Fuzzy based decision support method for selection of sustainable wastewater treatment technologies

Martin I. Kamami, George M. Ndegwa, Patrick G. Home

(*Biomechanical and Environmental Engineering Department, Faculty of Engineering, Jomo Kenyatta University of Agriculture and Technology, P.O. Box* 62000-00200, *Nairobi, KENYA*)

Abstract: Inadequate decision support tools have led to selection of inappropriate wastewater treatment technologies. The objectives of this research were to investigate performance data for wastewater treatment technologies, develop a Decision Support Method (DSM) for evaluating performance of technologies, and to validate the developed method. The method was developed through evaluation of performance of wastewater treatment technologies against environmental and economic indicators. Fuzzy logic techniques in form of linguistic variables were applied in order to support decision making under uncertainty. The DSM relied on performance evaluation in order to rate effectiveness of wastewater treatment technologies. DSM was validated through a training tool in ED-WAVE, a model developed by a consortium of European and Asian countries. The reliance of the DSM on performance evaluation was an improvement on the existing decision support tools such as ED-WAVE that relied on retrieval of past performance data. As DSM integrated 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.

Keywords: decision support method, ED-WAVE, wastewater treatment technologies, environmental indicators, performance rating, fuzzy logic

DOI: 10.3965/j.issn.1934-6344.2011.01.0-0

Citation: Martin I. Kamami, George M. Ndegwa, Patrick G. Home. Fuzzy based decision support method for selection of sustainable wastewater treatment technologies. Int J Agric & Biol Eng, 2011; 4(1): －.

1 Introduction

Water requirements of urban areas, industries, and the environment are increasing rapidly while the huge volumes of municipal and industrial wastewater require treatment and safe disposal. Agriculture consumes between 70% and 90% of abstracted fresh water resources in developing countries[1]. Using treated wastewater for agriculture provides a means through which wastewater can safely be reused and managed, thereby reducing demand on fresh water sources[2,3].

The potential of 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[4]. This is because most of the conventional technologies currently in use in industrialized nations are too expensive and complex for developing countries[5]. To ensure sustainable use of wastewater for food production in urban and peri-urban areas, there is need to implement safe wastewater use and management options[6].

The process of evaluating and selecting an appropriate wastewater treatment technology should consider the life cycle cost of such a system including design, construction, operation, maintenance, repair and replacement[7]. Decision support methods that simplify the selection process of wastewater treatment technologies are of vital importance[8,9]. The technologies would ensure protection of the environment

Received date: 2010-09-16 **Accepted date:** 2011-03-11

Corresponding author: Martin I. Kamami, Tel.:+254(0)722 458141; Email: engkamami@yahoo.com.

and public health and alleviate pressure on fresh water demand. The problem associated with the current treatment technologies is that they lack sustainability. For example 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 compared to those from the United States and Europe. This is extremely high and may cause a large amount of sludge production[10]. Issues that deserve further analysis are how selection of a particular wastewater treatment technology affects overall sustainability and whether there are certain aspects of a particular treatment technology that makes it more balanced in terms of economic, environmental, and social sustainability[11].

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[12].

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[12,13]. The ED-WAVE tool for wastewater treatment is an education tool which comprises of modules that support decision making. The tool includes the base of past cases of wastewater treatment and the database of technologies applied to wastewater treatment from various countries in Europe and Asia. It relies on retrieval of stored data on treatment technologies and comparing similarities in order to solve new cases.

The objectives of this research were to develop a Decision Support Method (DSM) for evaluating performance of wastewater treatment technologies and to validate the method through the ED-WAVE tool for wastewater treatment synthesis.

2 Methodology

2.1 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[8,9,11].

Environmental indicators measure resource utilization and performance of technology in removing or reducing conventional wastewater constituents. Wastewater environmental indicators used to gauge performance were final concentrations of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Fats, Oils and 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, odour potential and sludge generation.

Data on wastewater concentrations and performance efficiencies of treatment technologies were obtained from literature sources and analysed. The collected data 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.

2.2 Development of technology performance rating criteria

Rating criteria were 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 scoring scales that have been proposed in literature, the one according to Zhu[14] 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 1 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 the 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 from high concentration to small. In the moderate classification, almost 70% of the wastewater influent 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 1 Technology performance rating and scoring criteria

Technology performance rating	Level of achievement	Assigned score to performance, C_j
Excellent performance	Resulted in about 75% of influent wastewater indicators attaining 3 level reduction in higher concentrations	9
High	Resulted in about 75% of influent wastewater indicators attaining 2 level reduction in higher concentrations	7
Good	Resulted in 75% of influent wastewater indicators attaining 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

2.3 Performance evaluation

2.3.1 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 performance efficiencies were also rated.

2.3.2 Performance evaluation on wastewater economic indicators

Data on technology performance against wastewater economic indicators were 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.

2.3.3 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 2 presents weights of importance attached to wastewater indicators in determining agricultural reuse.

Table 2 Weights denoting 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 highest weight of 9 assigned to it. This meant that such an indicator had a big impact in determining agricultural reuse value of the treated wastewater.

2.3.4 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 (1).

$$O_R = \frac{\sum c_j w_i}{\sum w_i} \tag{1}$$

Where, O_R Overall technology performance rating; C_j Score 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.

2.4 Validation of Decision Support Method (DSM)

The ED-WAVE tool has modules that support decision making in wastewater treatment. One such module accumulates specific design experience contained in real cases and tries to reuse it when solving new user's problems. Data contained in wastewater treatment cases in ED-WAVE tool were on environmental indicators. Other literature sources provided a reference for validation of data on economic performance of treatment technologies. The validation was done in order to compare technology performance as predicted from the DSM and actual results obtained from case studies in ED-WAVE tool. For reliability of results, it was important to compare wastewater data from similar sources because wastewater characteristics are dependent on its sources.

3 Results and discussion

3.1 Performance of wastewater treatment technologies

3.1.1 Data on wastewater concentrations

Table 3 presents influent wastewater concentration data classified into seven classes from extreme concentration to traces.

The various municipal wastewater characteristics indicated different influent concentration values. Taking two wastewater indicators as an illustration, TDS concentration in influent wastewater ranged from 2000mg/L in the extreme class to zero while for COD, influent concentration ranged from 3,000 mg/L in extreme class to zero in traces.

Table 3 Concentrations of influent wastewater indicators (mg/L)

Concentration classes and values	Extreme(E)	Grand(G)	High(H)	Medium(M)	Low(L)	Small(S)	Traces(T)
Wastewater characteristics ……………………………………							
Total Dissolved Solids (TDS)	2,000	1,000	600	300	100	10	0
Total Suspended Solids (TSS)	1,000	500	350	100	30	3	0
Total Nitrogen	400	200	100	20	5	0.5	0
Total Phosphorous	200	100	20	5	1	0.1	0
Potassium (K)	200	100	50	20	1	0.1	0
Copper (Cu)	200	100	10	1	0	0	0
Iron (Fe)	1,000	500	100	5	1	0.1	0
Biochemical Oxygen Demand (BOD)	2,000	1,000	300	100	30	3	0
Chemical Oxygen Demand (COD)	3,000	1,500	500	250	50	5	0
Total Coliform per 100 mL	1.00E+14	1.00E+12	1.00E+08	1.00E+04	200	2	0

3.1.2 Data on performance efficiencies

Table 4 presents wastewater treatment technologies performance efficiencies. The efficiencies gave an indication as to 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 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 4 Wastewater treatment technology performance efficiencies (%)

Wastewater indicator	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 5-6 m)	50-60							
Facultative Ponds (FP- depth 1-2 m)	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^{-1}	66	80	90	58				
High filtration rate /2.3m.h^{-1}	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		05-14	11-27		
Intermittent Sand filter								
Depth of filter material 65 cm	85	57	75		90	78		
Depth of filter material 25 cm	76	42	63		82	68		
Land treatment (irrigation/infiltration)	98		98			85	95	

Note: NH_4-N – ammonia nitrogen; TP- total phosphorous; TN-total nitrogen.

3.1.3 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. Table 5 presents technology performance efficiency ratings.

Table 5 Technology performance efficiency ratings

Performance Rating	Performance efficiency level /%
Excellent(E_{xc})	97 - 100
High(H_h)	91 – 96
Good(G_d)	71 – 90
Moderate(M_d)	59 -70
Poor(P)	50 – 58
Very poor(VP)	Less than 50

3.2 Treatment technology evaluation

3.2.1 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 4 and efficiency ratings in Table 5. Each technology was rated depending on its performance in reducing concentration of various wastewater indicators. Table 6 presents evaluation results for wastewater treatment technologies as to the expected performance in reduction of influent wastewater characteristics.

Table 6 Technology performance rating on environmental indicators

Technology	BOD removal	COD	TSS	Bacteria emoval	Metals	Ammonia-N	TN	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 + Activate Sludge Process	high	high	high	high	good	moderate	good	moderate
Waste Stabilization Ponds (WSP)								
Anaerobic Ponds (AP - depth 5-6 m)	moderate	moderate	poor	Very poor	moderate	poor	poor	poor
Facultative Ponds (FP- depth1-2 m)	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/in filtration)	excellent	high	excellent	good	high	good	good	High

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 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 presented in Table 6 could hence be used in technology selection as they presented expected performance of wastewater treatment technologies.

3.2.2 Performance evaluation on economic indicators

Again, wastewater technologies were evaluated on performance against economic indicators. Evaluation of economic indicators was relatively depending on comparable costs associated with other technologies employed in wastewater treatment in a given region. Table 7 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. From data presented in Table 7, the following operational parameters could be deduced for the 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.

Table 7 Technology performance rating on economic indicators

Technology	Sludge generation	Effluent reuse	Capital cost/m^3	O & M	Energy reqms	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 5-6 m)	high	high	high	poor	excellent	Very poor
Facultative Ponds (FP- depth1-2 m)	high	high	moderate	moderate	excellent	poor
Maturation Ponds (MP)	high	high	moderate	good	excellent	poor
AP+ FP+ MP	high	high	moderate	good	excellent	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

3.2.3 Classification of effluent

The nature of effluent resulting from treatment with the various technologies was analysed. Table 6 presented the expected performances from treatment technologies on wastewater environmental indicators while Table 7 presented economic indicators performances.

Table 8 presents final effluent classification after application of treatment technologies of varying performance efficiencies. The results 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. Considering results in Table 8 for one of the indicators e.g. 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 (mg/L) 500 – 1,000

Concentration classification – grand (*G*)

Technology performance efficiency (%) 97 – 100

Performance classification – Excellent (*E*)

Effluent characteristics range

500×0.03 to 1000×0.03 = 15 to 30 mg/L

Classification – small(*S*)

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 analysed for various wastewater indicators.

Table 8 Effluent concentration classes

Technology rating	Excellent (E_{xc})	High (H_h)	Good G_d)	Moderate (M_d)
……………………				
Influent concentration class	Grand(G)			
…………………………………………………………..				
Effluent concentration classification				
Total Solids (TS)	S	M	H	H
Total Suspended Solids (TSS)	S	M	M	M
Total Dissolved Solids(TDS)	S	L	M	H
Volatile Suspended Solids (VSS)	S	M	M	H
Total Volatile Solids (TVS)	L	M	H	H
Turbidity, NTU	L	H	H	H
Oil & grease	L	H	H	H
Free ammonia	L	M	H	H
Nitrate – N	L	M	H	H
Total Nitrogen	L	M	H	H
Total Phosphorous	L	H	H	H
Chloride	L	H	H	H
Sulphate	L	M	H	H
Aluminum	L	M	H	H
Potassium (K)	L	M	H	H
Biochemical Oxygen demand (BOD)	L	M	H	H
Chemical Oxygen demand (COD)	L	M	H	H

3.3 Overall technology performance

The DSM enabled prediction of technology performance along the various treatment stages in the sequence and also to rate performance of overall treatment technology.

a) Municipal case

The treatment technology employed 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 9 presents influent wastewater characteristics. Concentration of TSS and COD in the influent wastewater was classified as grand while that of BOD was classified as high.

Table 9 Influent characteristics

Characteristic	Concentration(mg/L)	Classification of concentration in fuzzy linguistic terms
TSS	591	G
BOD	705	H
COD	1,890	G

Note: G – Grand concentration; H – High conc.

Table 10 presents treatment results for the units in the treatment sequence for given wastewater indicators.

Table 10 Effluent characteristics and 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

Note: G-Grand conc.; H-High conc.; VL-Very low; L-Low; M_d- 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. 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 11 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 1 while weights of importance of wastewater indicators were presented in Table 2. Summation of the product of indicator grade and weighing was done in order to get overall technology grading.

Table 11 Overall 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	9	27
COD	M_d	3	9	27
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
$\sum$			57	295

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

For TSS, the technology performance rating as presented in Table 10 was moderate with a score of 3 while weight of importance of TSS in agricultural reuse considerations was rated as extremely important with a weight of 9.

From Equation 1,

Overall technology weighing = 295/57 = 5.2 ≈ 5

A weighted average of five (5) corresponds to an overall technology performance that was rated as GOOD as presented in Table 1. The technology was thus capable of reducing about three quarters of wastewater influent indicators by one level of concentration

3.4 Validation through case studies in ED-WAVE

The ED-WAVE tool has modules that support decision making in wastewater treatment. However in the ED-WAVE tool there was no overall rating for technology performance as was proposed in the DSM. 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 obtained through the DSM.

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 12 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.

From the results presented in Table 12, 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 12 ED-WAVE treatment results

Environmental indicators				
Characteristic	Influent characteristics		Effluent characteristics	
	Influent conc.	Classification	Effluent conc.	Classification
BOD/mg•L^{-1}	155.6	M	51.6	L
COD/mg•L^{-1}	397.2	M	106.2	L
TSS/mg•L^{-1}	154.1	M	118	M
Nitrate/mg•L^{-1}	1.84	L	0.43	S
Economic indicators				
Capital costs /$.m^{-3}•d^{-1}	25.70-34.30		Low	
O & M /$.m^{-3}•d^{-1}	0.53-1.67		Low	
Land requirements /m^2.m^{-3}•d^{-1}	12.5-14		Moderate	
Energy requirements /kWh.m^{-3}•d^{-1}	0		Very low	

ii) Wastewater treatment results from DSM

Table 13 presents results from the decision support tool on application of the same treatment technology as applied in the ED-WAVE tool.

Table 13 Decision Support Method (DSM) results

Environmental indicators				
Characteristic	Influent characteristics		Effluent characteristics	
	Influent	Class	Effluent	Classification
BOD/mg•L^{-1}	155.6	M	45.12	L
COD/mg•L^{-1}	397.2	M	115	L
TSS/mg•L^{-1}	154.1	M	63.18	L
Nitrate/mg•L^{-1}	1.84	L	0.53	S
Economic indicators				
Capital costs /$.m^{-3}•d^{-1}	25.7-34.3		Low	
O & M /$.m^{-3}•d^{-1}	0.53-1.67		Low	
Land reqms /m^2.m^{-3}•d^{-1}	12.5-14.0		High	
Energy reqms /kWh.m^{-3}•d^{-1}	0		Very low	

In the DSM, the influent concentration of BOD, COD and TSS is reduced from moderate to low concentration in the effluent. This was on application of technology performance efficiency ratings in Table 5 and technology performance data in Table 6 as illustrated below with BOD.

Wastewater indicator considered – BOD

Technology performance rating – Good

Performance efficiency level (%) – 71- 90

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

$155.6 \times 0.29 = 45.12$ mg/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 14 presents results of both tools i.e. ED-WAVE and DSM.

From the results presented in Table 14, 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 varied depending on the capacity of treatment plant and locality.

Table 14 Treatment results comparison

Characteristic	Effluent concentration classification: ED-WAVE	DSM
Environmental indicators		
BOD/mg•L^{-1}	L	L
COD/mg•L^{-1}	L	L
TSS/ mg•L^{-1}	M	L
Nitrate/ mg•L^{-1}	S	S
Economic indicators		
Capital costs/\$.m^{-3}•d^{-1}	Low	Low
O & M /\$.m^{-3}• d^{-1}	Low	Low
Land reqms /m^{2}.m^{-3}•d^{-1}	Moderate	High
Energy reqms/kWh.m^{-3}•d^{-1}	Very low	Very low

4 Conclusions

The main objective of the research work was to develop a Decision Support Method (DSM) 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 DSM.

The following conclusions were made from the research work:

- 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 thus allowed for rating on technology performance.
- The developed 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 fuzzy logic.
- Classification of wastewater treatment technologies in DSM and ED-WAVE were in most cases similar thus indicating the validity of DSM.
- 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.
- 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.

Acknowledgements

The authors gratefully acknowledge support extended by Jomo Kenyatta University of Agriculture and Technology, the Ministry of Water and Irrigation, Kenya and Lappeenranta University of Technology for research funding through the CIMO-JKUAT training program.

[References]

[1] Seckler D, Upali A, Molden D, de Silva R, Barker R. World water demand and supply, 1990 to 2025: Scenarios and issues. 1998; Research Report 19: Colombo, Sri Lanka.

[2] Mensah E Amoh P, Abaidoo R C. Environmental concerns of Urban and Peri-urban agriculture: Case studies from Accra and Kumasi. In: Drechsel P, Kunze D (eds) Waste composting for urban and peri-urban agriculture: Closing the rural-urban nutrient cycle in sub-Saharan Africa.IWMI, FAO, CABI Publishing, Wallingford, UK. 2001; pp 55–68.

[3] Rose D G. Community-Based Technologies for Domestic Wastewater treatment and Reuse. Option for urban Agriculture. 1999; CFP Report 27.

[4] Kilelu C W. Wastewater Irrigation. Farmers' Perceptions of Health Risks and Institutional Perspectives: A Case Study in Maili Saba, Nairobi. Cities Feeding People Series, 2004; Report 38.

[5] Grau P. Low cost wastewater treatment. Water Science and Technology, 1996.

[6] Mara D D. The Production of Microbiologically Safe Effluents for Wastewater Reuse in the Middle East and North Africa. Water, Air and Soil Pollution, 2000; 123: 595–603.

[7] Massoud M A. Tarhini A, Nasr J A. Decentralized approaches to wastewater treatment and management: Applicability in developing countries. Journal of Environmental Management, 2009; 90: 652–659.

[8] Volkman S. Sustainable Wastewater Treatment and Reuse in Urban Areas of the Developing World. Michigan Technological University, 2003.

[9] Von Sperling M, de Lemos Chernicharo C A. Urban Wastewater Treatment Technologies and the Implementation of Discharge Standards in Developing Countries. 2002; Urban Water 4: 105–114.

[10] Bdour A N, Hamdi M R, Tarawneh Z. Perspectives on sustainable wastewater treatment technologies and reuse options in the urban areas of the mediterranean region. Desalination, 2009; 237: 162–174.

[11] Muga H E. Sustainability of wastewater treatment technologies. Journal of Environmental Management, 2008; 88: 437–447.

[12] Avramenko Y, Kraslawski A. Case Based Design. Applications in Process Engineering. Springer-Verlag Berlin Heidelberg, 2008.

[13] Balakrishnan M, Paraskeva P, Ratnayake N, Mungcharoen T. Wastewater Treatment in Asia and Europe, 2005.

[14] Anagnostopoulos K P, Gratziou M, Vavatsikos A P. Using the fuzzy analytic hierarchy process for selecting wastewater facilities at prefecture level. Journal of European Water, 2007; 19/20: 15–24.