Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

Sustainable Wastewater Management Planning using Multi-Criteria Decision Analysis (MCDA) A Case Study from Khartoum, Sudan

S. H. Ibrahim[1,2]
[1]Department of Environmental Science and Technology
Faculty of Science and Technology,
Al Neelain University
Khartoum Sudan
[2]Department of Biology,
Faculty of Science and Arts,
Taibah University
Al-Ula, KSA

A. K. Sabir Ali[1]
[1]Department of Environmental Science and Technology
Faculty of Science and Technology,
Al Neelain University
Khartoum Sudan

***Abstract* — Wastewater Management (WWM) is one of the major development challenging issues in developing countries, which need more innovative solutions to meet future sustainability goals. This paper aims to analyse and discuss different WWM sustainable options for Khartoum State. Three WWM approaches were investigated, centralised and decentralised wastewater management approaches, using Multi-Criteria Decision Analysis to evaluate their suitability and sustainability for fast-expanding cities like Khartoum State – in Sudan. The results revealed that centralised wastewater approach is costly to build and operate, especially with horizontally expanding cities with low population densities. Future expansions can be problematic in terms of design and finance aspects. Decentralised wastewater management approach (onsite and cluster) was regarded as more sustainable, where such an approach is more flexible for planning, and simple as well as complex technologies are available. The decentralised system is not only a long-term solution but is more reliable and cost effective for future development purposes and sustainability assurance.**

Keywords— Multi-Criteria Decision Analysis (MCDA); Wastewater Management; Sustainable planning; decentralised approach.

1. INTRODUCTION

Sub-Sahara Africa is the world's most rapidly urbanisation region in the world, and most of this growth and expansions have been in cities' peripherals and slum areas. Most expansions and mushrooming of urban usually require installation of basic services provision which adding extra burdens to the problem of wastewater management (WWM). Other authors have confirmed that this supply-driven approach will continue to put severe stresses on the water supply and sanitation services [1]. Reports indicate that there is a reasonable progress was achieved in most of the developing countries between 1990 and 2006, although sanitation coverage remains very low.

The North African countries have been pointed as the most on track part of Africa for sanitation services coverage. However, Sudan was the only country left behind on the list of these countries [2]. Recent urbanisation processes of Khartoum are characterised by rapid growth, spatial disparities, and socioeconomic disruptions (Figure 1). Due to a massive growth in the number of inhabitants from 250,000 after independence in 1956 [3, 4], to an estimated 5.3 million in 2008 [5], which made Khartoum the one of the largest city in Africa.

During the 80s, the city experienced an exceptionally high annual population growth (10-12%) and accelerated urbanisation, mainly due to local displacement and political unrest in the South of the country and the successive years of drought, that hit their areas. According to the statistics [5], the population growth slowed down from 4,5% per year in the 1990's to 2, 4% per year between 2002-2008. This increase was concentrated in the western part of Omdurman and the southern suburbs of Khartoum in and around the internal displaced people (IDP) camps. These poverty-led expansions on the peripheries of the Khartoum city are contrasted by a complete different large-scale schemes urban development in the centre of the city financed by Arabian and Asian investors. The new Dubai-style business centre which was constructed in a prominent location near the confluence of the two Niles is associated with upper-class residential areas [6], and it may eventually challenge the majority of Khartoum's inhabitants who are coming from the countryside and are living under conditions of scarcity.

Khartoum's drainage and sanitation systems are in a bad condition and cover only a portion of the population (28% of the population is connected to the sewage system, though others argue that the percentage of those connected to the sewage system is as low as 5%.). This situation heightens the risk of disease especially during the rainy season [3]. Most residents use pit latrines and other basic systems such as septic tanks [8]. Either way, the sewage system is clearly overstretched, old and is no longer working properly [9]. The rapid urbanisation in Khartoum state resulted in increased pressure on the sanitation services, treatment, and disposal. Currently, there are two main wastewater treatment stations, Wad Dafeeah station in the northern part of Khartoum, and Soba wastewater treatment station in the southern part of Khartoum. Both stations are relatively large waste stabilisation ponds and suffering from malfunctioning and technical problems. More recently two activated sludge systems were implemented but still out of operation due to technical/design problems.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

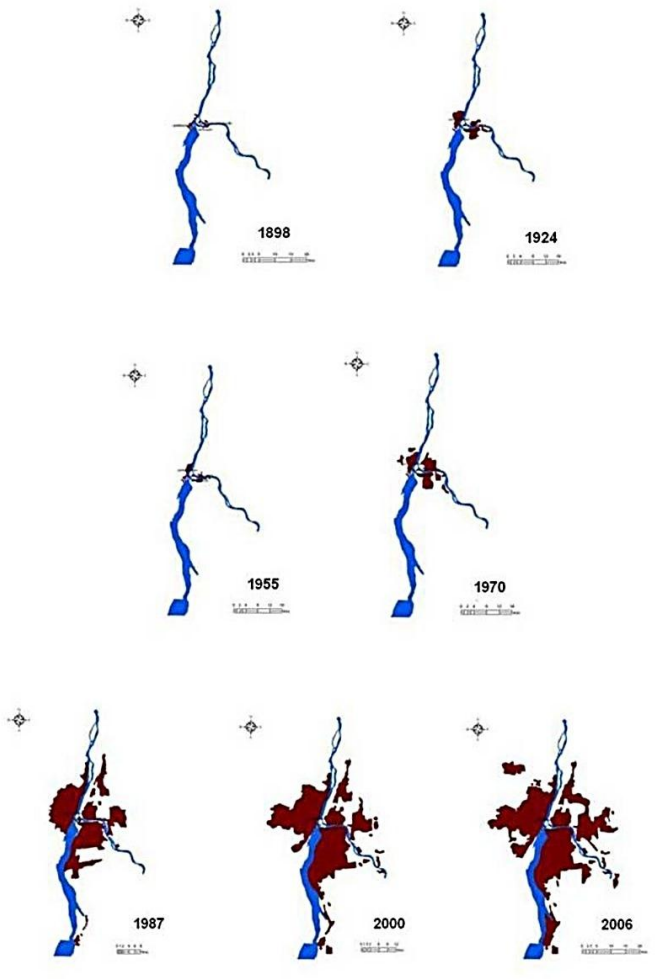

Fig.-1: The urbanisation and the expansion of Khartoum city from 1898-2006 [7].

From above it is clear that there is a need to develop a strategic wastewater management plans to go parallel with the urban development pattern of Khartoum City.

In the current paper, the problems associated with the wastewater management are discussed. Also, wastewater management planning and decision-making framework were constructed for selecting a sustainable wastewater management option for Khartoum State considering both present obstacles and future development. The framework examined three wastewater management approaches (Onsite; Cluster and Central wastewater treatment) using Multi-criteria Decision Analysis (MDCA) as a decision-making tool.

The decision process for wastewater planning has not been clear in terms of choices considered and the reasons for the selection of a particular system solution. Traditionally, many wastewater systems and adopted technologies have been selected based on ad-hoc decision with more attention paid to the economic data provided in the feasibility report of the management wastewater project, in addition to the political and economic influences rather than on the basis of performance requirements, environmental and public health considerations. Not to mention the efficiency and the sustainability considerations that should collectively form the core criteria for the decision-making process [10].

These factors and decision-making approaches resulted in selecting alternatives with the minimum capital and operational cost 'most economical option' without considering the long-term sustainability of the proposed project. Such approach does not meet with the Triple Bottom Line (TBL) requirements for achieving sustainable development-economical, environmental and social values [11]. Besides, the current selection approaches overlook the importance of the local context, which has been taken into consideration for assessing the sustainability of the specified wastewater solution since the technologies are not inherently guaranteeing the project's sustainability but the rule function of the local context specifies in the project's sustainability. For Khartoum State, the root cause of many factors that contributed to the unfortunate condition can be traced to insufficient considerations to planning principles, lack of harmonisation of different stockholders and the adoption of quick-fix approaches. Unfortunately, WWM planning in developing countries, in general, and in Khartoum specifically, often appears to be a non-strategic supply-driven planning approach and technology bias resulting in the provision of unsustainable solutions. Supply-driven approaches are always characterised by serious flaws, where planners and engineers assess needs to decide the type of service needed to be provided without extensive and meaningful consultation with the other stockholders [12].

For sustainable wastewater management planning, different criteria are required to be comprised and considered such as economical, social, environmental, etc. Solving such a multi-dimensional equation and to come up with the right decision can be hectic and difficult to achieve and sometimes either intentionally or unintentionally biassed. Multi-criteria decision-making (MCDM) techniques are enabled to structure the problem clearly and systematically. Integrating methods are very useful in MCDM problem solution [13]. One of the MCDA techniques is the analytical hierarchy process (AHP), which is helpful for handling multiple-criteria in decision-making. Moreover, AHP application enables the consideration of socio-cultural and environmental objectives which have the same importance as the economic objectives in selecting the optimal wastewater treatment alternative [14, 15]. The AHP approach is a systematic analysis technique which facilitates a rigorous definition of priorities and preferences of the decision makers. Besides, AHP also used to determine the weights of different factors [16, 17, 18].

2. Materials and Methods

2.1 Study layout:

A sustainability framework was constructed and used for the decision-making process, selecting strategic and sustainable wastewater management planning options for Khartoum State (Onsite, Cluster and Central wastewater treatment). The study was divided into three main phases (Figure. 2): 1) setting goals and systems boundaries; 2) selecting and verifying criteria; 3) Multi-criteria Decision Analysis. The decision-making criteria formulation was carried out based on literature survey for sustainability criteria used in wastewater management and planning. Verifying criteria and weighting were done through consulting experts from local authorities, independent consultants and NGOs.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

a. Phase one: Selecting Decision Making Criteria

The Decision-making framework was constructed and used for assessing wastewater management sustainability. The proposed decision-making framework considered four different attributes: Economical; Environmental; Technical and Social. Each attribute consisted of a number of criteria, which were used for the assessment process. In total 68 criteria were selected based on previous studies and report for assessing wastewater management. After criteria verification according to expert's consultation, 28 criteria were used (Table 1). New approaches in the wastewater field such as water reuse, nutrients reuse and recovery and energy recovery were included in the assessment.

b. Phase Two: Multi-criteria Decision Analysis (MCDA)

The MCDA was carried out considering the importance and interrelationship of various attributes associated with different decision alternatives. An attribute is a quantitative measure of per-performance related to a particular criterion, according to which an alternative measure to be evaluated [19]. The software Workbench for Interactive Preference Programming (WINPRE) was used for the analysis (System Analysis Laboratory – Helsinki University of Technology). The following procedure was followed [20]:

- Choose the most important attribute as reference attribute
- Regarding the reference attribute, compare the other attributes
- Assign 1.0 score to the best attribute.
- Select ratios to calculate the weights for the other attributes.

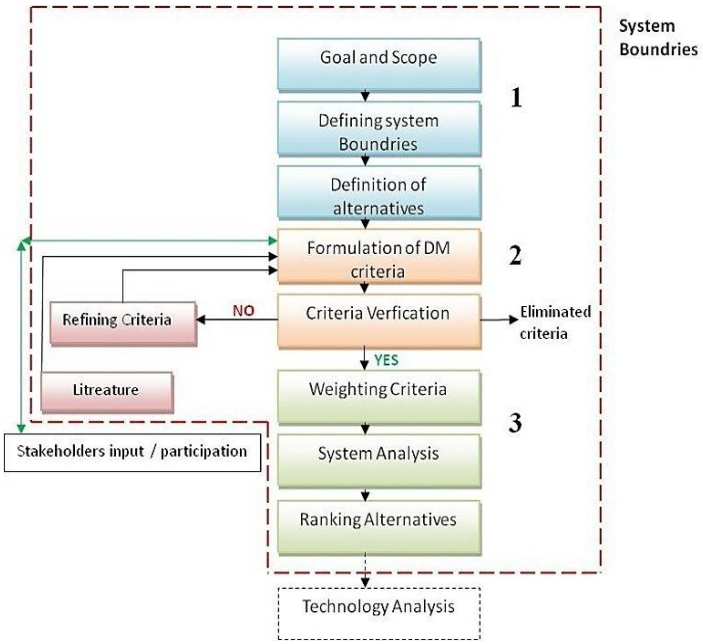

Fig.-2: Study layout and boundaries.

Table 1: Criteria and indicators used for the MCDA.

Economical
• *operational and running costs (Annual)*
• *Area requirements*
• *Affordability*
Environmental
• *Odour/noise*
• *Natural resources*
• *water reuse*
• *nutrients reuse*
• *Energy recovery*
• *Pathogens removal*
• *COD/BOD removal efficiency*
• *Heavy metals removal*
• *Chemical uses*
Technical
• *Durability*
• *Technical complexity*
• *shock loads*
• *Adaptability*
• *Operation and Maintenance*
• *Reliability*
• *Local competence and O&M*
Social and organisational
• *Awareness and participation*
• *Cultural acceptance*
• *Institutional requirements*
• *local development*
• *expertise*
• *future strategies*

The Attributes and criteria used are illustrated in figure 4. The interval SMART/SWING attributes weighting window of WINPRE is shown in figure 6. In SMART/SWING attributes window, a comparison was made between the identified attributes. In this case, the Environment was chosen as reference attribute.

The environment attribute was further Consisted a set of criteria (figure. 5); in this case, COD was chosen as reference criteria since it is the main objective of wastewater treatment.

3. Results and Discussion

In the current study, a comparative investigation was conducted to assess the sustainability of different wastewater management approaches (onsite, clustered and centralised wastewater treatment) and its suitability for Khartoum state, based on a set of sustainability criteria. This assessment was done using formulated decision-making framework as described in the previous section and multi-criteria decision analysis.

In General, the results have revealed that cluster type as decentralised wastewater management approaches was more favourable for Khartoum city according to the criteria used in the current study. According to the SWING/SMART analysis and the alternative dominance from the multi-criteria decision analysis, Cluster wastewater management was found to be more sustainable when compared with the other wastewater management approaches tested in the current study, with SWING/SMART score ranges from 0,67 to 0,93 (Figure 6). Where onsite wastewater treatment was found to be more sustainable compared to the central wastewater treatment systems, (SWING/SMART scores 0,48 to 0,79 and 0,35 to 0,71 respectively). These findings are in accordance with a number of previous studies comparing the decentralised and centralised wastewater management approaches [21, 22, 23, 24, 25, 26].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

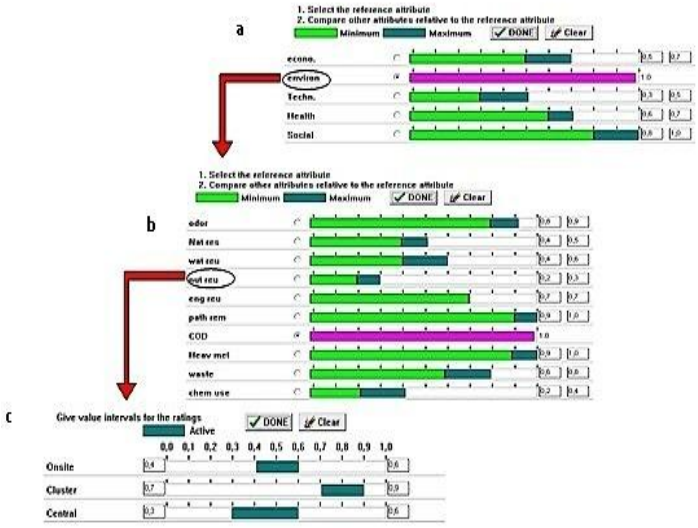

Fig.-4: Hierarchy and weighting of attributes and criteria using WINPRE software programme.

Conventional or centralised wastewater treatment systems involve high technology collection and treatment processes that collect, treat and discharge large quantities of wastewater [27]. Thus, constructing a centralised treatment system for fast horizontally expanding cities and suburban areas in low-income countries, as in Khartoum city, will result in a burden of debts for the local governments [28, 29]. Decentralised wastewater treatment systems (onsite and clustered systems) are designed to operate at small scale [30]. Also, they can be used effectively in fast horizontally expanding cities like Khartoum state. Decentralised systems do not only reduce the effects on the environment and public health but also increase the ultimate reuse of wastewater according to the community, technical, and local settings and aspects.

In addition, when used effectively, decentralised systems can promote the return of treated wastewater within the watershed of origin. Moreover, decentralised systems can be installed on request basis, therefore evading the costly implementation of centralised treatment systems. Unlike centralised wastewater treatment systems, decentralised systems are particularly more preferable for scattered low-density populated areas [26], which is similar to the case of the new settlements or IDP camps in the peripheral of Khartoum State.

Moreover, wastewater management planning is not a one-time investment; it should be a long-term sustainable investment to meet future needs and should be flexible for future modifications to meet strategies changes. Therefore, sustainability criteria were used in the current study to investigate which of the proposed approaches can be more sustainable for future planning. More focus was given to the environmental and financial aspects. According to the current study, the decentralised approach was found to be more sustainable compared with the centralised approach. Moreover, clustered systems are more preferred than onsite option in for Khartoum state. This is mainly due to the fact that groundwater aquifers are polluted in most areas in Khartoum. The average values of ammonia concentration in groundwater samples were found to be about 27 mg/l and which indicate that the quality of groundwater in the aquifers may be threatened by chemical pollution load [31]. This was referred to the use of septic tanks with soak away wells (shallow wells receiving septic tank effluents) which form about 21% of sanitation systems in Khartoum. Around 73% of Khartoum population use pit-latrines, and around 1.5% only connected to sewerage system, and the rest percentage use other poor sanitation system [31]. The adoption of onsite approach for wastewater management in Khartoum, with the current technologies, can increase the scale of the groundwater pollution in the state. In order to improve the current onsite sanitation systems, some technical as well as managerial measures must be taken. Technical measures such as adopting ventilated improved pit latrines, erecting small-bore sewers and expanding the coverage of conventional sewers have been suggested [31]. In addition, managerial issues such as monitoring and assessment programmes are required for future sustainability planning.

Although cluster systems are the most sustainable approach for wastewater management in Khartoum State according to the current study, some pre-requisites are needed to guarantee successful implementation. These pre-requisites are:

- Restructuring the institutional framework to meet the adaptation of the new plan. This is essential for implementing, operating, monitoring and assessment of the established cluster wastewater projects and to assure the integration between different stockholders (such as Urban Planning Ministry, the higher commission of Environment, Ministry of Health, localities, Khartoum state ministry and the privet sectors).
- Developing a new innovative approach for financial schemes to finance service (operation and maintenance).

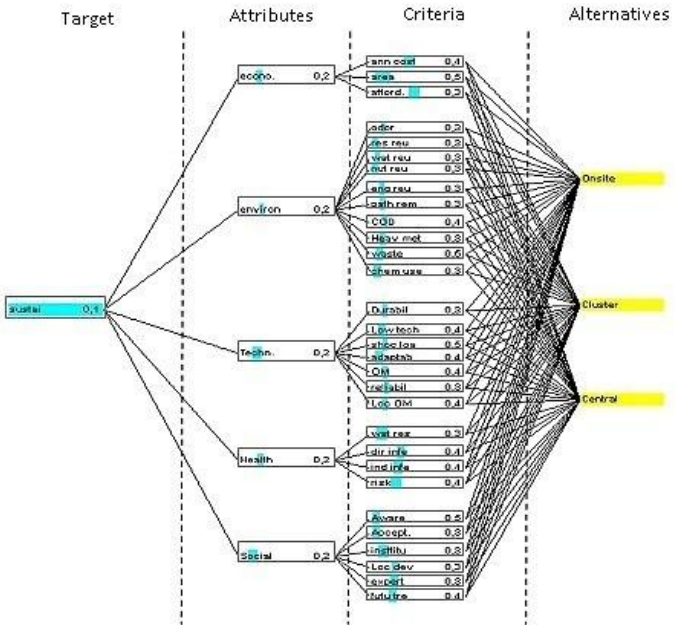

Fig.-5: Attributes weighting and reference attribute (a), Criteria weighting and reference criteria (b), and local score intervals for criteria "nutrient reuse" (c).

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

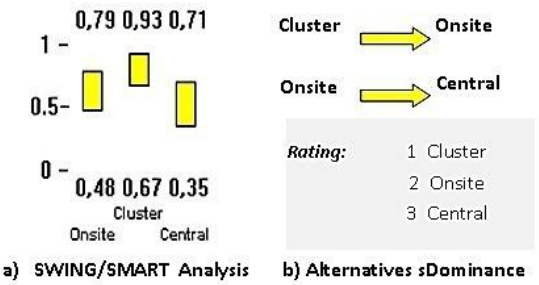

Fig.-6: Value intervals and intervals (a), Criteria weighting and reference criteria (b), and local score intervals for criteria "nutrient reuse" (c).

- Active public participation and private sector involvement are important issues for the successful implementation of decentralised wastewater systems for both the financial support (willingness to pay) and active public monitoring and reporting.

4. CONCLUSION

The fast urbanisation rate that took place in the last three decades in Khartoum State is far beyond the government capacity for financialy cover the costs of conventional centralised wastewater infrastructure supplies, which led to off tracking the millennium development goals (MDGs) objectives. Therefore, it is a high time to look for other wastewater management approaches to fill the gap. For strategic wastewater planning, long-term functionality and sustainability should be the core issue on which the whole planning process based on. Moreover, it should be more fixable for future service expansions and development. Decentralised approaches for wastewater management can verify those needs, and onsite wastewater treatment with the current technology available in Sudan is not suitable due to the high pollution load in the underground water. Therefore, cluster wastewater management approach can bridge this gap and replace the current wastewater systems in Khartoum. Also, sustainable wastewater planning and management cannot be successful without considering the institutional framework that will be responsible for implementing, monitoring and assessing the approaches used. Accordingly, the current institutional structure needs to be upgraded and re-framed to suit the plan objectives and different plan components. It is important to have inter-institutional communication and information flow in addition to active involvement of all stockholders including governmental sectors as well as the privet sector.

REFERENCES

[1] Gumbo, B. and Marjanovic, P., 2003, The role of Decentralized Systems in meeting challenges of Urban wastewater management in Africa contribution to meeting the millennium Development Goal 7 – New Project Initiative by WasterNet and UNESCO-IHE.

[2] WHO/UNICEF ,2008, WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, 2008 report, Second African Conference on Sanitation and Hygiene, Durban - South Africa, 18 – 20 Feb.

[3] Assal, M., 2008, 'Rights and Decisions To Return: Internally Displaced Persons in Post War Sudan', in K. Grabska and L. Mehta (eds), Forced Displacements: Whose Needs Are Right?. London, Palgrave Macmillan.

[4] Bannaga, S. E. I., 1996, MAWA: Unauthorised and Squatter Settlements in Khartoum. Minister of Engineering Affairs, Khartoum State. Zurich: Habitat Group, Swiss Federal Institute of Technology (ETH).

[5] Central Bureau of Statistics, 2009, 5th Sudan Population and Housing Census 2008.Sudan/Southern Sudan Commission for Census, Statistics and Evaluation. Priority Results.

[6] Crombé L., 2009, Building Khartoum's future? Urbanisation et „dubaïsation" à Khartoum.EspaceTemps.net. available online at : www.espacestemps.net/document7752.html (accessed 23 Feb. 2013)

[7] Seif El Islam, M, 2012, How planning can be wizard to solve third world cities problems?. 48th ISOCARP Congress 2012, 10 – 13 septemper 2012, Perm – Russia.

[8] UNEP (2007). Sudan Post-Conflict Environmental Assessment. Geneva: UNEP. Available at: http://postconflict.unep.ch/publications/UNEP_Sudan_synthesis_E.pdf. (accessed 18 Dec. 2012)

[9] Hamid, A., Mwiturubani D. and Osiro D., 2009, Situation Report: Nature and Extent of Environmental Crime in Sudan. Pretoria: Institute for Security Studies. Available at: http://www.iss.co.za/uploads/EnvironCrimeSudan.pdf. (accessed 18 Dec. 2012)

[10] Zeng, G., Jiang, R., Huang G., Xu, M. And Li, J., 2007, Optimization of wastewater treatment alternative selection by hierarchy grey rational analysis. Journal of Environmental Management 82, 250 – 259.

[11] Jackson, A., Boswell, K. and Davis, D., 2011, Sustainability and Triple bottom line reporting – What is all about?. International Journal of Business, Humanities and technology 3 (1), 55 -59.

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

[13] Tuzkaya, G.; Gülsün, B., 2008, Evaluating centralized return centers in a reverse logistics network: An integrated fuzzy multi-criteria decision approach. Int. J. Environ. Sci. Tech., 5 (3), 339-352.

[14] Ellis, K. V.; Tang, S. L., 1991, Wastewater treatment optimization model for developing world. I: Model development. J. Environ. Eng. Div., ASCE 117 (4), 501- 518.

[15] Ellis, K. V.; Tang, S. L., 1994, Wastewater treatment optimization model for development world. II: Model testing. J. Environ. Eng. Div., ASCE, 120 (3), 610–624.

[16] Saaty, T. L., 1977, A scaling method for priorities in hierarchical structures. J. Math. Psychol., 15 (3), 234-281.

[17] Cheng, S.; Wang, R., 2004, Analyzing hazard potential of typhoon damage by applying grey analytic hierarchy process. Nat. Hazard., 33 (1), 77-103

[18] Bandyopadhyay, G.; Chattopadhyay, S., 2007, Single hidden layer artificial neural network models versus multiple linear regression model in forecasting the time series of total ozone. Int. J. Environ. Sci. Tech., 4 (1), 141-150

[19] Belton, V and Stewart, T. J., 2003, Multi criteria decision analysis: an integrated approach . Kluwer academic Publisdhers. 2nd print. 2003. ISBN 0-7923-7505-X.

[20] Mustajoki, J., Hämäläinen, R. P. and Marttunen, M., 2004, Participaroty multicriteria analysis with Web-HIPPR: a case study of lake regulation policy. Environmental modeling & software 19, 537 – 547.

[21] Butler, R., MacCormick, T., 1996, Opportunities for decentralized treatment, sewer mining, and effluent reuse. Desalination 106, 273–283.

[22] Otterpohl, R., Grottker, M., Lange, J., 1997 Sustainable water and waste management in urban areas. Water Science and Technology 35 (9), 121–133.

[23] Hedberg, T., 1999, Attitudes to traditional and alternative sustainable sanitary systems. Water Science and Technology 39 (5), 9–16.

[24] Wilderer, P.A., Schreff, D., 2000, Decentralized and centralized wastewater management: a challenge for technology developers. Water Science and Technology 41 (1), 1–8.

[25] Paraskevas, P.A., Giokas, D.L., Lekkas, T.D., 2002, Wastewater management in coastal urban areas: the case of Greece. Water Science and Technology 46 (8), 177–186.

[26] USEPA (United States Environmental Protection Agency), 2005, Handbook for Managing Onsite and Clustered (Decentralized) Wastewater Treatment Systems, EPA/832-B-05-001. Office of Water, Washington, DC, 66 pp.

[27] West, S., 2001, Centralised: The Key to Successful On-Site Sewerage Service. On-site '01 Conference, Armidale - Australia, 30 September, 2001.

[28] Parkinson, J., Tayler, K., 2003, Decentralized wastewater management in peri-urban areas in low-income countries. Environment and Urbanization 15 (1), 75 - 90.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

[29] Seidenstat, P., Haarmeyer, D., Hakim, S., 2003, Reinventing Water and Wastewater Systems: Global Lessons for Improving Water Management. Wiley, New York.
[30] USEPA (U.S. Environmental Protection Agency), 2004, Primer for Municipal Wastewater Treatment Systems. Office of Wastewater Management and Office of Water, Washington, DC.
[31] Khaddam, M. A. A. and Albesheer, M. O., 2011, Assessment and Mitigation measures for water pollution in Khartoum State. Engineering journal, University of Khartoum, 1(1).