatment technologies which is organized in a conventional way (Balakrishnan et al., 2005). It has separate

elements for the passive data part and the active program part. The data part of the tool includes the base of past cases of wastewater treatment and the database of technologies applied to wastewater treatment. The active part of the system is composed of four modules, namely; Database Manager (also called the Reference Library), Case Study Manager, Treatment Adviser and Process Builder (Avramenko and Kraslawski, 2008).
A schematic layout of the ED-WAVE tool is shown in Fig.9.

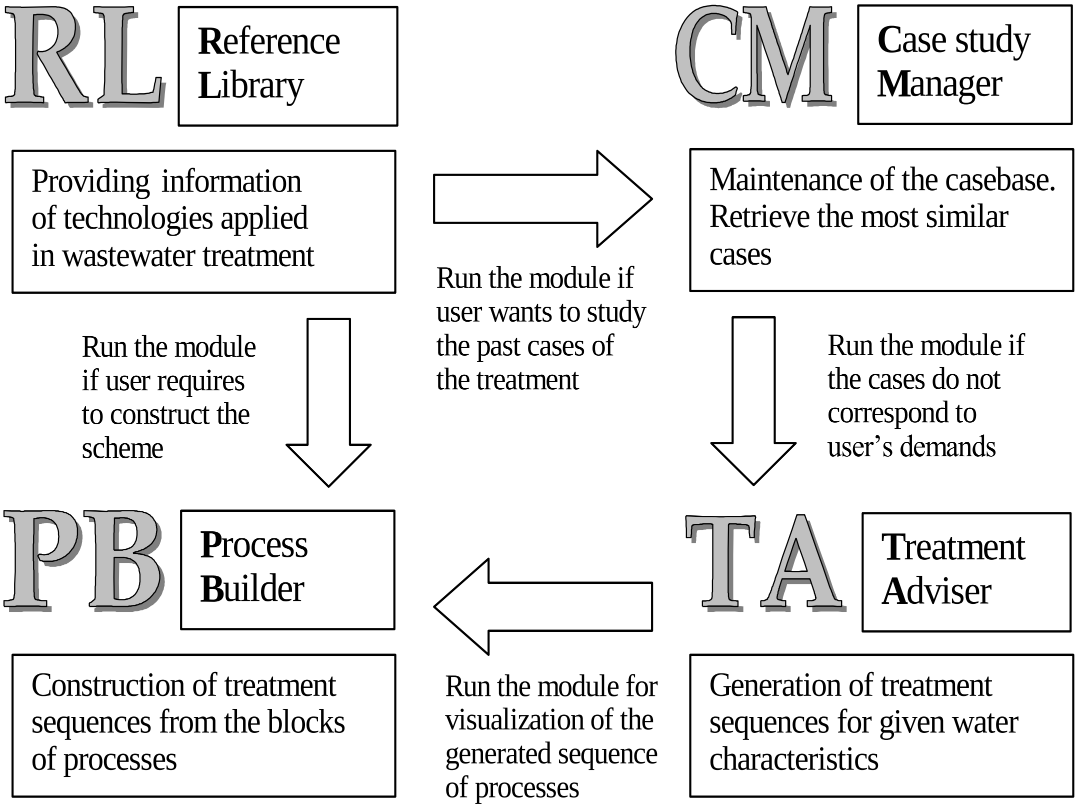
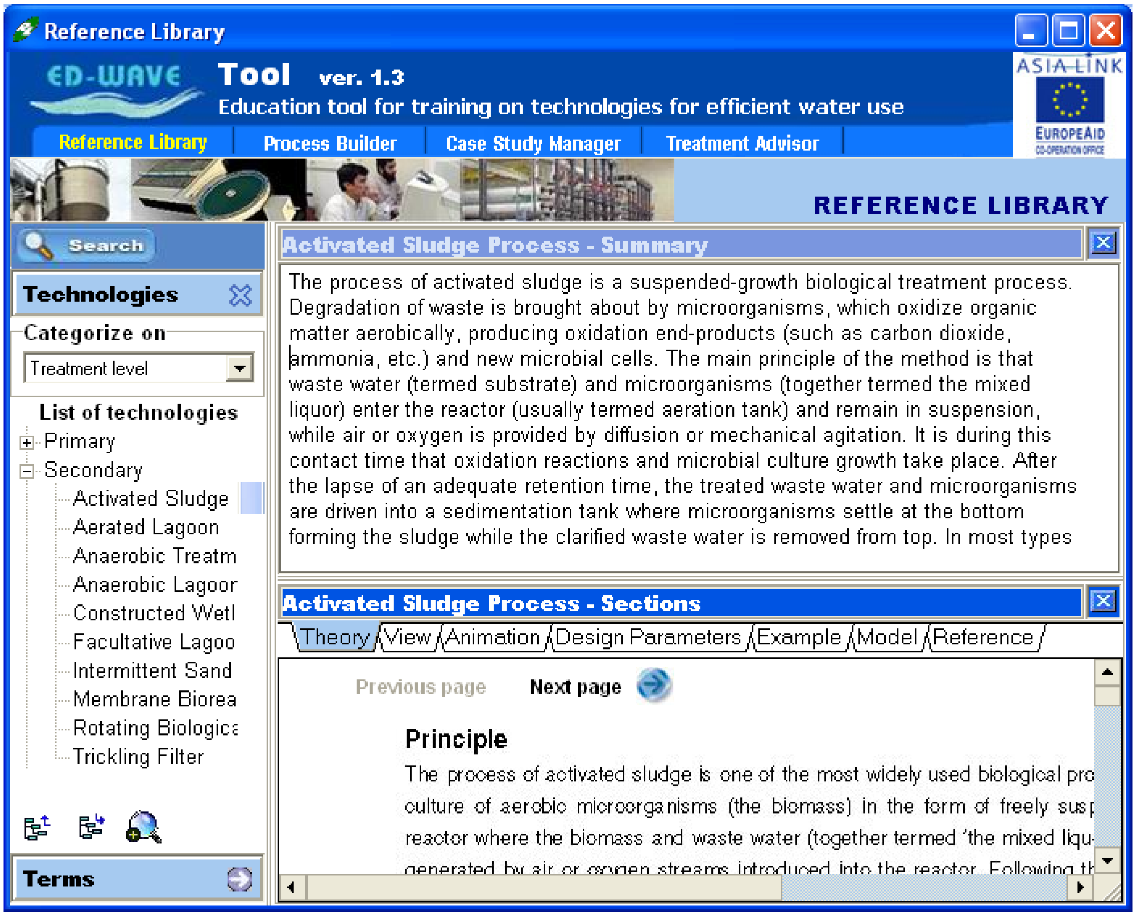


Figure 9. The structure of ED-WAVE tool.

2.9.1.1 Reference Library (Database Manager)

The Reference Manager, Figure 10, is able to navigate on overall data collections, i.e. treatment system case base, technology base, equipment data base and treatment methods base. However the interface is specially designed to work with the technology base.

The purpose of the reference Library (RL) is to provide the user with a comprehensive overview of processes and operations used for wastewater treatment through visualization of real life units. The general description of the wastewater treatment technology is supplemented by the theoretical background as well as worked out examples and an Excel spreadsheet model. The user can modify the selected parameters in the spreadsheet to understand their effect on the unit performance.



The process of activated sludge is a suspended-growth biological treatment process. Degradation of waste is brought about by microorganisms, which oxidize organic matter aerobically, producing oxidation end-products (such as carbon dioxide, ammonia, etc.) and new microbial cells. The main principle of the method is that waste water (termed substrate) and microorganisms (together termed the mixed liquor) enter the reactor (usually termed aeration tank) and remain in suspension, while air or oxygen is provided by diffusion or mechanical agitation. It is during this contact time that oxidation reactions and microbial culture growth take place. After the lapse of an adequate retention time, the treated waste water and microorganisms are driven into a sedimentation tank where microorganisms settle at the bottom forming the sludge while the clarified waste water is removed from top. In most types

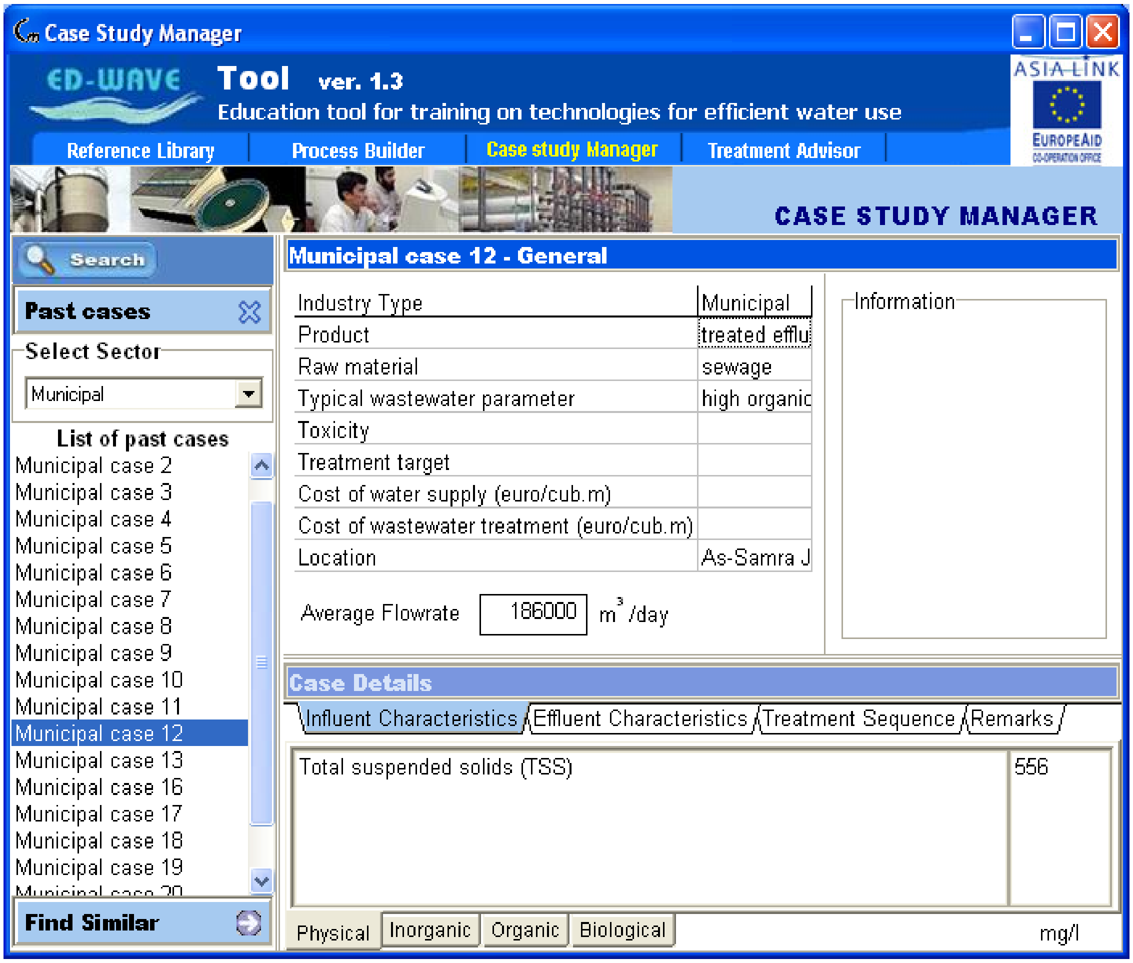
Principle

The process of activated sludge is one of the most widely used biological pro
culture of aerobic microorganisms (the biomass) in the form of freely sus
reactor where the biomass and waste water (together termed 'the mixed liqu
generated by air or oxygen streams introduced into the reactor. Following th

Figure 10. Reference Library.

2.9.1.2 Case Study Manager (Case Based Reasoner)

The Case Study Manager, Figure 11, accumulates the specific design experience contained in real cases and tries to reuse it when solving new user's problems. The manager performs the retrieval of the most similar cases to the current problem from the case base containing the past situations of wastewater treatment. It utilizes the case-based reasoning approach in solving new design task.



Select Sector: Municipal

List of past cases
- Municipal case 2
- Municipal case 3
- Municipal case 4
- Municipal case 5
- Municipal case 6
- Municipal case 7
- Municipal case 8
- Municipal case 9
- Municipal case 10
- Municipal case 11
- Municipal case 12
- Municipal case 13
- Municipal case 16
- Municipal case 17
- Municipal case 18
- Municipal case 19
- Municipal case 20

Municipal case 12 - General

Industry Type	Municipal
Product	treated efflu
Raw material	sewage
Typical wastewater parameter	high organic
Toxicity	
Treatment target	
Cost of water supply (euro/cub.m)	
Cost of wastewater treatment (euro/cub.m)	
Location	As-Samra J

Average Flowrate 186000 m^3/day

Information

Total suspended solids (TSS)	556

mg/l

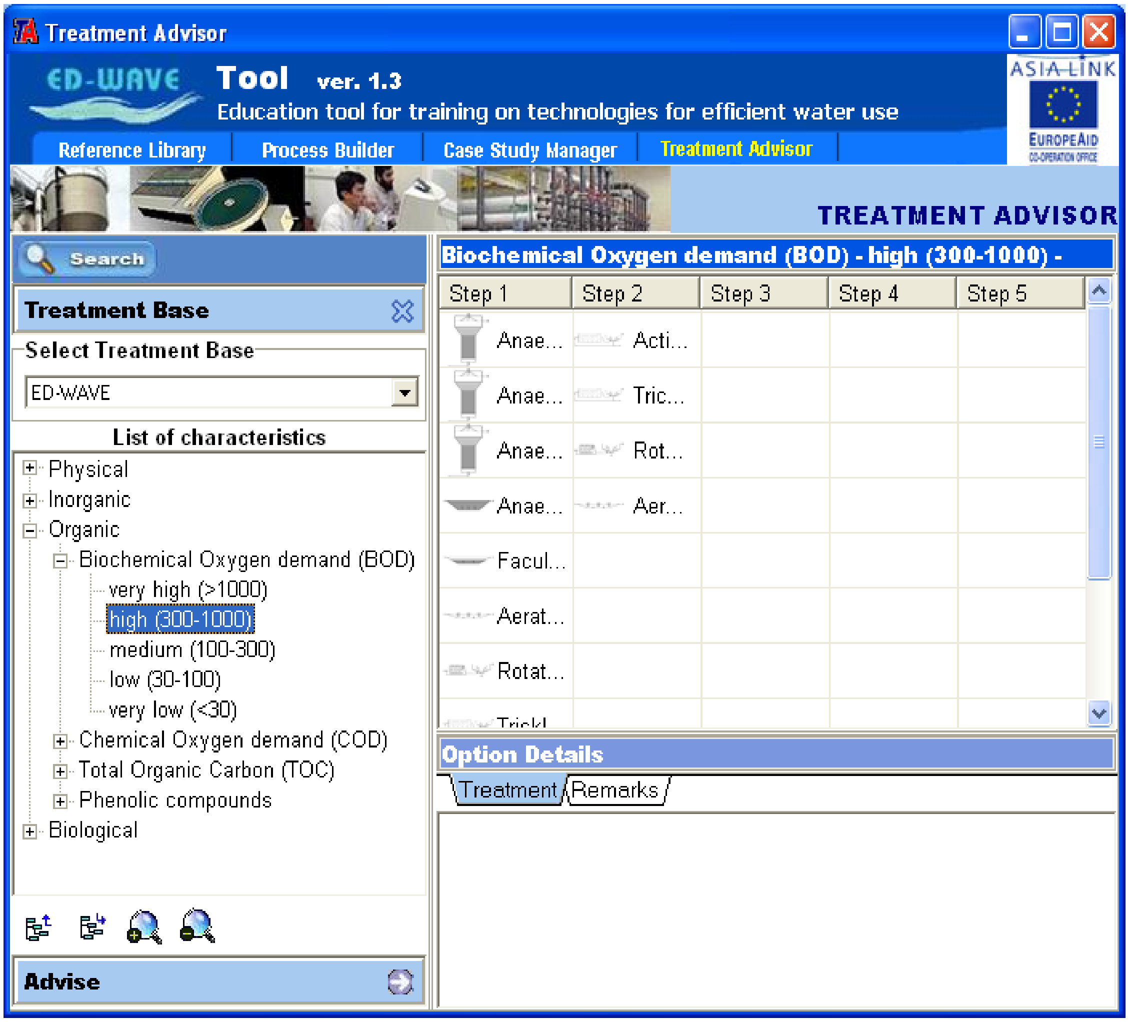
Figure 11. Case Study Manager.

2.9.1.3 Treatment Builder

Treatment builder is able to construct the treatment sequence for wastewater with specific characteristics based on basic principles and the heuristics. It supplements the

Case study Manager in decision support of design of wastewater treatment systems. The builder has two components; treatment adviser (TA) and process builder (PB).

i) The treatment adviser (TA), Figure 12, generates a simple sequence of treatment technologies for a given wastewater characteristics. It analyses the influent water characteristics and selects the method of treatment. The algorithm of selection is based on the search among the water parameters, so called harmful factors that have to be eliminated. The factors are determined by specific set of wastewater characteristics. Each harmful factor can be treated by a number of wastewater treatment technologies that are capable of removing the factor from wastewater. The stream may contain a number of harmful factors that can be processed by many sets of treatment methods.



Select Treatment Base: ED-WAVE

Biochemical Oxygen demand (BOD) - high (300-1000) -

Step 1	Step 2	Step 3	Step 4	Step 5
Anae...	Acti...			
Anae...	Tric...			
Anae...	Rot...			
Anae...	Aer...			
Facul...				
Aerat...				
Rotat...				
Trickl				

Figure 12. **Treatment Advisor.**

ii) The process builder, Figure 13, (PB) has the ability to construct the treatment sequence from the blocks. Each of the blocks represents a type of the treatment processes or specific part of the process. Blocks can be linked according to internal restrictions, rules and locations of connection points. When two or more blocks have been connected, flow animation or process visualization occurs. The main purpose of this component is to display a treatment sequence generated by the TA.

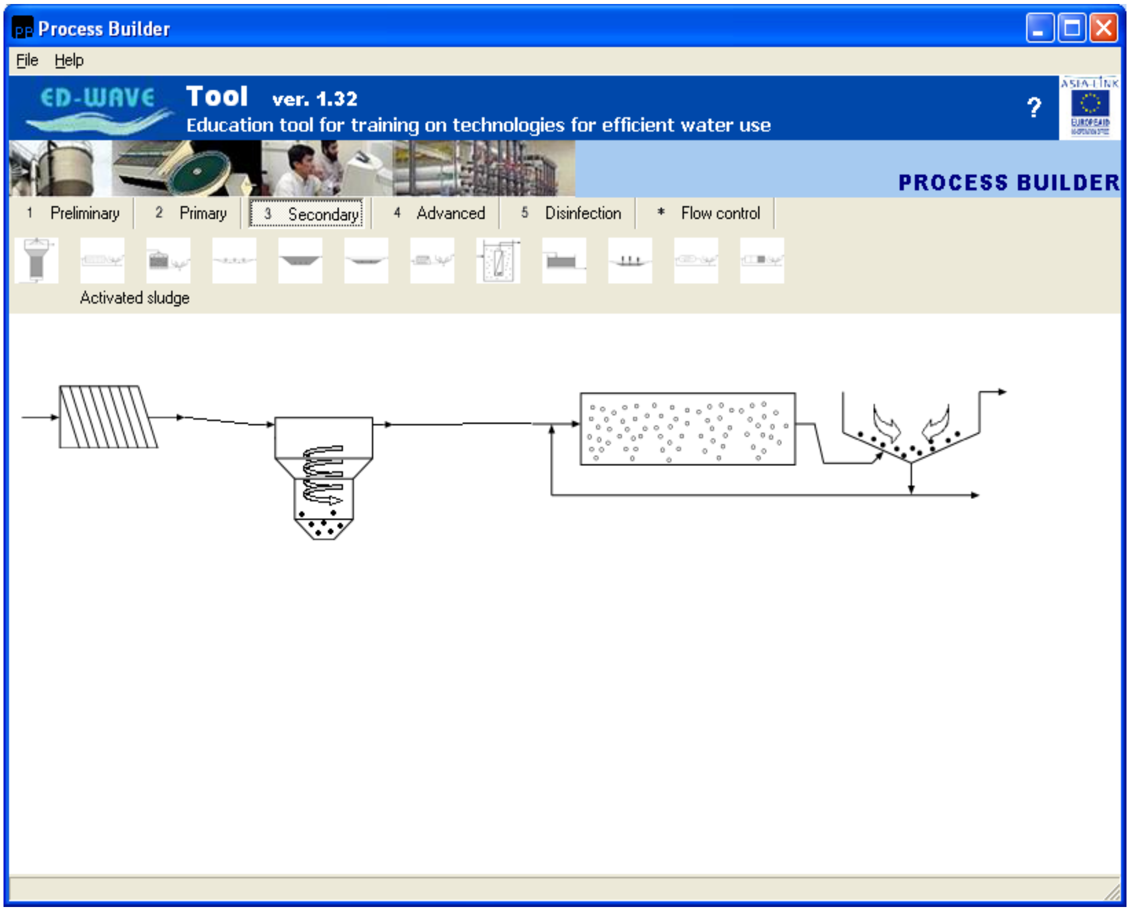
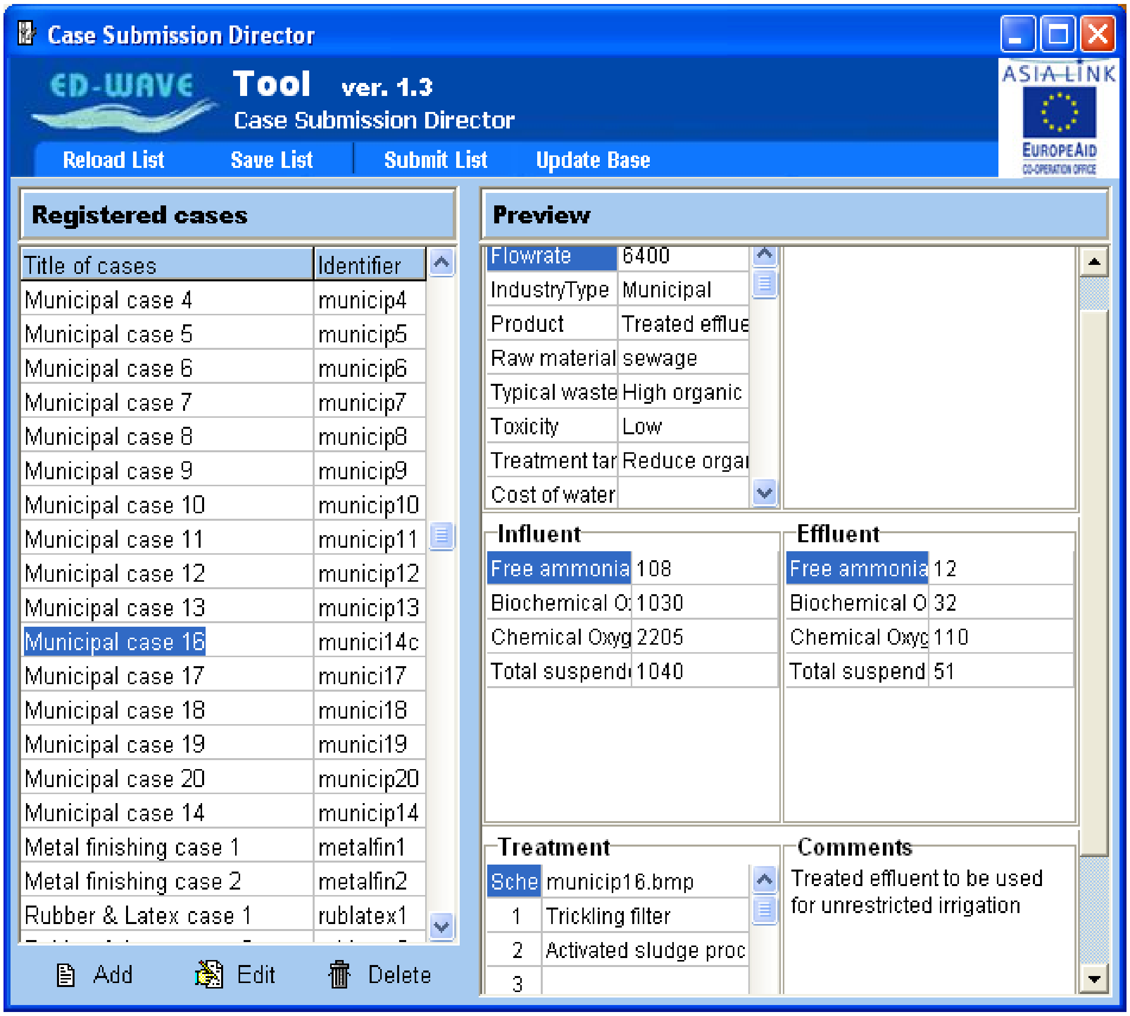


Figure 13. **Process Builder.**

2.9.1.4 Case submission director

The case submission director, Figure 14, allows for the addition of more wastewater data into the case data bank. The data bank is used for case based reasoning where new problems are solved by drawing on earlier experiences.



Title of cases	Identifier
Municipal case 4	municip4
Municipal case 5	municip5
Municipal case 6	municip6
Municipal case 7	municip7
Municipal case 8	municip8
Municipal case 9	municip9
Municipal case 10	municip10
Municipal case 11	municip11
Municipal case 12	municip12
Municipal case 13	municip13
Municipal case 16	munici14c
Municipal case 17	munici17
Municipal case 18	munici18
Municipal case 19	munici19
Municipal case 20	municip20
Municipal case 14	municip14
Metal finishing case 1	metalfin1
Metal finishing case 2	metalfin2
Rubber & Latex case 1	rublatex1

Flowrate	6400
IndustryType	Municipal
Product	Treated efflue
Raw material	sewage
Typical waste	High organic
Toxicity	Low
Treatment tar	Reduce orgai
Cost of water	

Influent

Free ammonia	108
Biochemical O:	1030
Chemical Oxyg	2205
Total suspend	1040

Effluent

Free ammonia	12
Biochemical O	32
Chemical Oxyc	110
Total suspend	51

Treatment

Sche	municip16.bmp
1	Trickling filter
2	Activated sludge proc
3	

Comments

Treated effluent to be used for unrestricted irrigation

Figure 14. Case submission director.

2.9.2 Fuzzy based Decision Support Method

Fuzzy logic is an important technology dealing with vague, imprecise and uncertain knowledge and data. The logic is concerned with the use of fuzzy values that capture the meaning of words, human reasoning and decision making. As a method to encode and apply human knowledge in a form that accurately reflects an expert's understanding of difficult, complex problems, fuzzy logic provides the way to break through the computational bottlenecks of traditional expert systems. At the heart of fuzzy logic lies the concept of a linguistic variable. The values of the linguistic variable are words rather than numbers.

Fuzzy logic provides a language with a syntax and semantics to translate qualitative knowledge into numerical reasoning. In most engineering problems, information about the probabilities of various risk items is only vaguely known. The term *computing with words* has been introduced by Zadeh (1996) to explain the notion of reasoning linguistically rather than with numerical quantities. Such reasoning has central importance for many emerging technologies related to engineering and the sciences. This approach has proved very useful in medical diagnosis (Lascio et al., 2002), information technology (Lee, 1996), water quality (Lu et al., 1999), reliability analysis (Sadiq et al., 2003) and many other industrial applications (Lawry, 2001), where reported data are either qualitative or decision-making is performed based on expert opinions.

In fuzzy rule-based modeling, the relationships between variables are represented by means of fuzzy *if– then* rules of the form "***If*** antecedent proposition ***then*** consequent proposition". The antecedent proposition is always a fuzzy proposition. We can view *information* as that which resolves uncertainty, and *decision making* is the progressive resolution of *uncertainty* and is a key to a purposeful behavior by any mechanism (Berson and Smith, 1998).An intelligent agent should demonstrate an ability to perform reasoning and support decision making under uncertainty.

Fuzzy logic, when applied to decision-making problems, provides formal methodology for problem solving, and incorporates human consistency, which are important characteristics required by fuzzy decision-making systems. Such systems should possess the following functionality:

(a) Explain the solution to the user.

(b) Keep a rigorous and fair way of reasoning.

(c) Accommodate subjective knowledge.

(d) Account for "grayness" in the solution process.

Rule based reasoning is grounded in qualitative knowledge representation and fuzzy logic allows us to mesh a quantitative approach with a qualitative representation. It is used to quantify certain qualifiers such as; very high, moderate, excellent. Nevertheless it is not a substitute for statistics. Indeed fuzzy logic is used when statistical reasoning is inappropriate. Statistics is used to express the extent of knowledge about a value and relies on tools such as variance, standard deviation and confidence intervals. However fuzzy logic is used to express the absence of a sharp boundary between sets of information (Jantzen, 2007; Ross, 2004).

The main weak point in the application of fuzzy logic is the fuzzy inference. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions are taken. The process of fuzzy inference involves membership functions, fuzzy logic operators and rules. There are no strong grounds for preferring one membership function to another. The way in which these membership functions are built is crucial in the performance and the results of fuzzy logic expert system (Manesis et al., 1998)

2.9.3 The Analytic Hierarchy Process (AHP)

Developed by T.L. Saaty, the Analytic Hierarchy Process (AHP) is a multi-criteria method for dealing with complex decision making problems in which many competing alternatives exist (Saaty, 2008). The alternatives are ranked using several quantitative and/or qualitative criteria, depending on how they contribute in achieving an overall goal. AHP is based on a hierarchical structuring of the elements that are involved in a decision problem. The hierarchy incorporates the knowledge, the experience and the intuition of the decision- maker for the specific problem. The evaluation of the hierarchy is based on pairwise comparisons. The decision-maker compares two alternatives A_i and A_j using a criterion and assigns a numerical value to their relative weight. The result of the comparison is expressed in a fundamental scale of values ranging from 1 (A_i, A_j contribute equally to the objective) to 9 (the evidence favouring A_i over A_j is of the highest possible order of affirmation). Given that *n* elements of a level are evaluated in pairs using an element of the immediately higher level, an *n* * *n* comparison matrix is obtained (Fig. 15).

K	A1	A2 ………..An
A1	1	a12………. a1n
A2	1/a12	1…………a2n
:	:	: :
:	:	: :
An	1/a1n	1/a2n…….. 1

Figure 15. **Pairwise comparisons matrix A of alternatives Pi with respect to criterion K.**

2.9.4 Fuzzy Extension of the AHP (FAHP)

In the fuzzy extension of the AHP, the weights of the nine level fundamental scale of judgments are expressed via the triangular fuzzy numbers (TFN) in order to represent the relative importance among the hierarchy's criteria (Zhu et al., 1999).

Table 3 presents the fuzzy scale of preferences in AHP showing how the linguistic variables used to describe how the relative importance of wastewater indicators was scored.

Table 3. Fuzzy scale of preferences.

Linguistic Variables	**Crisp AHP scale**
Equally Important	1
Equally to Moderately Important	2
Moderately Important	3
Moderately to Strongly Important	4
Strongly Important	5
Strongly to Very Strongly Important	6
Very Strongly Important	7
Very Strongly to Extremely Important	8
Extremely Important	9

A triangular fuzzy number(TFN) is fully characterized by a triple of real numbers (l, m, u), where parameter m gives the maximal grade of the membership function $\mu(x)$, and parameters l and u are the lower and upper bounds which limit the field of the possible evaluation.

$$\mu(x) = \begin{cases} (x - l)/(m - l) & x \in [l, m] \\ (u - x)/(u - m) & x \in [m, u] \\ 0 & \text{otherwise} \end{cases}$$

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Introduction

In order to develop the decision support method, criteria for evaluating performance of wastewater treatment technologies were first developed. The criteria considered the effectiveness of various technologies when measured against both environmental and economic wastewater indicators. Wastewater treatment technologies that were investigated were the secondary biological treatment processes such as activated sludge process, trickling filter, rotating biological contactors, waste stabilization ponds, constructed wetlands, land treatment and septic tank. These are the main technologies employed for wastewater treatment especially in developing countries (Muga, 2007; Volkman, 2003; von Sperling et al., 2001).

Environmental indicators measure resource utilization and performance of technology in removing or reducing conventional wastewater constituents. Wastewater environmental indicators used to gauge performance were biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), fats, oils & grease(FOG), nitrogen and phosphorous(nutrients), pathogens and heavy metals. On the other hand, economic indicators determine the affordability of a particular technology to a community. Economic indicators considered were energy and land requirements, capital costs, operation and maintenance costs, hydraulic retention time and sludge generation.

Data on wastewater concentrations and performance efficiencies of treatment technologies were obtained from literature sources and analysed. The data collected targeted water scarce regions such as the Mediterranean countries of Tunisia, Morocco, Egypt and Jordan. Both influent and effluent concentration data were classified from the highest (extreme) to the lowest (traces) using fuzzy logic in form of linguistic variables to denote the class of concentration. Fuzzy computation rules were used to express the absence of a sharp boundary between sets of information. Due to fluctuations in organic and hydraulic loading in a wastewater treatment plant, the application of fuzzy logic, using linguistic variables gave a better description of performance parameters. Technology performance efficiency reflected level of expected achievement in the removal of wastewater characteristics. This was expressed as a ratio of wastewater effluent concentration to influent concentration.

3.2 Data on wastewater concentrations

Data were documented from literature sources on concentrations of the various municipal wastewater characteristics. These were the important wastewater indicators when it came to reuse considerations or discharge of wastewater to other water bodies. The data were analysed and tabulated for each characteristic in classes of concentrations from the highest to the lowest concentration using linguistic variables to denote the range of concentrations.

Table 4 presents data format on concentrations of important indicators in wastewater grouped in seven classes from extreme concentration to traces.

Table 4. Presentation format on concentrations of important wastewater indicators.

Concentration ranges	**E (extreme)**	**G (grand)**	**H (high)**	**M (medium)**	**L (low)**	**S (small)**	**T (traces)**
Wastewater indicators	**Concentrations**						
Total solids (TS)							
Total suspended solids (TSS)							
Volatile suspended solids (VSS)							
Total volatile solids (TVS)							
Turbidity, NTU							
Free ammonia							
Total Nitrogen							
Biochemical Oxygen demand (BOD)							
Chemical Oxygen demand (COD)							

As shown in Table 4, the highest concentration for all indicators was denoted by the linguistic term extreme while the lowest was denoted by traces. Thus linguistic variables replaced numerical figures in describing the concentration levels of the various wastewater indicators.

3.3 Development of technology performance rating criteria

Rating criteria was based on analysis of technology performance data. For environmental indicators, the criterion was based on the degree of reduction between influent and effluent wastewater concentration. This degree of reduction was dependent on performance efficiency rating of a technology.

For purposes of rating treatment technology performances, six rating categories were adopted, ranging from excellent performance to very poor performance. A score was then assigned to each category which enabled a comparison of technologies to be made. From a number of scales that had been proposed in literature, the one according to Zhu (Anagnostopoulos et al., 2007) was adopted. A scale of values ranging from 0(very poor performance) to 9(excellent performance) was selected to denote score awarded for various performance levels of treatment technologies. Table 5 presents the ratings that were adopted for evaluation of technology performance and corresponding scores. Influent wastewater environmental indicators were classified according to their concentrations from very high (grand) to lowest (traces).Thus for a treatment technology to be rated as having excellent performance, about 75% of the influent wastewater environmental indicators had their higher concentrations lowered by three levels e.g. from grand concentration to low or high to small concentration. In the moderate classification, almost 70% of the wastewater indicators had their concentrations reduced and this degree of performance rating was assigned a score of 3. Very poor technology performance rating resulted in no change between influent and effluent concentrations and a score of zero was assigned. Treatment technologies were also rated on their performance regarding economic indicators based on utilization of resources.

Table 5. Treatment technology performance rating and scoring criteria.

Technology Performance rating	**Achievable degree of reduction in level of concentration between influent and effluent wastewater**	**Assigned score to performance , C_j**
Excellent performance	Resulted in about 75% of influent wastewater indicators attaining a 3 level reduction in higher concentrations	9
High	Resulted in about 75% of influent wastewater indicators attaining a 2 level reduction in higher concentrations	7
Good	Resulted in 75% of influent wastewater indicators attaining a 1 level reduction in higher concentrations	5
Moderate	Resulted in 70% of influent wastewater indicators attaining some reduction in concentration	3
Poor	Resulted in 30% of influent wastewater indicators attaining some reduction in concentration	1
Very poor	Resulted in no reduction in influent concentration	0

3.4 Performance Evaluation

3.4.1 Performance evaluation on environmental indicators

After developing the rating criteria for technologies and wastewater influent classified into six concentration ranges, between grand and traces, a performance evaluation was done. In order to carry out the evaluation, wastewater concentration data were applied to treatment technologies and the resulting effluent classified into the same concentration classes as influent. Treatment technologies were also evaluated on their performance efficiencies in reduction of influent wastewater characteristics.

Data manipulation was done in MS Excel environment using linguistic variables to denote technology performance rating and wastewater concentration.

3.4.2 Performance evaluation on wastewater economic indicators

Data on technology performance against wastewater economic indicators was evaluated and results presented in fuzzy linguistic variables. Economic indicators considered were energy and land requirements, capital costs, operation and maintenance costs, hydraulic retention time, effluent reuse potential for agriculture, and sludge generation. Performance data obtained expressed how each of the treatment technologies performed when evaluated against economic indicators. For instance a technology that required a lot of energy for treatment purposes or had high capital costs was rated poorly. Conversely, low energy requirements resulted in high rating of a technology.

3.4.3 Weights of importance for indicators

Environmental and economic wastewater indicators were weighted depending on their relative degree of importance in determining agricultural reuse potential of treated wastewater. Degrees of importance of wastewater indicators were grouped into six categories from extremely important to not important and a scale of values ranging from 0 to 9 used to denote weight of importance. Table 6 presents weights of relative importance attached to wastewater indicators. In this study, the importance of wastewater reuse for agriculture was considered. Other reuse considerations which could have been considered include:-

i) Groundwater recharge

ii) Industrial use

iii) Discharge into water bodies

iv) Reuse for recreation purposes

Table 6. Weights attached to relative importance of wastewater indicators.

Wastewater indicator degree of importance	**Assigned weight, W_i**
Extremely important	9
Very important	7
Moderately important	5
Marginally important	3
Least important	1
Not important	0

An indicator whose degree of importance was rated as extremely important had the weight of 9 assigned to it. This implied that efficient and effective removal of such an indicator from wastewater was a prerequisite for reuse. Relative importance of wastewater indicators was rated and corresponding weights assigned.

3.4.4 Overall technology performance

Overall performance of technology was defined as the product of summation of grade of performance rating and weighted importance of characteristics divided by the summation of weights of importance, as expressed in equation 2.

$$O_R = \frac{\sum c_j w_i}{\sum w_i} \qquad (2)$$

where,

O_R = Overall technology performance rating

C_j = Graded value of technology performance rating

W_i = Weighted value of degree of importance for indicator

The numerical value obtained was then converted to a linguistic variable and the technology rated on its overall performance. The treatment technology under consideration could be one unit e.g. a septic tank or series of units such as a septic tank in combination with constructed wetlands.

3.5 Validation of Decision Support Method

Validation of the decision support method was done through the application of past cases in the ED-WAVE tool and field collected data from Nairobi, Nakuru and Thika wastewater treatment plants. The ED-WAVE tool has modules that support decision making in wastewater treatment. One such module, Case Study Manager, accumulates specific design experience contained in real cases and tries to reuse it when solving new user's problems. Data contained in the case studies in ED-WAVE were on environmental indicators. Other literature sources were used to validate data on economic performance of the technologies. The validation was done in order to compare technology performance results as predicted in the decision support method and actual results obtained from case study data in the ED-WAVE tool and data collected from the field. For conformity and reliability of results, it was important to compare wastewater data from similar sources or with similar characteristics. In this research work, municipal wastewater was the main considered source.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Performance of wastewater treatment technologies

4.1.1 Data on wastewater concentrations

Table 7 presents influent wastewater concentration data classified into six classes ranging from grand concentration to traces as obtained from literature sources.

The various municipal wastewater indicators had different influent concentration values. Taking two wastewater indicators as an illustration, total dissolved solids (TDS) concentration in influent wastewater ranged from 1000 - 2000mg/l in the grand class to zero while for chemical oxygen demand (COD), influent concentration ranged from 1500 - 3000mg/l in grand class to zero in traces.

Table 7. Concentrations of influent wastewater indicators (mg/l).

Concentration classes and values	**Grand(G)**	**High(H)**	**Medium(M)**	**Low(L)**	**Small(S)**	**Traces(T)**
Wastewater characteristics						
Total dissolved solids (TDS)	1000 - 2000	600 -1000	300 - 600	100 - 300	10 - 100	0 - 10
Total suspended solids (TSS)	500 - 1000	350 - 500	100 - 350	30 - 100	3 - 30	0 - 3
Total Nitrogen	200 - 400	100 - 200	20 - 100	5 - 20	0.5 - 5	0 - 0.5
Total Phosphorous	100 - 200	20 - 100	5 - 20	1 - 5	0.1 - 1	0 - 0.1
Nitrate- N	200 - 400	50 - 200	10 - 50	1 - 10	0.1 - 1	0 – 0.1
Potassium (K)	100 - 200	50 - 100	20 - 50	1 - 20	0.1 - 1	0 - 0.1
Copper (Cu)	100 - 200	10 - 100	1 - 10	0 - 1	0.0 - 0	0.0
Iron (Fe)	500 - 1000	100 - 500	5 - 100	1 - 5	0.1 - 1	0 - 0.1
Biochemical Oxygen demand (BOD)	1000 - 2000	300 - 1000	100 - 300	30 - 100	3 - 30	0 - 3
Chemical Oxygen demand (COD)	1500 - 3000	500 - 1500	250 - 500	50 - 250	5 - 50	0 - 5

4.1.2 Data on Performance efficiencies

The wastewater treatment technologies performance efficiencies are presented in Table 8. The efficiencies gave an indication of the expected degree of removal of various municipal wastewater characteristics during treatment process. Taking activated sludge process (ASP) as an example, the technology was able to attain 85-95% reduction in BOD concentration, 90% reduction in COD, 85-95% in TSS, 99.9% in bacteria and 84% in fats, oils & grease(FOG). The corresponding values for a septic tank were 30-35% reduction in BOD, 25-35% in COD and 55-65% in TSS concentration.

Table 8. Wastewater treatment technologies performance efficiencies (%).

	BOD	**COD**	**TSS**	**Bacteria**	**NH_4-N**	**TN**	**TP**	**Turbidity**	**FOG**
Technology									
Activated Sludge process(ASP)	85-95	90	85-95	99.9					84
Rotating Biological Contactors(RBC)	80-90	75-85	80-90	80-90		20-35	10-30		
Waste Stabilization Ponds(WSP)									
Anaerobic Ponds(AP - depth 5-6m)	50-60								
Facultative Ponds(FP- depth1-2m)	70		40-50	60-70					
Maturation Ponds(MP)	80			70-80		80-90	80-90		
AP+ FP+ MP	75-85	70-80	40-80	99.9-99.99		40-80	30-60		
Constructed Wetland(CW)									
Free Water Surface flow(FWS)	76		65			60	47		
Vertical sub-surface flow(VF)	88	79	77	98	79	44	48		
Imhoff tank+ CW	80-90	75-85	80-90	99-99.99		35-50	20-35		
WSP+CW(planted HF)									
Low filtration rate(0.27m/h)		66	80	90				58	
High filtration rate(2.3m/h)		50	50	28				38	
Trickling Filter(TF)									
low hydraulic loading rock filter	80-90			90-95					
Anaerobic Pond+Trickling Filter	80-90	75-85	80-90	80-90		20-35	10-35		
Septic tank(ST)	30-35	25-35	55-65			5-14	11-27		
Intermittent Sand filter									
Depth of filter material									
65cm	85	57	75		90	78			
25cm	76	42	63		82	68			
Land treatment(irrigation/infiltration)	98		98			85	95		

NH_4-N – ammonia nitrogen; TP- total phosphorous; TN-total nitrogen;

4.1.3 Rating of technology performance efficiency

Wastewater treatment technologies were rated depending on the degree of reduction of the various environmental wastewater characteristics. Performance efficiency was used as a gauge to rate technologies. Thus a technology achieving efficiency above 96% in the removal of wastewater indicators was rated as having an excellent performance while a technology achieving a removal efficiency of less than 50% was rated as very poor in performance. Technology performance rating was combined with efficiency rating and results presented in Table 9.

Table 9. **Treatment technology performance efficiency ratings.**

Performance rating	**Achievable performance efficiency level (%)**	**Achievable degree of reduction in level of concentration between influent and effluent wastewater**	**Assigned performance score**
Excellent(E_{xc})	97 - 100	75% of influent wastewater indicators attained a 3 level reduction in final concentration	9
High(H_h)	91 – 96	75% of influent wastewater indicators attained a 2 level reduction in final concentration	7
Good(G_d)	71 – 90	75% of influent wastewater indicators attained 1 level reduction in final concentration	5
Moderate(M_d)	59 -70	70% of influent wastewater indicators attained some reduction in concentration	3
Poor(P)	50 – 58	30% of influent wastewater indicators attained some reduction in concentration	1
Very poor(VP)	Less than 50	No noticeable reduction between influent and effluent wastewater concentration	0

4.2 Treatment Technology Evaluation

4.2.1 Performance evaluation on environmental indicators

Wastewater treatment technologies were evaluated and rated on environmental indicators. The basis of this evaluation was performance efficiency of technologies presented in Table 8 and ratings as presented in Table 9. Each technology was rated depending on its performance in reducing concentration of various wastewater indicators between influent and effluent.

Table 10 presents evaluation results for wastewater treatment technologies as to the expected performance in reduction of influent wastewater environmental indicators.

Performance rating of technologies determined degree of removal for the various wastewater indicators and hence reuse potential of treated wastewater. Considering, for instance a technology like activated sludge process (ASP), the rating of the technology in removal of BOD, COD and TSS was high. For bacteria and nitrogen removal, ASP was rated as moderate while it was rated as poor in removal of phosphorous. The results of Table 10 could hence be used as a basis in technology selection.

Table 10. Technology performance rating on environmental indicators.

Technology	BOD removal	COD removal	TSS removal	Bacteria removal	Metals removal	Ammonia-N removal	TN removal	TP removal
Activated Sludge process(ASP)	high	high	high	moderate	poor	moderate	moderate	poor
Rotating Biological Contactors(RBC)	good	good	good	good	good	good	poor	Very poor
Trickling Filter + Activated Sludge Process	high	high	high	high	good	moderate	good	moderate
Waste Stabilization Ponds(WSP)								
Anaerobic Ponds(AP - depth 5-6m)	moderate	moderate	poor	Very poor	moderate	poor	poor	poor
Facultative Ponds(FP- depth1-2m)	moderate	moderate	poor	moderate	moderate	moderate	poor	poor
Maturation Ponds(MP)	moderate	moderate	poor	good	good	high	high	moderate
AP+ FP+ MP	good	good	moderate	high	good	good	high	good
Imhoff tank	poor	poor	poor	poor	Very poor	poor	poor	poor
UASB reactor	moderate	moderate	moderate	poor	Very poor	poor	poor	poor
Intermittent Sand filter	good	poor	good	moderate	moderate	good	good	moderate
Land treatment(irrigation/infiltration)	excellent	high	excellent	good	high	good	good	High

4.2.2 Performance evaluation on economic indicators

Again, wastewater technologies were evaluated on performance against economic indicators. Evaluation of economic indicators was relative depending on comparable costs associated with other technologies employed in wastewater treatment in a given region. Table 11 presents technology performances against economic indicators which determine economic viability of selected technology.

Performance ratings on wastewater economic indicators also determine affordability of a particular treatment technology to a community in comparison to other available technologies.

Table 11. Technology performance rating on economic indicators.

Technology	Rating on Capital Cost/m^3	Rating on O & M*	Sludge generation	Effluent reuse for agric*	Rating on Energy reqms*	Rating on Land reqms
Activated Sludge process(ASP)	poor	poor	low	High	poor	high
Rotating Biological Contactors(RBC)	moderate	moderate	low	High	moderate	high
Trickling Filter + Activated Sludge Process	Very poor	Very poor	Very low	High	Very poor	high
Waste Stabilization Ponds(WSP)						
Anaerobic Ponds(AP - depth 5-6m)	high	high	high	poor	excellent	poor
Facultative Ponds(FP- depth1-2m)	high	high	moderate	Moderate	excellent	v. poor
Maturation Ponds(MP)	high	high	moderate	good	excellent	v. poor
AP+ FP+ MP	high	high	moderate	good	excellent	v. poor
Imhoff tank	good	excellent	moderate	poor	excellent	excellent
UASB reactor	high	high	moderate	poor	high	excellent
Intermittent Sand filter	good	moderate	moderate	Moderate	good	good
Land treatment(irrigation/infiltration)	moderate	high	low	High	high	Very poor

*agric= agriculture; reqms=requirements; O&M=operation and maintenance

From data presented in Table 11, the following economic operational parameters could be deduced for the activated sludge process (ASP) technology. Capital costs, operation and maintenance costs, energy requirements were high hence ASP was poorly rated. The technology was rated high in effluent reuse potential and in land requirements. This implied that treated wastewater from activated sludge process could readily be used for agriculture while land requirements were low.

4.2.3 Classification of Effluent

The nature of effluent resulting from treatment with the various technologies was analysed. Table 10 presented the expected performances from treatment technologies on wastewater environmental indicators while Table 11 presented economic indicators performances.

The results presented in Table 12 were obtained by taking into consideration the performance efficiency of a treatment technology and influent wastewater concentration. The degree of reduction in wastewater concentration between influent and effluent was dependent on technology performance efficiency and was expressed as a ratio between influent and effluent concentrations. Table 12 presents final effluent classification after application of treatment technologies of varying performance efficiencies.

Considering results in Table 12 for one of the indicators e.g. total suspended solids (TSS), wastewater influent classified as of grand concentration and a treatment technology which had a performance rated as excellent. The resulting effluent after treatment was classified as of small final concentration.

TSS influent concentration range (mg/l) 500 to 1000

Concentration classification – grand (G)

Technology performance efficiency range (%) 97 to 100

Performance classification – Excellent (E_{xc})

Effluent characteristics

Concentration range 500*0.03 to 1000*0.03 = 15 to 30mg/l

Classification – small(S) as these values fall within the small concentration range.

This is a four level reduction in concentration between influent and effluent. Influent concentrations and technology performance ratings were varied and data from resulting effluent analyzed for various wastewater indicators.

Table 12. Wastewater effluent concentration classes.

Degree of technology performance	Excellent(E_{xc})	High(H_h)	Good(G_d)	Moderate(M_d)	Poor(P)
Influent characteristic class	Grand(G)				
Total solids (TS)	S	M	H	H	G
Settlable solids, ml per litre	L	M	H	H	G
Total dissolved solids (TDS)	S	L	M	M	G
Total suspended solids (TSS)	S	M	M	M	G
Volatile suspended solids (VSS)	S	M	M	M	G
Total volatile solids (TVS)	L	M	H	H	G
Turbidity, NTU	L	H	H	H	G
Oil & grease	L	H	H	H	G
Free ammonia	L	M	H	H	G
Nitrate - N	L	M	H	H	G
Total Nitrogen	L	M	H	H	G
Total Phosphorous	L	H	H	H	G
Chloride	L	H	H	H	G
Sulphate	L	M	H	H	G
Aluminum	L	M	H	H	G
Potassium (K)	L	M	H	H	G
Biochemical Oxygen demand (BOD)	L	M	H	H	G
Chemical Oxygen demand (COD)	L	M	H	H	G
Total Organic Carbon (TOC)	L	M	H	H	G

G=grand concentration; H=high; M=medium; L=low; S=small;

4.3 Overall technology performance

The overall technology performance was evaluated with a view of determining effluent characteristics. Decision support method (DSM) analysis enabled prediction of performance along the various treatment units in the sequence and also to rate the performance of overall treatment process.

i) Municipal Case study 1

The treatment technology employed in the case study was a sequence of treatment units comprising of a screening device, a grit chamber and finally waste stabilization ponds which in this case comprised of anaerobic and facultative lagoons.

Table 13 presents influent wastewater characteristics from the case study.

Concentration of TSS and COD in the influent wastewater was classified as grand while that of BOD was classified as high.

Table 13. Case study 1 influent characteristics.

Wastewater indicator	Concentration(mg/L)	**Classification of concentration in linguistic variable**
TSS	591	G
BOD	705	H
COD	1890	G

G - Grand concentration; H – High concentration

Table 14 presents treatment results for the units in the treatment sequence for the given wastewater indicators in Table 13 derived from DSM analysis.

Table 14. Case study 1 effluent characteristics & technology rating.

Characteristic	Environmental indicators- effluent concentration classification at each unit			**Overall Technology performance rating**
	Screen	Grit chamber	WSP	
TSS	G	H	M	M_d
BOD	H	H	M	M_d
COD	G	H	M	M_d
	Economic indicators			
Capital costs	VL	VL	L	E_{xc}
Operation & Maintenance costs	VL	VL	L	E_{xc}
Energy requirements	VL	VL	VL	E_{xc}
Land requirements	VL	VL	H	P

G-Grand conc.; H-High conc.; VL-Very low; L- Low; Md- Moderate E_{xc}- excellent

In the screening unit, the concentration of TSS does not change while in the grit chamber it is reduced from grand to high concentration. Finally in the waste stabilization ponds, TSS concentration is reduced from high to medium giving a final TSS of medium concentration. The overall rating of the technology sequence in the reduction of TSS concentration in the influent wastewater was hence moderate performance. For BOD and COD, overall performance of the treatment technology comprising of screen, grit chamber and waste stabilization ponds was rated as moderate. On economic indicators, the treatment technology was given similar considerations. In case of capital costs, operation and maintenance, and energy requirements, the rating was excellent implying these costs and energy requirements were low. Land requirements for the technology were high thus resulting in poor rating for the overall technology.

Table 15 presents overall technology performance when the score of performance and degree of importance were taken into consideration. The scores of performance were presented in Table 5 while weights of importance of wastewater indicators were presented in Table 6. Weights of importance for agricultural reuse considered use of wastewater for irrigation. Thus the irrigation method adopted was important and in this case reuse with drip irrigation was considered. Summation of the product of indicator score and weighting was done in order to derive overall technology grading.

Table 15. Overall treatment technology performance.

Characteristic	Technology rating	Score of performance(a)	Weighted Importance(b)	Product(a*b)
TSS	M_d	3	9	27
BOD	M_d	3	7	21
COD	M_d	3	7	21
Capital costs	E_{xc}	9	7	63
O & M	E_{xc}	9	9	81
Energy reqs	E_{xc}	9	7	63
Land reqs	P	1	7	7
$\sum$			**53**	**283**

E_{xc} – Excellent performance; M_d – Moderate performance; ; P – Poor performance

For TSS, the technology performance rating as presented in Table 15 was moderate with a grade of 3 while weight of importance of TSS removal for reuse with drip irrigation method was rated as extremely important with a weight of 9.

From equation 2:-

Overall technology weighting = 283/53

$$= 5.33$$

$$\approx 5$$

A weighted average of five (5) corresponds to an overall technology performance that was rated as **GOOD** as presented in Table 5. The technology was thus capable of reducing about three quarters of wastewater influent indicators by one level of concentration.

4.4 Validation of Decision Support Method (DSM)

Case studies in ED-WAVE tool were used in the validation of decision support method (DSM). The ED-WAVE tool has modules that support decision making in wastewater treatment through reference to the database. However in the ED-WAVE tool there was no overall rating for technology performance as was proposed in the decision support method. Thus validation was done for single unit processes and results from both tools compared. Validation provided the basis for verification on the accuracy of wastewater treatment results data obtained through the decision support method.

In the validation, actual case study results in ED-WAVE were compared with performance results obtained from application of decision support method.

A) Municipal case

The treatment technology considered for validation comprised of a screening chamber and waste stabilization ponds.

i) Wastewater treatment results from ED-WAVE tool

Table 16 presents treatment results when the ED-WAVE tool was applied to influent wastewater. The final classification shows the characteristics of effluent derived from the applied treatment technology. The data were retrieved from ED-WAVE database.

From the results presented in Table 16, influent concentration of BOD and COD was reduced from moderate to low concentration by the applied treatment technology. There was no appreciable reduction in TSS concentration while that of nitrate was reduced from low to small concentration. On economic indicators, capital costs, operation and maintenance costs for the treatment technology were low, while land requirements were moderate.

Table 16. **ED-WAVE tool treatment results.**

	Environmental indicators			
	Influent characteristics		**Effluent characteristics**	
Wastewater indicator	Influent conc.	Classification	Effluent conc.	Classification
BOD(mg/L)	155.6	M	51.6	L
COD(mg/L)	397.2	M	106.2	L
TSS(mg/L)	154.1	M	118.0	M
Nitrate(mg/L)	1.8	L	0.4	S
	Economic indicators			
Capital costs($\$/m^3/d$)	25.70-34.30	Low		
O & M($\$/m^3/d$)	0.53-1.67	Low		
Land requirements($m^2/m^3/d$)	12.5-14	High		
Energy requirements ($kWh/m^3/d$)	0	Very low		

ii) Wastewater treatment results from decision support method (DSM)

Using the same treatment technology as employed in the municipal case, wastewater of similar characteristics was subjected to decision support method (DSM) analysis. Table

17 presents results from the decision support method. The rating of technology in removal or reduction of given wastewater indicator was also presented in Table 17.

Table 17. Decision support method (DSM) analysis results.

		Environmental indicators			
		Influent characteristics		**Effluent characteristics**	
Wastewater indicator	Technology rating(WSP)	Influent conc.	Class	Effluent conc.	**Classification**
BOD(mg/L)	Good	155.6	M	45.1	L
COD(mg/L)	Good	397.2	M	115.0	L
TSS(mg/L)	Moderate	154.1	M	63.2	L
Nitrate(mg/L)	Good	1.8	L	0.5	S
	Economic indicators rating				
Capital costs($\$/m^3/d$)		High			
O & M($\$/m^3/d$)		High			
Land reqms($m^2/m^3/d$)		Poor			
Energy reqms($kWh/m^3/d$)		Excellent			

In the decision support method, the influent concentration of BOD, COD and TSS was reduced from moderate to low concentration in the effluent. This was on application of technology performance efficiency ratings in Table 9 to wastewater data as illustrated below with BOD.

Wastewater indicator considered – BOD

Technology performance rating – Good (G_d)

Performance efficiency level (%) – 71 to 90

Taking the lower efficiency value, then effluent concentration is given by:-

155.6*0.29 = 45.12mg/l

Other wastewater indicators were similarly analysed in order to get the characteristics of final effluent

Analysis of economic indicators was done and requirements on capital, operation and maintenance costs were low. Land requirements for the technology were moderate while energy requirements were very low.

Table 18 presents treated effluent results from both tools i.e. ED-WAVE and decision support method.

Table 18. Comparison of results from ED-WAVE and Decision support method.

	Environmental indicators	
Characteristic	Effluent concentration classification	
	ED-WAVE	Decision support method(DSM)
BOD(mg/L)	L	L
COD(mg/L)	L	L
TSS(mg/L)	M	L
Nitrate(mg/L)	S	S
	Economic indicators	
Capital costs($\$/m^3/d$)	Low	Low
O & M($\$/m^3/d$)	Low	Low
Land reqms($m^2/m^3/d$)	High	High
Energy reqms($kWh/m^3/d$)	Very low	Very low

From the results presented in Table 18, the two methods showed quite similar results in concentrations of final effluent. Both BOD and COD attained a final effluent of low concentration. For TSS, the variation in final concentration for both tools was within acceptable range when it was noted that performance efficiency fell within a range. Land requirements, which were classified as high, varied depending on the capacity of treatment plant and locality.

4.5 Validation through field collected data

Available treatment data were collected from three wastewater treatment plants, namely, Nairobi, Nakuru and Thika. It was only the Nairobi treatment plant at Ruai where data were collected on a daily basis while the Nakuru plant sampled on a weekly basis. Data collection at the Thika plant was irregular as even the laboratory facilities had gone into disuse at the time of study and previously collected data were used.

a) Nairobi treatment plant - Ruai

The treatment technology employed at the Ruai sewage treatment plant consisted of biological treatment in waste stabilization ponds. Primary treatment was achieved through the application of screening and grit removal. The ponds cover an area of 200ha.

Wastewater received at the treatment plant is mainly from domestic sources while industries are supposed to pre-treat their wastewater before discharging it into the sewer lines. Treated wastewater is discharged into river Ruai which is a tributary of Nairobi River. The layout of wastewater treatment sequence at Ruai is shown in Fig. 16.

Presented below is a summary on wastewater operational parameters at Ruai treatment plant.

Average actual inflow (m^3/d) = 78886
Average actual outflow (m^3/d) = 64557
Maximum capacity (m^3/d) =120000
Capacity utilization (%) = 65.74

Table 19 presents collected data on influent and effluent characteristics from Ruai wastewater treatment plant. The values presented are averages for a two year period (2007/2008 and 2008/2009) with readings being recorded on a daily basis. Thus Table 19 was a summary on important wastewater indicators.

Table 19. Ruai treatment plant data.

Parameter	**BOD** (mg/L)	**COD** (mg/L)	**TDS** (mg/L)	**TSS** (mg/L)	**NO3** (mg/L)	**pH**
Influent conc.	386.0	945.0	672.5	531.0	13.2	7.6
Final effluent conc.	73.5	265.6	589.9	126.3	12.1	7.8

Conc.=concentration

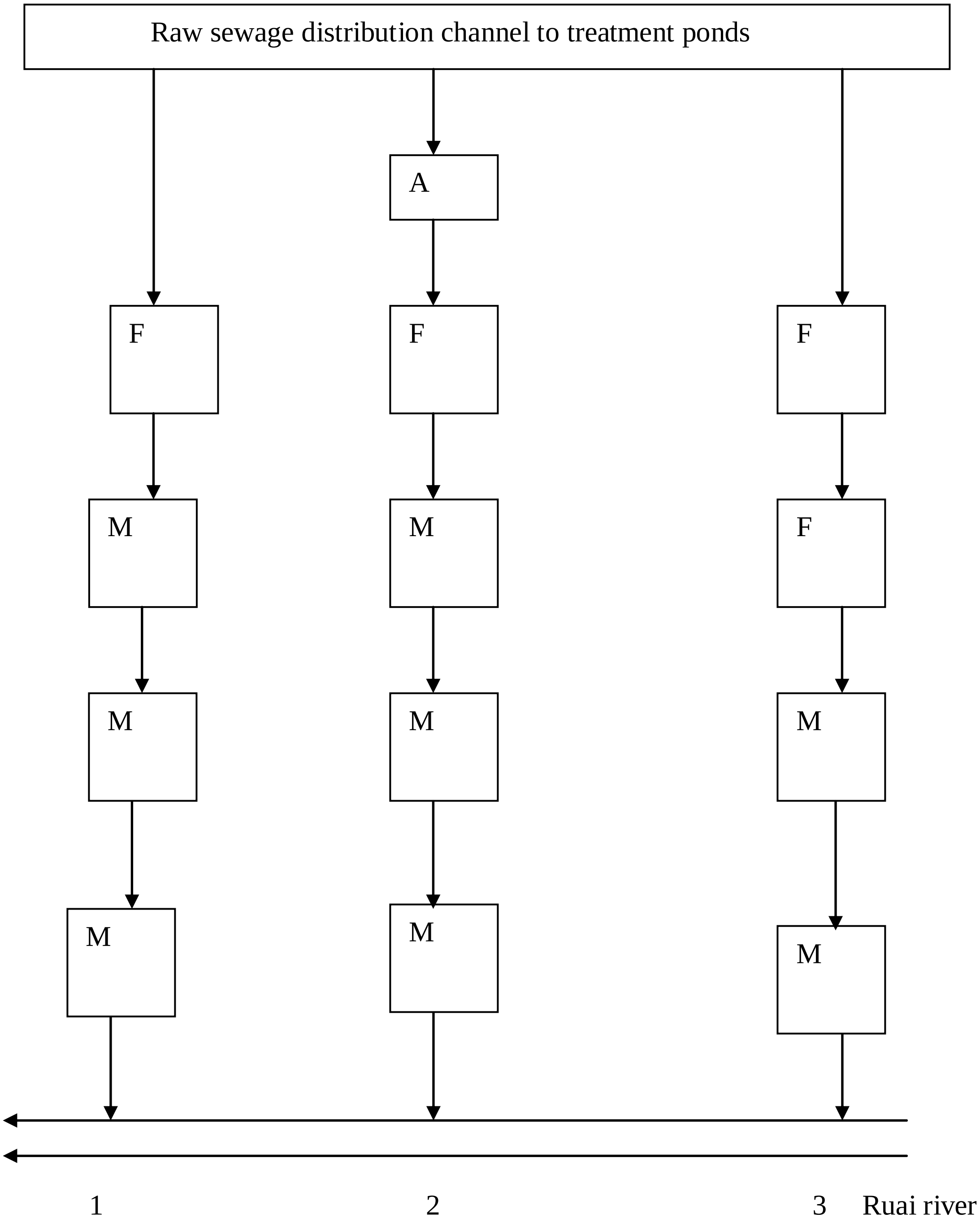


Figure 16. **Layout of Ruai treatment plant.**

A – Anaerobic pond
F- Facultative pond
M – Maturation pond

1, 2 and 3 are treated wastewater outfalls into Ruai river

Table 20 presents laboratory data collected on influent and effluent wastewater characteristics at the Ruai treatment plant. The data were also classified according to classification for the DSM tool. Wastewater was discharged into Ruai River after treatment in the waste stabilization ponds.

Table 20. Ruai wastewater concentration classification.

	Environmental indicators			
	Influent characteristics		**Effluent characteristics**	
Wastewater indicator	Influent conc.	Class	Effluent conc.	Classification
BOD(mg/L)	386.0	H	73.5	L
COD(mg/L)	945.0	H	265.6	M
TSS(mg/L)	531.0	G	126.3	M
Nitrate(mg/L)	13.2	M	9.4	L
	Economic indicators			
Capital costs($/m^3/d)	25.7-34.3	Moderate		
O & M($/m^3/d)	0.53-1.67	Low		
Land reqms(m^2/m^3/d)	12.5-14	High		
Energy reqms(kWh/m^3/d)	0	Very low		

On treatment, BOD was reduced from high to low while that of COD was reduced to medium. TSS concentration was reduced from grand concentration to medium before discharge. Capital costs were classified as moderate while operation & maintenance costs are low. Land requirements for the ponds were assessed as high.

The same influent data for Ruai plant were subjected to DSM analysis and the resulting effluent data presented in Table 21.

Table 21. **Ruai wastewater characteristics on application of DSM analysis.**

		Environmental indicators			
		Influent characteristics		**Effluent characteristics**	
Wastewater indicator	Technology rating(WSP)	Influent conc.	Class	Effluent conc.	Classification
BOD(mg/L)	Good	386.0	H	112.0	M
COD(mg/L)	Good	945.0	H	274.0	M
TSS(mg/L)	Moderate	531.0	G	217.7	M
Nitrate(mg/L)	Good	13.2	M	3.8	L
	Economic indicators rating				
Capital costs($\$/m^3/d$)		High			
O & M($\$/m^3/d$)		High			
Land reqms($m^2/m^3/d$)		Poor			
Energy reqms($kWh/m^3/d$)		Excellent			

G=grand concentration; H=high; M=medium; L=low

On application of DSM performance rates in Table 10, influent BOD and COD concentration was reduced from high to medium concentration while TSS concentration was reduced from grand to medium. Nitrate concentration was reduced from medium to low.

Table 22 presents a comparison of effluent data obtained from Ruai and when the same wastewater stream was subjected to DSM performance ratings.

Table 22. **Comparison of effluent characteristics for Ruai field data and DSM analysis.**

	Environmental indicators	
Characteristic	**Effluent classification**	
	Decision support method (DSM)	Ruai treatment plant
BOD(mg/L)	M	L
COD(mg/L)	M	M
TSS(mg/L)	M	M
Nitrate(mg/L)	L	L
	Economic indicators rating	
Capital costs($/m^3/d)	High	Good
O & M($/m^3/d)	High	High
Land reqms(m^2/m^3/d)	Poor	Poor
Energy reqms(kWh/m^3/d)	Excellent	Excellent

It was observed that effluent data collected from the field and DSM data for COD, TSS and nitrate were similar. BOD data were slightly different though it still fell within the range of performance efficiency as classified in DSM.

b) Nakuru Treatment Plant

The Nakuru treatment plant utilizes biological treatment consisting of waste stabilization ponds and constructed wetland. The wastewater first went through preliminary treatment process which consisted of several screens with different gauges and grit removal. The treatment ponds series comprised of anaerobic, facultative and maturation ponds.

The treatment plant also had a conventional system consisting of a trickling filter. At the time of carrying out the research, the trickling filter and the wetland were out of use and only the biological system was operational. Laboratory analysis of wastewater was being done once weekly. Operational challenges like availability of transport for collection of samples did at times affect this schedule. The treated wastewater was discharged into Lake Nakuru which is an important habitat for birds. The layout of wastewater treatment sequence at the Nakuru plant, with constructed wetland, is shown in Fig. 17.

Table 23 presented collected influent and effluent wastewater data from Nakuru plant after treatment through the stabilization pond system.

Table 23. Nakuru treatment plant wastewater characteristics.

Parameter	**BOD** (mg/L)	**COD** (mg/L)	**TSS** (mg/L)	**Nitrate** (mg/L)	**T-P** (mg/L)	**pH**
Influent conc.	756.0	1940.0	794.0	40.0	12.7	7.1
Final effluent conc.	108.0	396.0	222.0	15.4	3.9	7.9

Table 24 presents laboratory data collected on influent and effluent wastewater characteristics at the Nakuru treatment plant.

Table 24. Nakuru wastewater classification.

	Environmental indicators			
	Influent characteristics		**Effluent characteristics**	
Wastewater indicator	Influent conc.	Class	Effluent conc.	Classification
BOD(mg/L)	756.0	H	108.0	M
COD(mg/L)	1940.0	G	396.0	M
TSS(mg/L)	794.0	G	222.0	M
Nitrate(mg/L)	40.0	M	15.4	M
	Economic indicators			
Capital costs($/m^3/d)	25.7-34.3	Moderate		
O & M($/m^3/d)	0.53-1.67	Low		
Land reqms(m^2/m^3/d)	12.5-14	High		
Energy reqms(kWh/m^3/d)	0	Very low		

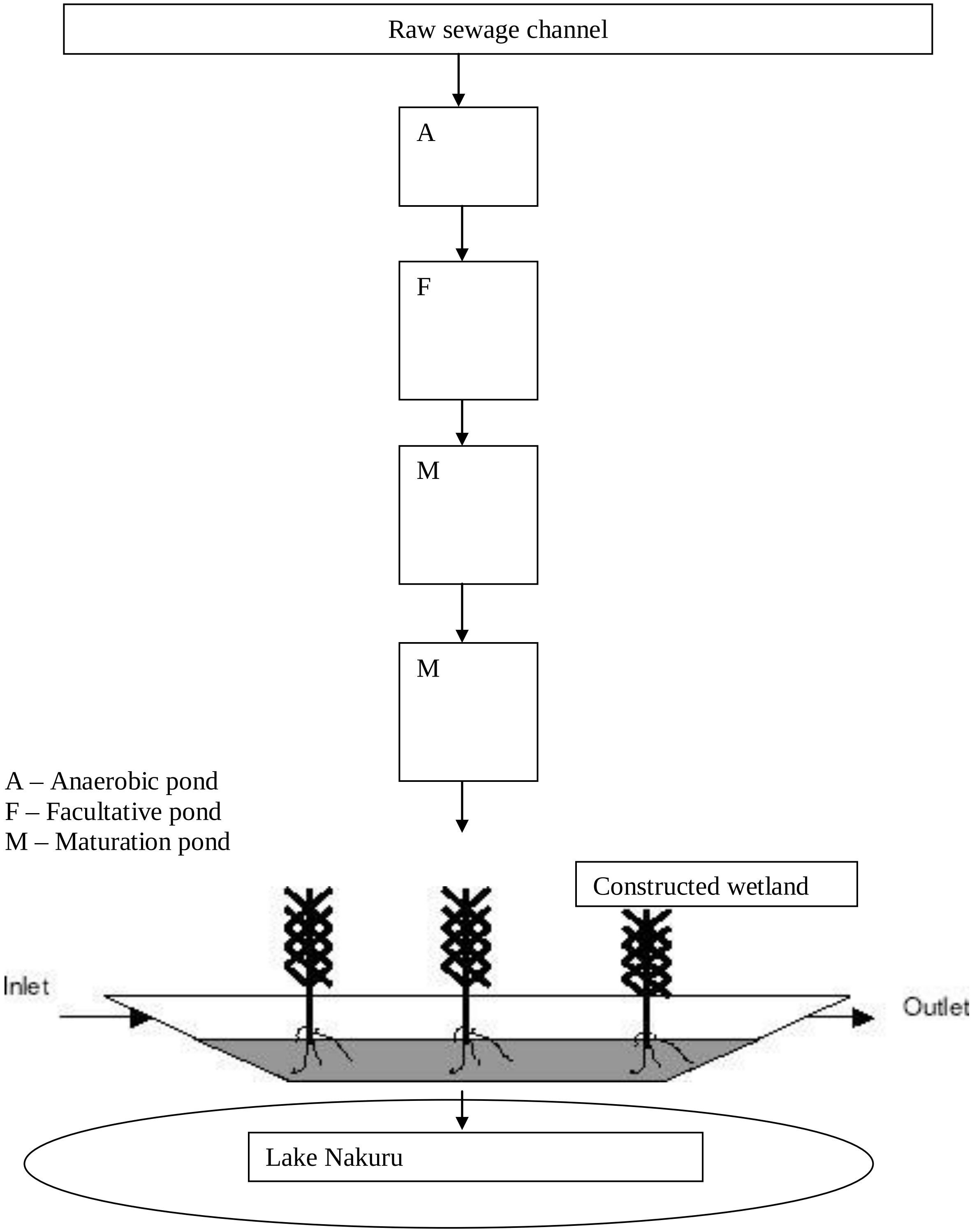


Figure 17. **Layout of Nakuru treatment plant.**

On treatment, concentration of BOD was reduced from high to medium while that of COD and TSS was reduced from grand to medium before discharge. There was no noticeable reduction in nitrate concentration. Capital costs were classified as moderate while operation and maintenance costs were low. Land requirements for the ponds were classified as high when compared to requirements of other treatment technologies like trickling filter.

The same wastewater stream was applied to decision support method (DSM) analysis and effluent results presented in Table 25.

Table 25. Nakuru wastewater characteristics on application of DSM analysis.

		Environmental indicators			
		Influent characteristics		**Effluent characteristics**	
Wastewater indicator	Technology rating(WSP)	Influent conc.	Class	Effluent conc.	Classification
BOD(mg/L)	Good	756.0	H	219.2	M
COD(mg/L)	Good	1940.0	G	562.6	H
TSS(mg/L)	Moderate	794.0	G	325.5	M
Nitrate(mg/L)	Good	40.0	M	11.6	M
	Economic indicators rating				
Capital costs($/m^3/d)		High			
O & M($/m^3/d)		High			
Land reqms(m^2/m^3/d)		Poor			
Energy reqms(kWh/m^3/d)		Excellent			

G=grand concentration; H=high; M=medium; L=low concentration

A comparison of final effluent characteristics was made between data collected from Nakuru treatment plant and data from DSM analysis and results presented as in Table 26.

Table 26. **Comparison of effluent characteristics for Nakuru plant and DSM analysis.**

	Environmental indicators	
Characteristic	**Effluent classification**	
	Decision support method (DSM)	Nakuru treatment plant
BOD(mg/L)	M	M
COD(mg/L)	H	M
TSS(mg/L)	M	M
Nitrate(mg/L)	M	M
	Economic indicators rating	
Capital costs($/m^3/d)	High	Good
O & M($/m^3/d)	High	High
Land reqms(m^2/m^3/d)	Poor	Poor
Energy reqms(kWh/m^3/d)	Excellent	Excellent

It was observed that apart from COD, there was similarity in final effluent classification between data collected and analysis results from DSM. Results for COD still fell within the performance range in DSM.

c) Thika Treatment plant

Thika treatment plant has basins with earthen embankment. It was designed to discharge 6100m^3/day but it discharges 8000m^3/day. The treatment facility employs biological treatment in a series of stabilization ponds comprising of anaerobic, facultative and maturation ponds. This is done after preliminary treatment comprising of screening and grit removal. Treated effluent is discharged into river Komu which flows to Athi River. The layout of wastewater treatment sequence at Thika is shown in Fig. 18.

Table 27 presents influent and effluent wastewater data after treatment through the stabilization pond system.

Table 27. Thika treatment plant wastewater characteristics.

Parameter	**BOD**	**COD**	**TSS**
Influent conc.(mg/L)	220.0	299.0	488.0
Final effluent conc. (mg/L)	55.0	62.0	320.0

Table 28 presents laboratory data collected on influent and effluent wastewater characteristics at the Thika treatment plant.

Table 28. Thika wastewater concentration classification.

	Environmental indicators			
	Influent characteristics		**Effluent characteristics**	
Characteristic	Influent conc.	Class	Effluent conc.	Classification
BOD(mg/L)	220.0	M	55.0	L
COD(mg/L)	299.0	M	62.0	L
TSS(mg/L)	488.0	H	320.0	M
	Economic indicators			
Capital costs($\$/m^3/d$)	Moderate			
O & M($\$/m^3/d$)	Low			
Land reqms($m^2/m^3/d$)	High			
Energy reqms($kWh/m^3/d$)	Very low			

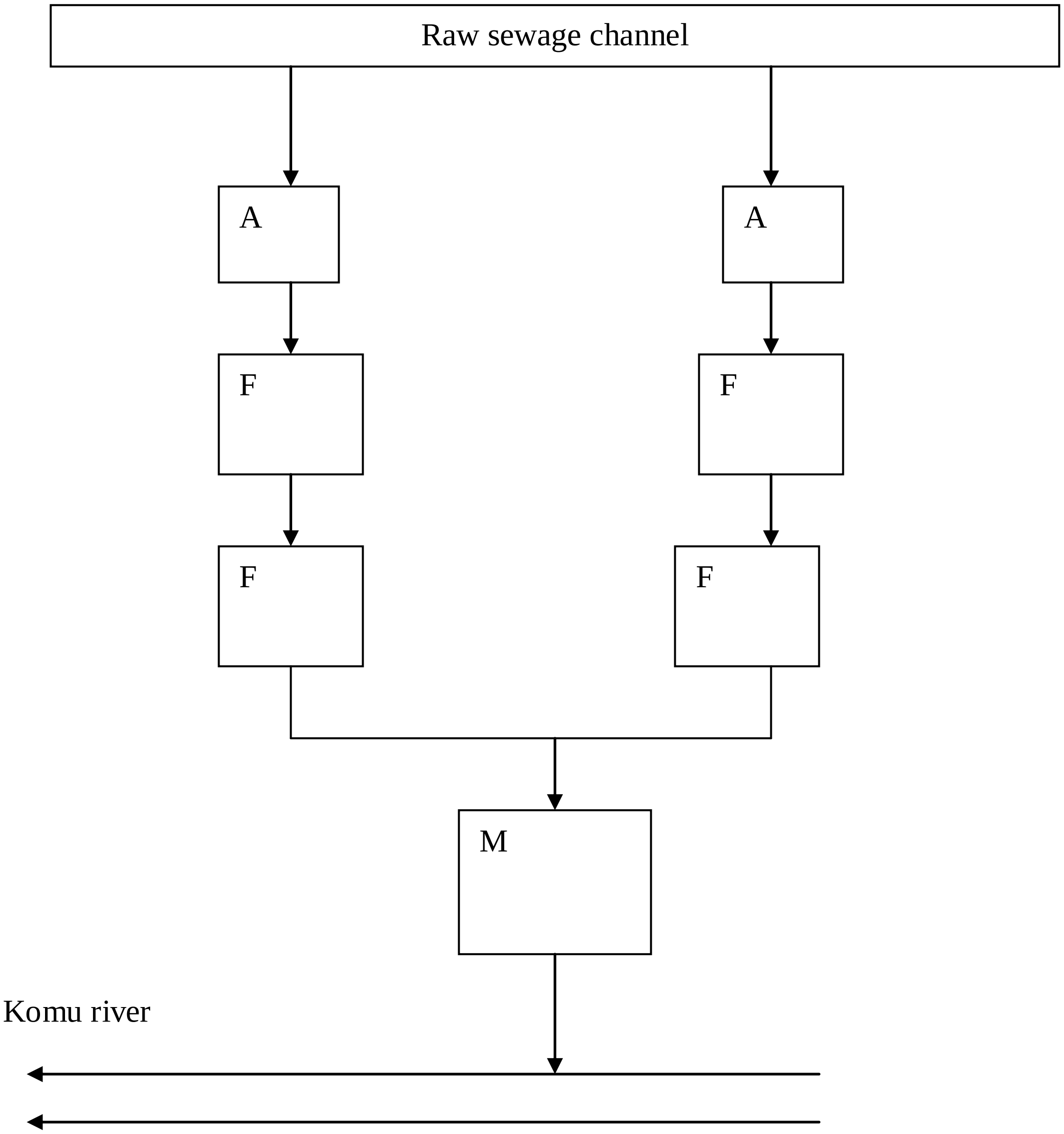


Figure 18. **Layout of Thika treatment plant.**

A – Anaerobic pond M- Maturation pond

F – Facultative pond

In the ponds, concentration of BOD and COD was reduced from medium to low while that of TSS was reduced from high to medium before discharge. Capital costs were classified as moderate while operation and maintenance costs were low. Land requirements for the ponds were classified as high when compared to requirements of other treatment technologies like trickling filter and activated sludge process.

The laboratory where wastewater analysis was being carried out had been vandalized and no analysis had been carried out for several years. The data collected were for the period the facility was operational.

The same wastewater stream was applied to DSM analysis and results presented in Table 29.

Table 29. **Thika wastewater characteristics on application of DSM analysis.**

		Environmental indicators			
		Influent characteristics		**Effluent characteristics**	
Wastewater indicator	Technology rating(WSP)	Influent conc.	Class	Effluent conc.	Classification
BOD(mg/L)	Good	220.0	M	63.8	L
COD(mg/L)	Good	299.0	M	86.7	L
TSS(mg/L)	Moderate	488.0	H	200.0	M
	Economic indicators rating				
Capital costs($/m^3/d)		High			
O & M($/m^3/d)		High			
Land reqms(m^2/m^3/d)		Poor			
Energy reqms(kWh/m^3/d)		Excellent			

Field data on final effluent characteristics collected from Thika treatment plant were compared with data from DSM analysis and results presented in Table 30.

Table 30. Comparison of effluent characteristics for Thika field data and DSM analysis.

	Environmental indicators	
Characteristic	**Effluent classification**	
	Decision support method (DSM)	Thika treatment plant
BOD(mg/L)	L	L
COD(mg/L)	L	L
TSS(mg/L)	M	M
	Economic indicators rating	
Capital costs($\$/m^3/d$)	High	Good
O & M($\$/m^3/d$)	High	High
Land reqms($m^2/m^3/d$)	Poor	Poor
Energy reqms($kWh/m^3/d$)	Excellent	Excellent

It was observed that data on final effluent concentration and that obtained from subjecting the same wastewater stream to DSM analysis were similar.

4.6 Application of Decision Support Method (DSM)

The Decision Support Method (DSM) analysis was applied to results obtained from Nakuru treatment plant in order to illustrate how DSM could be used to facilitate decision making in selection of appropriate treatment technology. This was done in order to improve the quality of final wastewater effluent being discharged from the treatment plant.

The existing wastewater treatment technologies at the time of data collection at the Nakuru plant comprised of screen, grit chamber and waste stabilization ponds. A trickling filter and constructed wetland which had been installed at the plant were out of use. Table 31 presented performance of each unit in the treatment sequence on a given wastewater indicator at the Nakuru plant during the period of data collection. Overall rating for the whole treatment process was also established.

Table 31. Treatment technology performance at Nakuru plant.

Characteristic	**Environmental indicators- effluent concentration classification at each unit**			**Overall Technology performance rating**
	Screen	**Grit chamber**	**WSP**	
TSS	G	H	M	M_d
BOD	H	H	M	M_d
COD	G	H	M	M_d
Nitrate	M	M	L	G_d
	Economic indicators			
Capital costs	VL	VL	L	H_h
Operation & Maintenance costs	VL	VL	VL	E_{xc}
Energy requirements	VL	VL	VL	E_{xc}
Land requirements	VL	VL	H	P

G=grand concentration; H=high; M=medium; L=low conc; E_{xc}=excellent performance; H_h=high; M_d=moderate; P=poor performance; VL=very low; WSP=waste stabilization pond

Rating of the treatment process at the Nakuru plant was done by considering the score on technology performance rating and weighting attached to wastewater indicators in determining reuse. Results are presented in Table 32.

Table 32. **Performance rating at Nakuru plant.**

Characteristic	**Technology rating**	**Score of performance(a)**	**Weighted Importance(b)**	**Product(a*b)**
TSS	M_d	3	9	27
BOD	M_d	3	7	21
COD	M_d	3	7	21
Nitrate	G_d	5	5	25
Capital costs	H_h	7	7	49
O & M	E_{xc}	9	9	81
Energy reqs	E_{xc}	9	7	63
Land reqs	P	1	7	7
$\sum$			**58**	**294**

Overall technology weighting = 294/58

= 5.06

≈ 5

A weighted average of five (5) corresponds to an overall technology performance that was rated as **GOOD** as presented in Table 5. The technology was thus capable of reducing about three quarters of wastewater influent indicators by one level of concentration.

In order to improve on the quality of final effluent, a constructed wetland was proposed to be added to the treatment sequence.

A constructed wetland was proposed for addition to the treatment process in order to improve the quality of wastewater before discharge. Reference was made to Decision Support method (DSM) for performance rating of overall treatment sequence. Expected performance of the new treatment sequence for the various wastewater indicators was analysed and results presented in Table 33.

Table 33. Treatment technology performance at Nakuru plant with constructed wetland.

	Environmental indicators- effluent concentration classification at each treatment unit				**Overall technology performance rating**
Characteristic	Screen	Grit removal	WSP	Constructed wetland	
TSS	G	H	M	L	G_d
BOD	H	H	M	L	H_h
COD	G	H	M	L	H_h
Nitrate	M	M	L	S	E_{xc}
	Economic indicators				
Capital costs	VL	VL	L	L	H_h
Operation & Maintenance costs	VL	VL	VL	VL	E_{xc}
Energy requirements	VL	VL	VL	VL	E_{xc}
Land requirements	VL	VL	H	L	P

Rating of the proposed treatment process was done by considering the score on technology performance rating and weighting attached to wastewater indicators in determining reuse. Results on scoring and weighting of overall performance of the treatment process were presented in Table 34. DSM enabled overall performance of treatment technology to be derived.

Table 34. **Performance rating at Nakuru plant with constructed wetland.**

Characteristic	**Technology rating**	**Score of performance(a)**	**Weighted Importance(b)**	**Product(a*b)**
TSS	G_d	5	9	45
BOD	H_h	7	7	49
COD	H_h	7	7	49
Nitrate	E_{xc}	9	5	45
Capital costs	H_h	7	7	49
O & M	E_{xc}	9	9	81
Energy reqs	E_{xc}	9	7	63
Land reqs	P	1	7	7
$\sum$			**58**	**388**

Overall technology weighting = 388/58

$$= 6.7$$

$$\approx 7$$

A weighted average of seven (7) corresponds to an overall technology performance that was rated as **HIGH** as presented in Table 5. The technology was thus capable of reducing about three quarters of wastewater influent indicators by two levels of concentration.

Thus it was observed that with addition of an extra treatment technology in form of constructed wetland, overall performance of the treatment technology sequence could be improved from GOOD to HIGH.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main objective of the research work was the development of a decision support method that would assist in the selection of sustainable municipal wastewater treatment technologies. In this research work, the sustainability of treatment technologies was evaluated using a set of environmental and economic indicators. Scores were assigned to the different ratings on performance and a weight given depending on the degree of importance attached to reuse of treated wastewater for agriculture. This enabled a comparison of the overall performance of technologies to be made. Validation through the ED-WAVE tool and field collected data provided the basis for verification on the accuracy of wastewater treatment results data obtained through the decision support method.

The following conclusions were made from the research work:-

1. Performance data obtained from different authors and publications indicated the same performance trends for similar treatment technologies that were evaluated. This enabled a common conclusion to be made and hence allowed for rating on technology performance.
2. The developed Decision Support Method (DSM) was able to rate wastewater treatment projects in the range of excellent to very poor based on

performance of individual wastewater treatment technologies in the treatment sequence using linguistic variables.

3. Using DSM to analyse expected performance, laboratory data collected from the three treatment plants were compared with data obtained when the same wastewater stream was subjected to DSM analysis. Both sets of data were similar implying that DSM could be used to determine expected outcome of applying a given treatment technology. This would therefore assist in the selection process.
4. Again applying DSM analysis, it was determined that an addition of constructed wetland could improve performance of treatment process at Nakuru plant from **GOOD** to **HIGH** performance rating.
5. DSM was able to rate individual treatment technologies and overall rating of a treatment project. This was not the case with ED-WAVE which only rated individual treatment technologies.
6. As DSM was able to integrate environmental and economic factors in evaluating wastewater treatment technologies, it was thus able to select a process that was not only environmentally sustainable but also economically affordable.

5.2 Recommendations

1. DSM should be applied in selection of wastewater treatment technologies and improvement of treatment plants in existing and upcoming wastewater treatment plants in urban areas.

2. DSM can be improved further and its applicability in decision making enhanced through:-
    - i. Considering varied sources of wastewater e.g. from industrial sources.
    - ii. Considering more case studies and treatment technologies.
    - iii. Development of Graphical User Interface (GUI) to ease data input and analysis.

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