(online) = ISSN 2285 – 3642
ISSN-L = 2285 - 3642
Journal of Economic Development, Environment and People
Volume 1, Issue 1, 2012

URL: http://jedep.spiruharet.ro
e-mail: office_jedep@spiruharet.ro

Decision Making Support in Wastewater Management: Comparative Analysis of Techniques and Tools Used in Centralized and Decentralized System Layouts

UDK 628.2

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Abstract

Wastewater management has been seen primarily as a technical and economic issue but it is now recognized that these are some of the elements in an array of other factors that affect sustainability of wastewater systems. Literature studies point out that municipal authorities have a general and long-standing tradition of using indicators in monitoring performance, reviewing progress and reporting the state of the environment as part of the regulatory enacted compliance. However, they have neglected other critical aspects of use of these indicators such as their input into the planning and decision making process. This research advocates for the use of sustainable indicators in a context based planning approach and the utilization of Multi Criteria Decision Aid (MCDA) in a two step approach for comparative analysis and assessment of the sustainability of wastewater systems. The overall objective was to develop a methodology for wastewater systems selection and to produce a practical planning tool to aid in decision making for municipalities. Another objective was to provide recommendations for wastewater and sanitation management improvement in the case study area. The methodology consisted of comprehensive literature review, case study analysis, a review of the Decision Support Systems (DSS) in use and the development of the DSS for Gauteng Province. The full spectrum of viable wastewater or sanitation options was incorporated into the DSS. From the sustainability assessments carried out using Multi criteria decision analysis, one result showed that varying degrees of sustainability are obtainable with each treatment technology involved and decentralized technologies appear more sustainable. Based on the local context and indicators used in this research, the DSS results suggest that land treatment systems, stabilization ponds and ecological treatment methods are more sustainable. One major finding from literature is that no technology is inherently sustainable on its own but is a function of the local context specifics. Since there is so much variation in social and economic needs within the areas; the overall results imply that a differential wastewater management approach should be employed with tailor made solutions resulting for each municipality or certain areas within a municipality.

Keywords: centralized systems, decentralized systems, decision support systems, multi criteria decision analysis, sustainability

JEL Classification: Q25, Q28, Q53, Q58.

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ISSN-L = 2285 – 3642
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1. Introduction

The decision making process within wastewater planning has not been clear in terms of the choices considered and the reasons for the selection of a particular system solution. Zeng, Jiang, Huang, Xu, & Li (2006) have pointed out that traditionally, many wastewater systems and technologies have been selected on an ad-hoc basis with more attention being paid to the economic data provided in the feasibility report of the Wastewater Treatment Plant project and the political and economic strength of the recipient communities rather than on the basis of performance requirements and environmental and public health considerations not to mention the efficiency and sustainability considerations that should collectively forming the core criteria for the decision. This resulted in the selection of the alternatives with minimum capital and operation costs being lauded as 'the most economical' means of meeting the applicable water quality and public health requirements without consideration of the long term sustainability. This approach does not meet the triple bottom line requirements for sustainable development and overlooks the importance of the local context, which has to be taken into consideration in assessing the sustainability of specific wastewater solutions since technologies are not inherently sustainable but are rule function of the local context specifics.

The root cause of many of the factors that have contributed to this unfortunate situation can be traced to insufficient attention to planning principles, lack of harmonization of policy guidelines and implementation of quick fix approaches.This inadequate planning is surprising considering that 80-90% of life cycle costs and environmental impacts or costs of the solutions provided are formulated and decided on during this crucial planning stage (Massoud, 2007). Unfortunately, wastewater system planning in developing countries often appears to be a non-strategic supply driven approach and technology bias resulting in the provision of inappropriate and unsustainable solutions. The supply driven approach is characterised by serious flaws where planners and engineers assess needs and decide what type of service to provide without extensive and meaningful consultation with the primary stakeholders (Ilemobade, 2003; Massoud, Tarhini& Nasr, 2007).

Generally there is evidence from practice that one of the primary obstacles to achievement of sustainable wastewater management is actually the lack of a structured and adequate decision making framework and especially so at the level of system level decisions and technology selection. This research advocates for the use of sustainable indicators in a pro-active context based input to planning, utilising Multi Criteria Decision Aid (MCDA) for comparative analysis and assessment of the sustainability of wastewater systems. The overall objective of this research is to make use of Multi Criteria Decision Aid (MCDA) in a Decision Support System (DSS) for the comparative evaluation and selection of wastewater systems technology with respect to technical, environmental and social in one step and then carryout a detailed economic analysis on the finite solution set as a second step. The specific objectives of the research were defined as to improve or restructure the current planning and decision-making and to produce a practical planning tool to aid in decision making for municipalities in South Africa and other developing countries.

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ISSN-L = 2285 - 3642
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2. Background

It is a known fact now that Sub-Saharan Africa is the world's most rapidly urbanizing region, and most of all this growth has been in slums. UN Millennium Report (2010) states that in the slums, the new city residents' face overcrowding, inadequate housing, and a lack of water and sanitation. Jackson (2002) expands this by pointing out that the mushrooming of informal settlements in most major cities usually precedes installation of basic services provision thus leading to exacerbation of the problem of waste management. Other researchers such as Gumbo &Marjanovic (2003) have confirmed that this approach will continue to put severe strains on the water supply and sanitation services resulting in many African cities having an increasing number of overcrowded, informal settlements or 'shanty towns', characterized by inadequate sheltered housing and poor provision of infrastructure services. According to Tayler, Parkinson & Colin (2003)
the informal sector is now the main provider of urban housing, but informal developers seldom provide their schemes with anything more than the most basic services and this has an impact in meeting the Millennium Development Goals.

Millennium Development Goal # 7 calls for the reduction by 50% of the number of people living without access to reliable and safe water supply by the year 2015 as well as a 50% reduction in the number of people without access to appropriate sanitation services. Estimates indicate that some reasonable progress was made in most of the developing regions between 1990 and 2002 but sanitation coverage still remains very low. Over the period 1990-2002, about 1 billion people globally gained access to improved sanitation (UN Report, 2004).

From a global perspective, the world is on track to meet the water target, however sub-Saharan Africa, despite impressive programs, still lags behind as evident in (Fig 1.1). If the 1990-2002 trends holds, the world will miss the sanitation target by more than half a billion people. With a business as usual investment scenario, the population without adequate facilities would increase to 3.2 billion by 2030.The situation is most serious in sub-Saharan Africa and Southern Asia. Research findings by Gumbo &Marjanovic (2003) reveal that;

- Connection levels for al l services in Africa are lower than in all other world regions
- Approximately 40% of residential accommodation in Africa is non-permanent over 148 million people live in urban slums
- House price-to-income ratios in Africa are the highest in the world at 12.5% which is double that of cities in highly industrialized countries.

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The United Nations Millennium Development Goals Report (2004) showed the global urban and rural population without adequate sanitation was 1.7 billion in 1990 and 2.6 billion in 2002. The projected estimates reveal that even with accelerated investment and improved process and operation efficiency of centralized systems, this number would not reduce before the year 2030 because of population growth (Gumbo &Marjanovic, 2003).Based on literature studies, the likelihood of achieving MDGs therefore increases with decentralization of wastewater management and innovative approaches to water management rather than with centralized wastewater management systems but the most important question is how sustainable are the technologies employed within the decentralized systems? Decision support systems have played an important role in answering the above question.

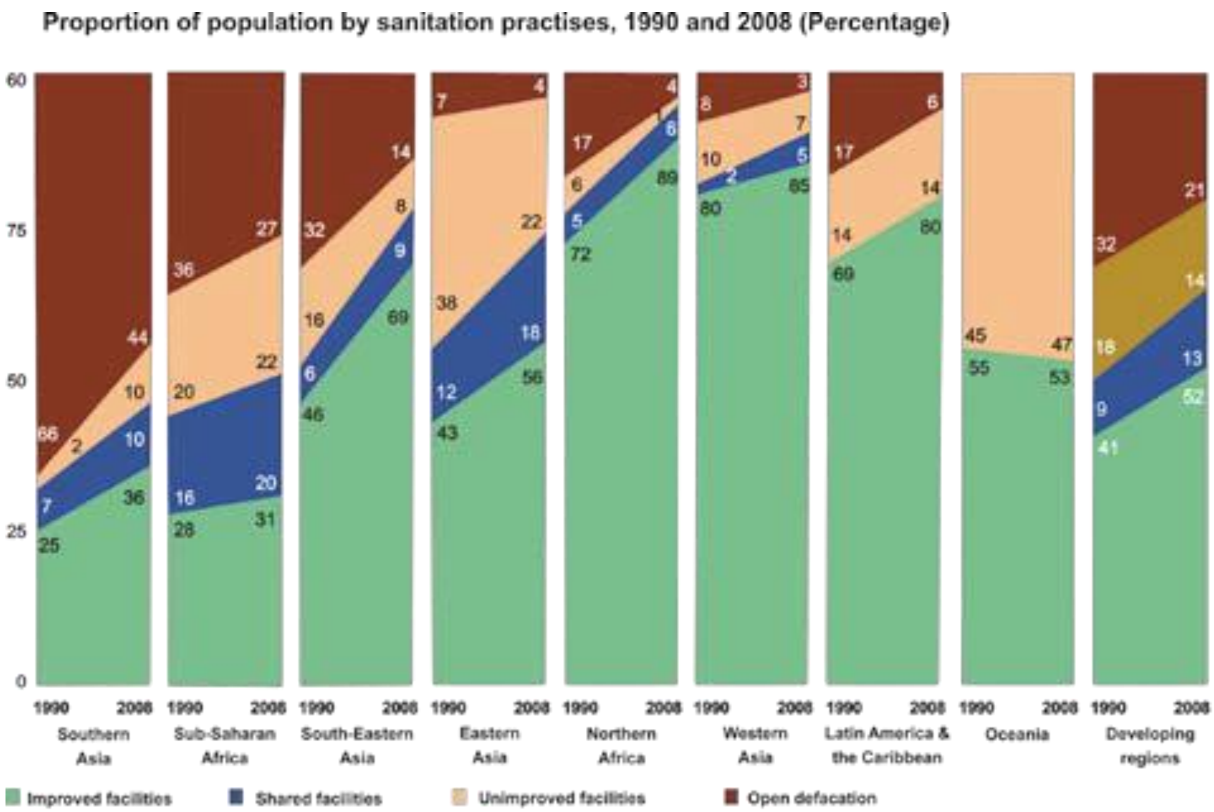

Fig. 1: Proportion of population by sanitation practices, 1990 and 2008 Percentages, (Data Source: United Nations Report, 2010)

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3. Decision Support Systems

In developing countries, water, sanitation, and hygiene practitioners need a way to choose among the numerous available options for securing safe water and sanitation. According to Palaniappanet al., (2008) effectively addressing community needs requires that technologies or approaches be economically, ecologically, and socially appropriate and sustainable. Decision-making supports tools help address this need, guiding practitioners to the most appropriate water and sanitation solutions. Several efforts have been done in the development of decision support programs as valuable tools in finding solutions to many engineering and management problems (Ndiritu and Daniel, 2001; Safaaet al., 2002; Ndiritu, 2003; Ilemobadeet al., 2005; Ilemobade and Stephenson, 2006;; Kahindaet al.,2009; Adewumi, 2010). In the field of wastewater treatment engineering, several contributions have been made to arrive at optimum treatment design by the use of computer programs utilizing decision criteria or indicators. According to Agudelo et al., (2007), many efforts have been done to define multi criteria methodologies as an aid in the selection of urban water systems. Agudelo et al., argue that the methodologies used in each unique case are not comparable since they differ in objectives and boundaries definitions. Ellis and Tang (1990) and Tang and Ellis (1994) also used multi criteria analysis (20 criteria) that cut across technical, economic, environmental and socio-cultural factors to form a decision matrix to rank 46 wastewater treatment processes.

2.2 Multi criteria Decision Aid

Malamis (2008) defines Multi criteria Decision Aid (MCDA) as a branch of a general class of operations research models dealing with decision problems under the presence of a number of decision criteria in a structured and systematic way. According to many authors, Multi-Criteria Decision Making is divided into multiple objective decision making (MODM) and multi-attribute decision making (MADM). Joubert & Stewart (2004) state that multi-Criteria Decision Making (MCDM) is an umbrella term for a wide range of techniques that explicitly include multi criteria in the evaluation of alternatives.

Hidalgo et al. (2007) used multi criteria analysis to develop a decision support system to promote safe urban wastewater reuse. The analysis assigned weights to various indicators like treatment technology, costing factor, land availability, type of soil, type of crops cultivated and their water requirements, meteorological conditions and legislative requirements to score the safe reuse of wastewater effluent. Muga et al., (2007) avoid aggregation of criteria and presents results in a radar plot which is satisfactory for communication and discussion requirements. All these methods have been used as form of support for the decision making process. Agudelo et al, (2007) acknowledge that complicated software to make complex analysis have been developed, however, the reliability of the results depends on the quality of the input data.

Despite the many DSSs developed in the wastewater management, the chance of Decision Support Systems failing to meet the challenge of real-world problems is reported to be high and even the criteria for judging whether a DSS has been successful or not are often a matter of discussion (e.g. Zapatero, 1996; Newman et al., 1999;Giupponi, 2007). There is therefore a widely-recognised need to develop new decision support tools in this field, with greater attention to the context specific needs of the users and which can be tangibly applied to solve practical situations.

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This research presents a practical toolfor decision support system that was developed that is context oriented and enables all sustainable criteria to be evaluated in two steps and across many alternatives (solutions) through the utilisation of Multi Criteria Decision Aid (MCDA)with respect to technical, environmental and social impacts first and later with respect to economics. Earlier studies have used a comprehensive, multi-disciplinary set of indicators but they did not compare conventional/mechanical, package plants, ecological land treatment technologies as proposed in this research. In order to fulfill the objectives of the research and achieve the desired research output, a rather unique methodological approach had to be followed. This approach poses a set of fundamental research questions with reference to a particular real life situation (Case study approach) and tries to answer them by the analysis of the existing situation for particular case (study area) and then uses the findings of this process to identify the problems in current decision making processes in order to develop and propose a new approach to decision making and offer a useful decision making support tool in the form of a user friendly decision support system.

4. Methodology

The first step in the overall methodology was to establish a clear understanding of sustainable wastewater management and the concepts involved. This understanding formed the foundation for step 2 which was the status quo analysis in study area (eight municipalities in Gauteng). The expected findings of step 2 were formulated as the primary drivers of this research. The status quo analysis identified a deficient decision making framework in wastewater management in South Africa and this established the justification for step 3 which was the establishment of a clear understanding of Decision Making in Wastewater Management. Literature review and synthesis were the main approach in completing step 3 of the research. With clear understanding of the problem of Sustainable Wastewater Management and the associated decision making framework it was then possible to engage in steps 4 and 5 and develop decision making methodology and the associated decision support tool to enable better decision making in practice as shown in Fig 2. Finally, in step 6, the conclusions were formulated and recommendations were made.

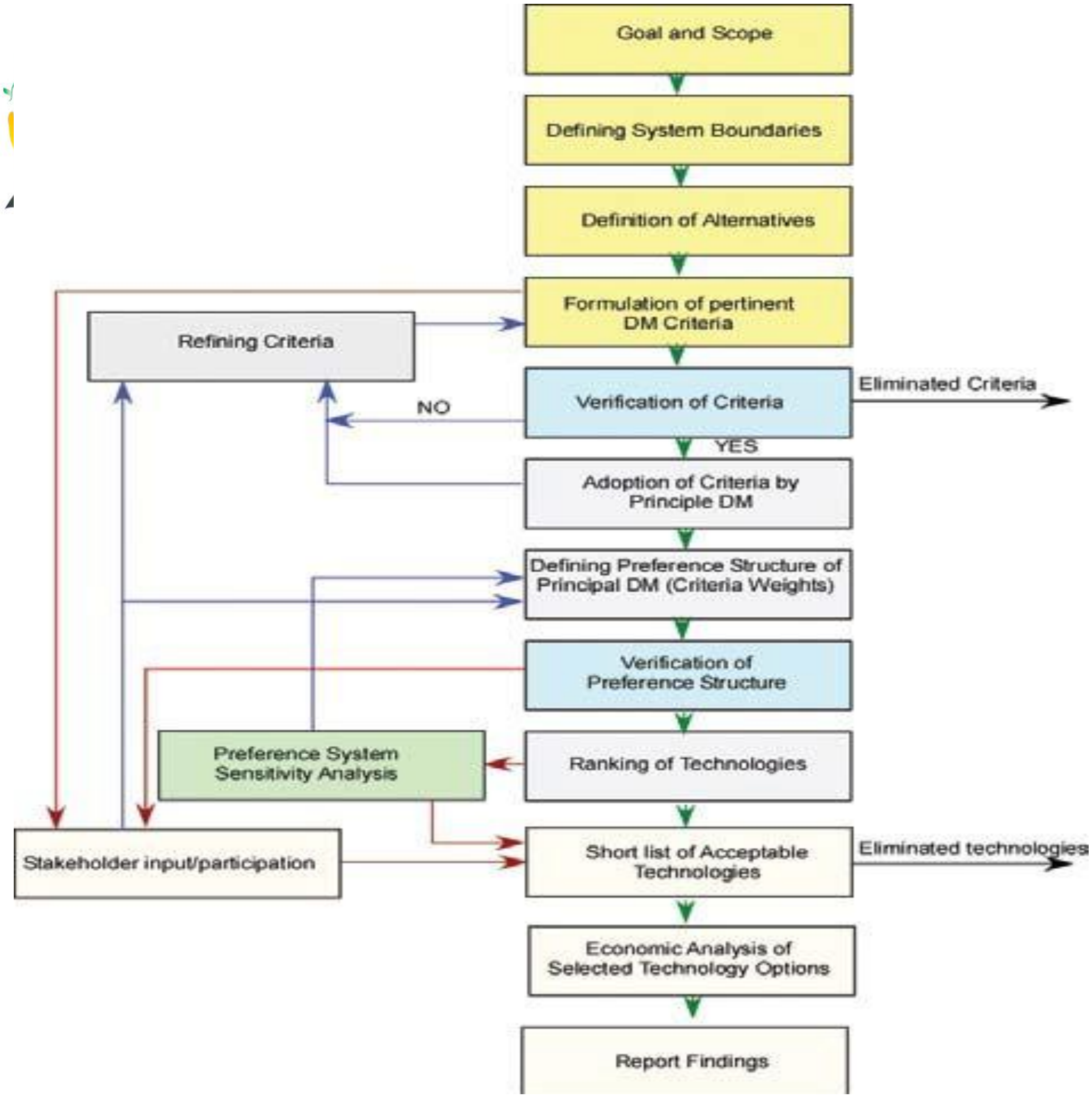

Fig. 2: Technology Option selection Process and Steps

4.1. Goal and Scope Definition

In this stage of the assessment the system boundaries and sustainability criteria are defined. It is convenient to employ a checklist so that key aspects are not overlooked since in the definition of the goal and scope one can rule out sustainable solutions beforehand.

4.2. Defining Alternatives

Alternatives represent the different choices of action available to the decision maker. The alternatives were chosen on the basis of the available knowledge, sound engineering judgement, and practical experience within the South African environment. The technologies were classified on a scale of 1-5 for suitability for use in centralised and decentralised systems. At a workshop and in various meetings all municipal authorities in the 8 municipalities were given an opportunity to list the possible technologies that could be utilised in their respective municipalities.

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4.3. Formulation of Pertinent Criteria

This research considered the use of MCDA in sustainability assessment of wastewater technologies and systems. Indicators developed in this study were reviewed and customized to the South African conditions based on the input from the Water Service Providers (WSPs) and DPLG and as well with reference to published indicators. In light of field testing experiences, it was recommended that Ranking and/or Rating be used as initial screening tools as they provide a quick way to filter out criteria that are not sufficiently significant. A set of 41 criteria was initial set and was consolidated by eliminating overlaps as much as possible. The final set of criteria ended with eleven main criteria. A ranking exercise using a set of questionnaires and criteria were accepted or rejected over the average value score obtained from the ranking. The screening of criteria was done on the basis of the scale shown in Table1.

Table 1:Criteria Classification

Classification of Criteria	Score Range	Decision
Highly Significant	10	Accept
Significant	7-9	Accept
Fairly Significant	5-6	Accept/Reject
Insignificant	<5	Reject

The set of eleven criteria excluding economic criteria is presented in Table 3.2 and is not to be regarded as a final set in any aspect other than representing the final result of this research. In order to be useful this set needs to be continuously revised since the choice of criteria may change as knowledge advances. The rejected criteria for this research are archived in a set which is not considered in further upstream processes for the decision making.

Table 2: Sustainable Criteria

Social	Technical criteria	Environmental
Acceptance	Performance	Resource Utilisation
Awareness	Reliability	Environmental Impact
Job Creation	Adaptability	
Institutional Requirements	Ease of Construction	
Health &Safety Impact		

4.4. General Assessments Methodology

A questionnaire was administered to the decision makers/service. The responses derived from the questionnaire were input into the DSS for analysis. The DSS uses a scale of 1-5 to generate a score from a set of questions/statements. The result obtained by summation of all questions/statements is then aggregated to obtain standardized outcome score on the scale 0 to 10 for the technical, social and environmental criteria. Arithmetic mean is used to aggregate the standardized value obtained in questions/statements involved in DSS questionnaires using the expression below:

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$$a_j = \frac{1}{m}\sum_{i=1}^{m} wx_{ij}$$ Eqn (5.1)

Where aj= aggregation result for assessment criteria j (j = 1, 2, 3, 4…n)
xij= merit of criteria j with regard to statement i (i = 1, 2, 3, 4…m)
wi= weight of criteria I i(i = 1, 2, 3, 4…m)
The final score on a scale of 0 to 10 is derived from the following positions;
If the Target for an indicator is Maximum score, then
Score= (dave – dlow)/dmax – dlow)*10
If the Target for an indicator is Minimum score, then
Score= |(dave – dlow)/dmax – dlow) -1|*10, where
dave is the average value over the range of scale considered
dlow is the lowest value over the range of scale considered
dmax is the maximum value over the range of scale considered

4.5. Weighted Sum Method

The Weighted Sum Method involves computation through maximising the expected utility function, Hj, as in the following:

$$H_j = \sum_{i=1}^{m} w_i v_{ij}$$ Eqn (4.2)

where m is the number of criteria of alternative j, vij is the value of jth alternative with respect to the ith criterion, and wi is the weight of importance assigned to criterion i with the constraints of wi≥0 and

$$\sum_{i=1}^{m} w_i = 100$$ Eqn (4.3)

The scores derived from use of the above equations are based on theoretical values, which were formulated using a combination of literature studies and assessments by the researcher in collaboration with Gauteng Provincial local government officials as well as Witwatersrand University postgraduate students for the Wastewater Engineering course. The research initially sought to base the scores from the municipal officials in the case study but due to the low responses on the questionnaires it was decided to use the above combinations in order to generate data for analysis and input in the decision support system as a way of testing the methodology. Full validation of the model and the methodology is recommended for the next level of research.

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4.6. Sensitivity Analysis

The results of the ranking can never be completely objective because of the weighting procedure, but confidence in the results can be increased by carrying out a sensitive analysis. This was done by looking at the effects on ranking caused by changes in the weighting. The criteria most open to subjective interpretation was selected and the weights of the criteria were slightly changed, recalculated and the final scores are summed up and re-ranking the technologies was done. Comparisons between the ranking order for different scoring and weighting scenarios indicated the level of confidence that can be given to the results.

4.7. Justification of the Methodology

The normal and most common multi criteria decision making methods employed in DSS evaluate all the alternatives against all the criteria simultaneously in order to get as sustainability measure of index. This is usually done with limited economic data thus rendering the whole exercise a rough planning exercise which still needs further analysis of the options. In developing countries, economic indicators are often decisive when choosing a technology. Unfortunately, in most cases cost data are hard to find, and many consulting firms or WSPs are not keen to share or publish their data for reasons best to known to themselves.

Since Cost data are hard to get, this research advocates for a two step approach in the normal multi criteria evaluations. The first stage will cover the three main criteria which will be termed stakeholder needs (social, environmental and technical). The shortlist of technologies from the screening exercise is then sent for detailed economic analysis based on the economic criteria. Economic criteria have their own indicators thus become a mini MCDA analysis within the broader MCDA analysis based on the economic criterion adopted. The process of adopting the criteria and the weighing systems is the same as the one employed in the first stage.

The advantages of carrying out the two stage approach in MCDA analysis is that cost data on the technologies and systems is not easily accessed and in the initial stage there will be so many technologies to be evaluated but doing the first stage eliminates some technologies thus the remaining feasible option set has fewer technologies which at that stage the analysis stops and then a detailed economic analysis be carried out involving total annual costs, specific unit costs and Life cycle costs. If the data is not readily available the municipality can carry out the detailed investigation or appoint consultants to come out with accurate figures on the economic costs of the technologies. Once that data is collected the MCDA process starts again on the basis of the economic data only. This will enable detailed investigations to be carried out which requires detailed costing that the municipals officials can commit to find/get before the final decision making and implementation of the findings.

The results from the detailed economic analysis are then sent to the decision makers to enable them to make sound judgment in a structured way and transparent way. The above process can be carried out using excel spreadsheets as a decision support system but this usually requires that users must have a higher understanding of the excel functions. The research aim is to present this methodology that would assist inexperienced or semi skilled personnel to ensure the integration of economic, social and environmental considerations in decision-making at all levels in the wastewater sector and hence, develops a simpler graphical user interface in a DSS that will make it easier for people to use.

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5. Results

5.1. Outline of the Analytical methodology

From the insights gained by the study of decision making processes in wastewater management and in particular the insights gained by doing a case study for the 8 municipalities in Gauteng a clear algorithm for the decision making methodology for wastewater management in Gauteng emerged and is shown in Figure 3.

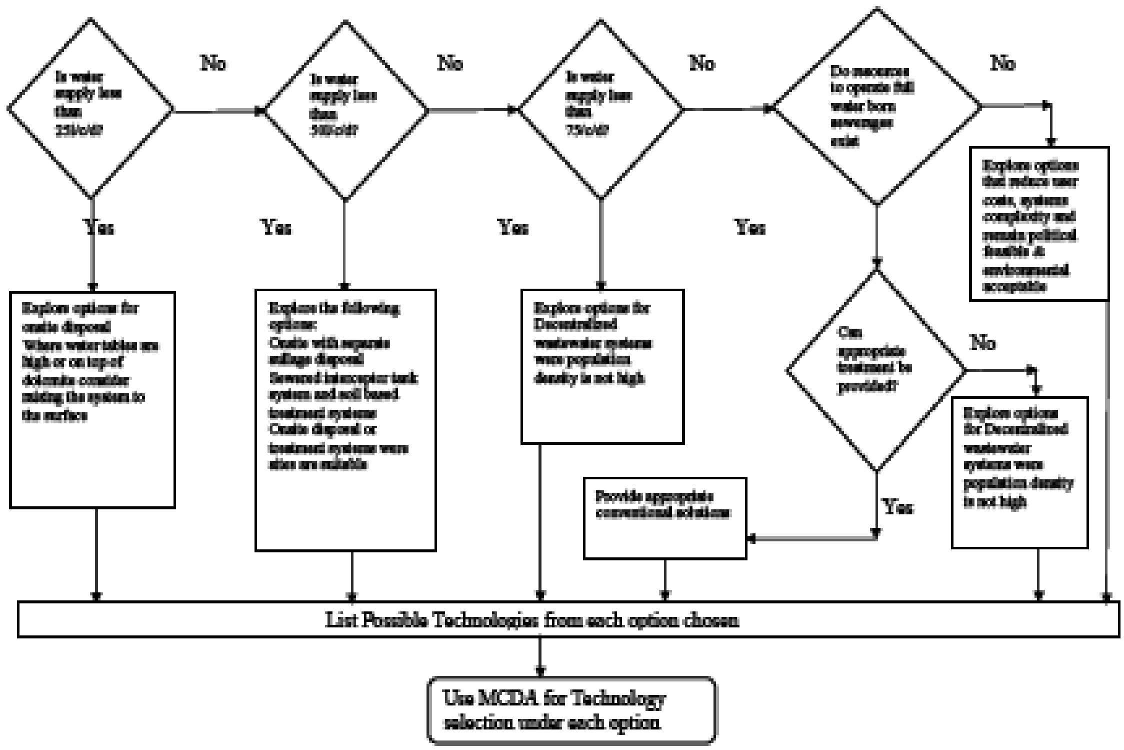

Fig. 3: Algorithm for Technology Selection

The algorithm in Fig 4.1 when used with the technology database in the DSS makes it easier to narrow down the options based on the local context and preferences of the stakeholders in technology selections. As can be seen in Fig 4.1, an array of all possible wastewater treatment technologies can be considered from onsite dry sanitation to offsite full waterborne systems which then based on the local context is taken to the next level of analysis using MCDA.

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5.2. Discussion of Results

The results presented in this section are from the outcomes of the questionnaire survey. It should be noted the results presented herein are not conclusive of the research studies since in the case for Municipal officials the responses out of a possible 35 only 6 responded and the other 15 responses could not be used since there were incompletely filled. Despite repeated efforts to get responses there was no commitment to complete the exercise. This might be understood from a practical case in the study areas where municipal officials are bombarded with questionnaires from different consultants asking the same things in different ways and formats but from the surveys there is nothing tangible that comes from the researches. On the other hand the responses from the postgraduate students for the wastewater engineering course were encouraging. Out of a possible 42 students 37 managed to complete the questionnaires with high enthusiasm.

In order to make the selection much easier this research constructed a technology database in the DSS as shown in figure 4. By double clicking on the technology name, a summary of information of the technology is found which enables a comparative analysis with other technologies in the database. The database also allows for further addition of technology in the prescribe format in which the user is guided through. The database provides a description of the different technology types which will act as information for educating and providing better understanding of the technologies which will eventually lead to the decision makers having confidence in the decisions they make.

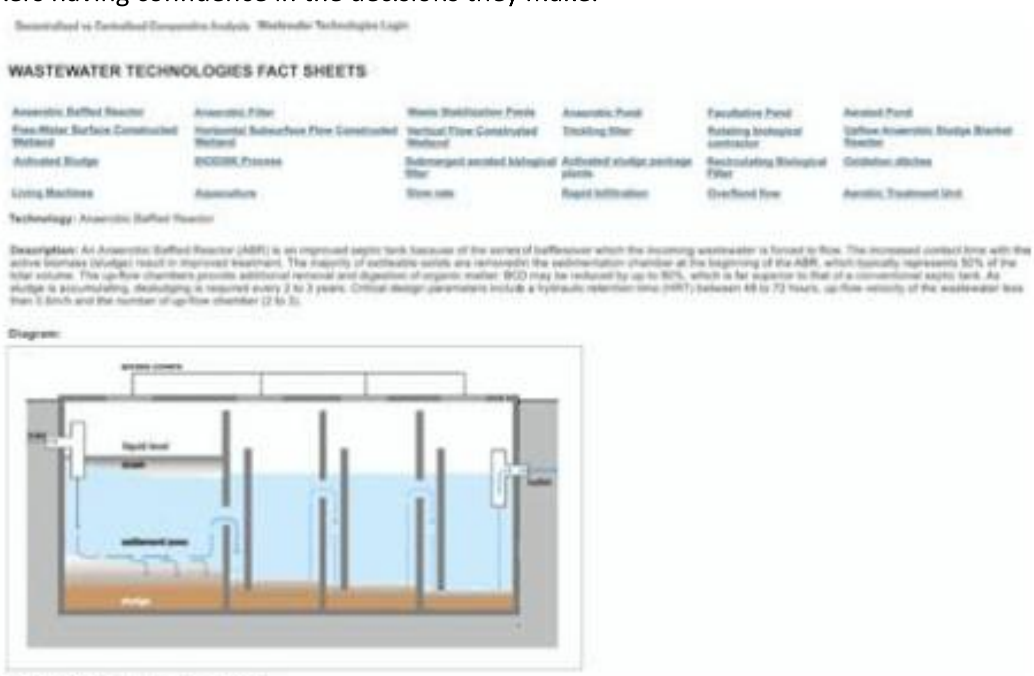

Fig. 4: Dialogue Screen on Technology Factsheets

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5.3. Perceptions to Wastewater Systems

Figure 5 shows that decentralized systems are perceived to perform better than centralized systems. This rational is not surprising since the analysis comes from postgraduate students who are deemed to have more theoretical knowledge of wastewater systems. The results also show a bias since the students had gone through the Wastewater Engineering course which in a way contributed to the bias since the course seeks to challenge conventional thinking in wastewater management. Technical officials' survey reveals the opposite and the explanation is simply that they have not had chance to explore the new knowledge on decentralized systems available and also have a high inertia to change to the critical thinking required.

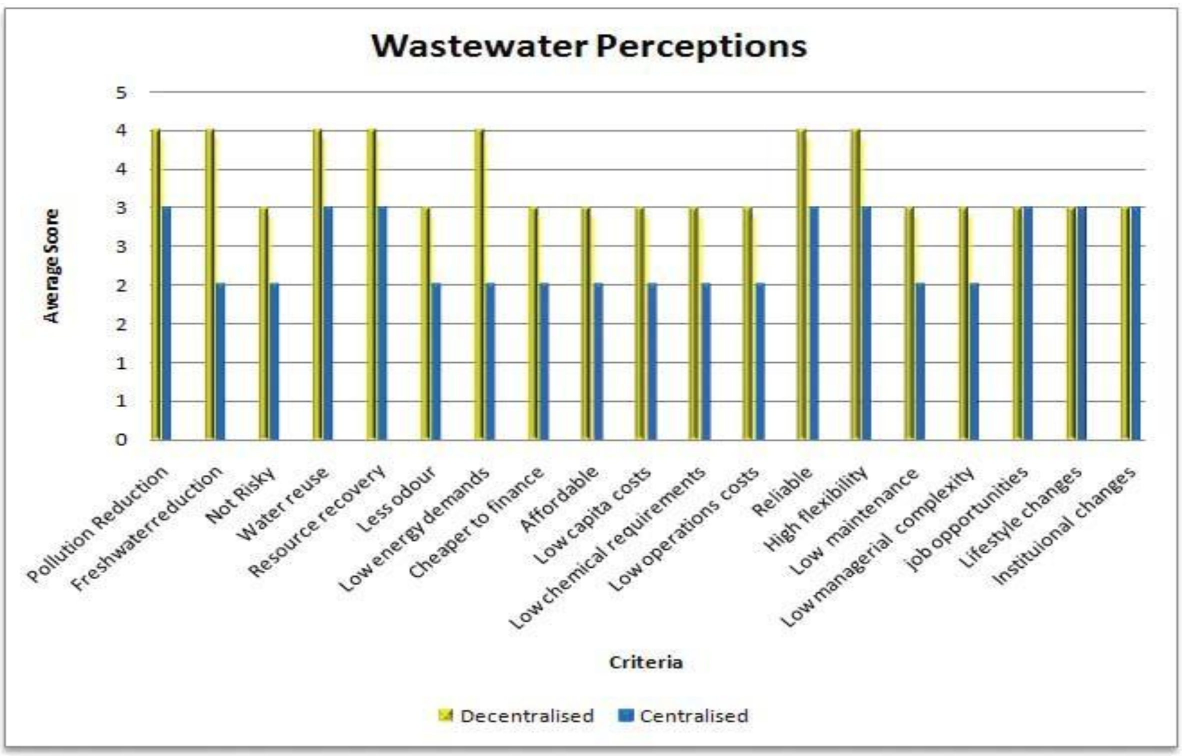

Fig. 5: Perceptions to Wastewater Systems

The list of technologies adopted for the case study is shown in Table 3. Literature studies and a survey among the water practitioners were used to determine the level of suitability of the technologies for either centralization or decentralized systems. The suitability factor was used to measure the degree of centralization or decentralization of the technologies through assessment on a scale measurement as follows; 1- Not suitable, 2- partially suitable; 3-fairly suitable; 4- suitable, 5- High suitable.

Table 3. Technology Suitability for Centralised or Decentralised Systems

Technologies	Suitability For		How Suitable for Centralised Systems					How Suitable for Decentralised Systems				
	Centralised	Decentralised	Highly Suitable	Suitable	Fairly Suitable	Partial Suitable	Not Suitable	Highly Suitable	Suitable	Fairly Suitable	Partial Suitable	Not Suitable
Activated sludge	√	√	√						√			
Trickling filter (biofilters)	√	√		√					√			
Rotating Biological Contactors	√	√		√					√			
Aerated lagoons	√	√				√			√			
Anaerobic lagoons	√	√				√			√			
Facultative ponds	√	√				√			√			
Recirculating biological filter		√				√			√			
Submerged aerated biological filter		√				√			√			
Sequence batch reactor	√	√				√			√			
Oxidation ditches	√	√				√			√			
Bio disc units	√	√				√			√			
Constructed wetlands	√	√				√			√			
Living machines		√					√		√			
Aquaculture		√					√		√			
Slow infiltration		√					√		√			
Rapid Infiltration		√					√		√			
Overland Flow		√					√		√			

(online) = ISSN 2285 – 3642

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There are many wastewater treatment technologies available for centralized and decentralized systems. Choosing from the large range of set of centralized and decentralized systems can be complex and time consuming, which may cause the municipal authorities to disregards decentralized technologies.

5.4. Results of the first step MCDA Evaluations

The main criteria overall weightings for the case study were as follows technical (30%), social (30%) and environmental (40%). The weightings were derived using the swing method in the second workshop held with the municipal officials. The evaluations using MCDA show that land treatment systems, followed by package plants, ecological and stabilization ponds are more sustainable than the mechanical systems (Figure 4.4). The mechanical systems have high requirements for resources in terms of energy and may require the use of chemicals in some instances. The advantages of the land treatment systems are their low odor potential, as well as high performance in removals of BOD, TSS, N, P and fecal coli forms. Land treatment systems and lagoons both have lower energy requirements although they have high land requirements.

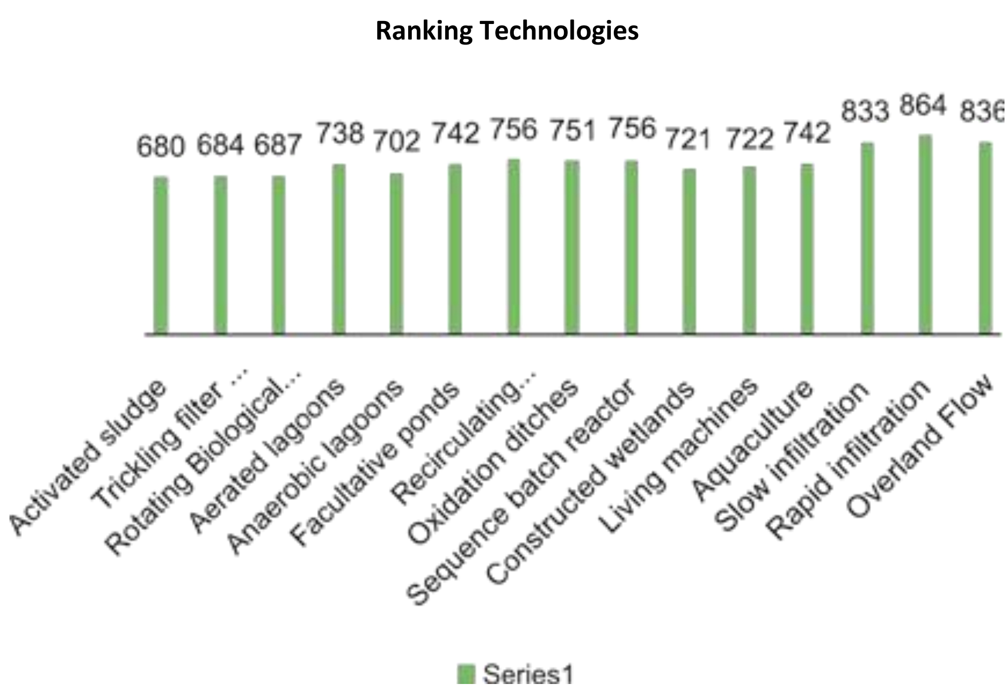

Fig. 6. Ranking of Technologies

The overall results from the calculation are ranked through a bar chart as shown in Fig 4.4, with the most sustainable technologies having a higher score or length on the chart. The overall score possible with all three main criteria considered simultaneously is 900. Table 4 shows the scale used for analysis and for acceptance for the possible sustainable solutions.

Table 4. Sustainability Index Classification

Classification of Choice	Score Range	Sustainability Ranking
Excellent	800 - 900	Sustainable
Very Good	700 - 800	Sustainable
Good	600 – 700	Partial Sustainable
Fair	400 - 600	Partial Sustainable
Poor	<400	Not sustainable

5.5. Technologies Shortlist

Based on the scale highlighted in Table 4.2, all the technologies having a score above 700 were shortlisted for further assessment after a sensitivity analysis test. Table5 lists the shortlisted technologies.

Table 5. Technology Ranking Shortlist

Rank Number	Technology
1	Rapid Infiltration
2	Overland Flow
3	Slow infiltration
4	Recirculating biological filter (RBF)
5	Sequence batch reactor
6	Oxidation ditches
7	Facultative ponds
8	Aquaculture
9	Aerated lagoons
10	Living machines
11	Constructed wetlands

5.6. Sensitivity Analysis

The only sensitivity test done was by varying the weight percentages of technical main criteria over the range 20% and it showed that there were no significant changes in the rankings. The environmental criteria proved to be the one more sensitive to weight changes but the rank order in terms of the categories of the technologies remained the same in as much there were rank changes within the categories depended on the increase in weighting for the environment. Sensitivity analysis is of prime importance since it shows how much the results and especially the final ranking of the proposed technologies are influenced by fluctuations in the weight coefficients of the criteria.

5.7. Results of the Economic analysis

The Caribbean data only accounts for the capital and operation and maintenance and it was on this basis that the final ranking was done. The weightings for the economic criteria were 70% capital cost and 30% on operation cost. The results from the evaluation using MCDA is shown in figure 4.5 The results show that land treatment system (Rapid infiltration), ponds and the ecological treatment methods (constructed wetlands and aquaculture) are more sustainable than the package plants. This is because the capital costs for the package plants are higher than those for the land and ponds treatment methods. It should be noted that sustainability measure should not be limited to now but should be over a defined period say at least a minimum of forty years. Since what might not be sustainable now i.e. the high capital costs for the package plants might end up being feasible as the technologies start to be mass produced. It suffices to say that under present conditions the land, ecological and ponds treatment technologies are more sustainable but sustainability also has the connotation of the present generation having a knowhow of the needs of future generations. In view of this, this research advocates for continual review of the criteria and the dynamics involved with the changes in the economics and breakthrough in technologies which might occur in these decentralized technologies.

5.8. Final Ranking of Technologies

The results from the detailed economic analysis are then sent to the decision makers to enable them to make sound judgment in a structured way and transparent way. The results from the methodology employed imply that technologies under decentralized wastewater systems appear to be more sustainable. The above assessments are all employed in the decision making support system developed for this study. It has a simpler graphical user interface which enables the user to navigate through and apply the methodology described here for selection of wastewater technologies

(online) = ISSN 2285 – 3642
ISSN-L = 2285 – 3642
Journal of Economic Development, Environment and People
Volume 1, Issue 1, 2012

URL: http://jedep.spiruharet.ro
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6. Conclusions

Wastewater management has been seen primarily as a technical and economic issue but it is now recognized that these are some of the elements in an array of other factors that affect sustainability of wastewater systems. Literature studies point out that municipal authorities have a general and long-standing tradition of using indicators in monitoring performance, reviewing progress and reporting the state of the environment as part of the regulatory enacted compliance. However, they have neglected other critical aspects of use of these indicators such as their input into the planning and decision making process. This research advocated for the use of sustainable indicators in a context based planning approach and the utilization of Multi Criteria Decision Aid (MCDA) in a two step approach for comparative analysis and assessment of the sustainability of wastewater systems. The overall objective was to develop a methodology for wastewater systems selection and to produce a practical planning tool to aid in decision making for municipalities. The methodology consisted of comprehensive literature review, case study analysis, a review of the Decision Support Systems (DSS) in use and the development of the DSS for Gauteng Province. The full spectrum of viable wastewater or sanitation options was incorporated into the DSS. From the sustainability assessments carried out using Multi criteria decision analysis, one result showed that varying degrees of sustainability are obtainable with each treatment technology involved and decentralized technologies appear more sustainable. Based on the local context and indicators used in this research, the DSS results suggest that land treatment systems, stabilization ponds and ecological treatment methods are more sustainable. One major finding from literature is that no technology is inherently sustainable on its own but is a function of the local context specifics. Since there is so much variation in social and economic needs within the areas; the overall results imply that a differential wastewater management approach should be employed with tailor made solutions resulting for each municipality or certain areas within a municipality. This research implies a necessity for a paradigm shift in wastewater management which minimizes current and future environmental and human health negative impacts in wastewater management. The use of the DSS incorporating multi criteria decision analysis will aid local authorities in making informed decisions and enhance their planning capabilities. It has been clear in this research that if sustainable indicators are to contribute substantially to the increased sustainability of urban water systems, they must be applied not only in a retrospective way but in a future oriented manner for planning and decision making.

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(online) = ISSN 2285 – 3642
ISSN-L = 2285 – 3642
Journal of Economic Development, Environment and People
Volume 1, Issue 1, 2012

URL: http://jedep.spiruharet.ro
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