IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 10, Issue 4 Ver. I (Apr. 2016), PP 83-90
www.iosrjournals.org

Development of Composite Performance Index for Solid Waste Management

Hala Elsadig[1], Dr Kamal Eldin Eltayeb Yassin[2], Dr Mohamed Elseory[3]
[1] *Institute of Engineering & Material technology Research, The National Centre for Research. Khartoum, Sudan*
[2] *Department of Chemical Engineering, University of Khartoum Khartoum, Sudan*
[3] *Department of Mechanical Engineering, University of Khartoum Khartoum, Sudan*

Abstract: *The objective of this research is to present a conceptual model for Solid Waste Management (SWM) through the utilization of key performance indicators (KPIs) in order to quantify the general observations of having unclean state with its negative impacts on the environment and health of citizens in Khartoum State. This paper presents a method for development of composite Solid Waste Management Index (SWMI) that addresses the performance of SWM along the seven groups of SWM: collection & transport, Environment, Awareness, Final disposal, Finance, Policy & management plans, and institutional. The index is formed by aggregation (summation) of KPIs. The weights of the indicators were established by Analytical Hierarchy Process (AHP). The 2013 data was used to evaluate SWMI. SWMI result was 0.0999 (in a scale from 0 to 1). This study demonstrates that SWMI is a simple and robust tool to assess and compare SWM performance.*
Keywords: *Solid Waste Management, Key Performance indicators, Solid waste Management In*dex.

I. Introduction

This paper is concerned with Municipal Solid waste (MSW). The study area covers the jurisdiction of Khartoum State- the capital of Sudan which is divided into 3 citieswith an estimated generation amount of solid waste (SW) 3,635 tons/day.Waste generation increases with population expansion and economic development. MSW poses a daunting task for local authorities worldwide[1]. Improperly managed solid waste poses a risk to human health and the environment. Planning for and implementing a comprehensive program for waste collection, transport and disposal(landfill) – along with activities to prevent or recycle waste can eliminate these problems [2].

Performance indicators (PIs) are simple measures, easy to interpret, accessible and reliable for monitoring various types of systems including waste management services (United Nations 2007). To design and develop monitoring and evaluation system to track SWM performance, the first step is to establish list of KPIs [3].

Composite indicators are an innovative approach to evaluate performance. Computing aggregate values is a common method used for constructing indices. Indices represent aggregate measures of a combination of complex development phenomena. Indices are very useful in focusing attention and , often simplify the problem[4]. Such an approach allows for the evaluation of a multitude of aspects, which can then be deciphered into a single comparable index.

II. Objective

This paper aims to contribute in SWM at Khartoum State through a development of a methodological foundation for the construction of a composite indicator for SWM evaluation. The study will focus on MSW including medical waste because the number of private clinics and laboratories are increasing within districts.

III. Materials and Methods

3.1 Identification of Key Performance Indicators

The potential PIs that can be used to evaluate the performance of SWM were identified from the literature review. These PIs formed the basis of 4 different sets of questionnaires which targeted: Management officers and interest groups, health officers, landfill officers and citizens. This questionnaires was used to sample the opinions on the degree of importance of the PIs on a 5- point Likert scale, i.e. 1 = not important, 5 = very important. The relative importance of the PIs was identified using the relative importance index (RII) as Eq. (1) [5].

$$\mathrm{RII} = \sum_{i=1}^{5} \mathrm{Wi\ Xi}/\mathrm{A} \times \mathrm{n} \qquad (1)$$

Where Wi = the weight given to the ith response: I = 1,2,3,4,5, Xi = frequency of the ith response, A = the highest weight (5 in this study), and n= the number of respondents.

To obtain the KPIs, the cut off value of 90 % for RII was used. These KPIs t formed the SWMI.

3.2Analytical Hierarchy Process and Indicators' Weight

In this work, AHP was adopted. This method is theoretically sound for weighting and selecting individual indicators. The AHP decision factors by pairs and assigns weights to reflect their relative importance. Once these hierarchies are established, a matrix is constructed within which elements within each level (and between levels) are compared pair wise. The result is a clear priority statement of an individual or group. The comparisons were made by posing the question which of the two indicators I and j is more important with respect to SWM in Khartoum state respectively. The pair-wise comparisons resulted in (N×N) positive reciprocal matrix A, where the diagonal $a_{ii} = 1$ and reciprocal property $a_{ji} = (1/a_{ji})$, I, j = 1, n assuming: if indicator i is "ρ –times" the importance of indicator j, then necessarily, indicator j is " 1/ρ –times" the importance of indicator j. The next step was the synthesis of the pair-wise comparison matrix to obtain the relative weights of the selected indicators. Solving the right eigen vector of the matrix will provide an excellent estimate of the relative weights of the indicators indicating their priority level [6], (The weights have to sum up to one). The intensityof preference is expressed on a factor scale from 1 (equally preferred) to 9 (extremely preferred). Inconsistency is likely to occur when decision- maker makes careless errors or exaggerated judgments during the process of pair-wise comparison[7]. The ratio can range from 0.0, which reflects perfect consistency to 1.0, which indicates no consistency. Saaty recommends consistency ratio (CR) of 0.1 as the acceptable upper limit.In this work, AHP calculation software was used to determine values I weight and CI for each indicator.CR is calculated using the formula:

CR = CI/RI

where CI is the consistency index. The value of Random Consistency Index (RI) depends on the number of criteria being measured[8]. In this work, AHP calculation software was used to determine values I weight and CI for each indicator.

3.3 Mathematical Formulation

The Solid Waste Management Index (SWMI) is formed by combination (aggregation) of the several indicators *qi* and each one has a weight *wi*. The method of aggregation used was the summation model whose mathematical formulation is presented in Eq. (2) [9].

$SWMI= \sum_{i=1}^{n} wi.qi$ (2)

Where wi = weight given to each indicator whose sum is equal to 1; qi = indicator value normalized;
i= performance indicator included in the index; n = total number of indicators.

The SWMI value, which could vary from **0 (very bad) to 1 (excellent)**, allows evaluating certain SWM plans. According to the SWMI value, SWM is classified in terms of performance from excellent to very bad.

3.4 Normalization of input Data

The normalization aims to attribute comparability to available data, as they usually have different scales. Therefore, it was used the method of min-max normalization that allows convert to values between 0 and 1 using the maximum and minimum of values of reference (benchmark)[10]. Two normalization equations were used. Eq.(3) is applied when an increase in the indicator acts favorable to the index raise and Eq. (4) is used for normalization of indicators whose value increase reduces the index .

$q= (x_{variable} – min)/(max-min)$ (3)

$q= 1- ((x_{variable} – min)/(max-min))$ (4)

where q = normalized value of the indicator; $x_{variable}$ = indicator not normalized; min = lower value of benchmarking; max = higher value of benchmarking.

3.5 Benchmark Establishment

The SWMI may be applied to compare the performance of SWM for different years. Maximum and minimum values (benchmarks) for each indicator were defined from major stakeholders experts and citizens, reports and literature review.

3.6 Model Validation

Model validation was carried out using the data for the year 2013 for the identified performance indicators. It is important to note that the output measure for each indicator was chosen according to literature and the data available. The data was collected from major stakeholders,experts and citizens.

IV. Results and Discussion

4.1 Identification of Key Performance Indicators

List of 76 potential PIs have been identified through the literature review. These PIs were distributed among 4 different sets of questionnaires targeting 4 groups as follows:

1. Managing directors of all government organizations and the 2 main nongovernmental organizations (NGOs) involved in SWM giving a total sample of 14.
2. Managers and monitors of landfills giving a total sample of 5.
3. Health officers giving a total sample of 38.
4. Citizens; Khartoum state is divided into 3 cities. The residential areas for each city are classified by 3 housing classes giving a total sample of 9. The – head of the public committee for services – was the respondent for each sample.

("Table 1") presents the number of responses for each target group. Note that the standard error for the group of health officers was set equal to 10% [11].

The RII was calculated using Excel spread sheet. Using a cut-off value of 90%, indicators were eliminated. The others 31 indicators that make up the SWMI are presented in ('table3") with their weights from AHP results.

Table 1 : Number of responses for each target group

Target group	**Answers received**	**Response rate**
Managers & NGOs	14	100%
Landfill officers	5	100%
Health officers	23	60.5%
Citizens	9	100%

4.2 Analytical Hierarchy Process

An appropriate AHP model was formulated consisting of the goal, groups of SWM, and performance indicators for each group as shown in ("fig. 1")

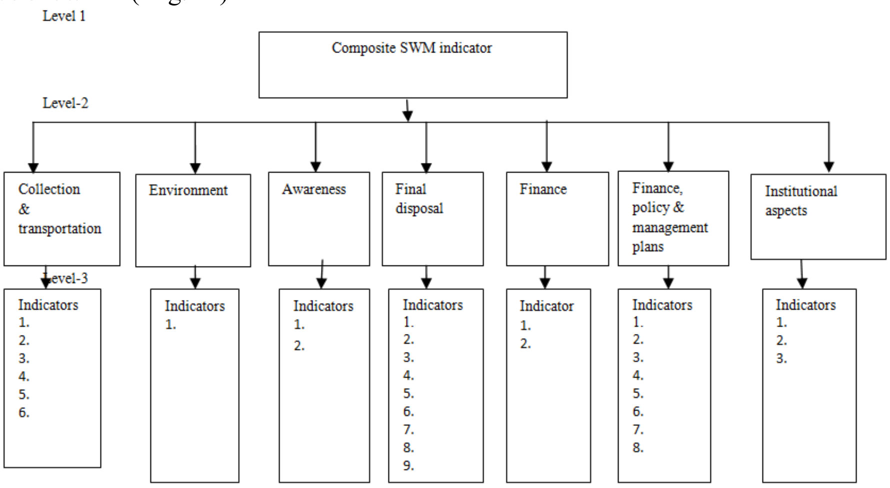

Fig. 1 AHP model for composite performance indicator index

The next phase was data collection, which involves a team of evaluators assigning pair-wise comparisons to the second and third level used in the AHP hierarchy. The nine –point scale as suggested is used to assign pair-wise comparisons of all elements in each level of the hierarchy[12]. Each member assigns his or her pair wise comparisons, which was translated into the corresponding pair-wise comparison judgment matrices (PSJMs). If there are n items that need to be compared for a given matrix, then a total of n(n-1)/2 judgments are needed. For example, for SWM groups pair-wise comparison matrix, n=7, only 21 judgments are needed as shown in ("table 2").

Table 2: Pair-wise comparison matrix for various groups of solid waste management indicators

	C&T	ENV	AW	FD	FIN	PL	INS
Collection & transport (C& T)	1						
Environment (ENV)		1					
Awareness (AW)			1				
Final Disposal (FD)				1			
Finance (FIN)					1		
Policy & management plans (PL)						1	
Institutional (INS)							1

AHP calculation software was used to determine the normalized local priority weights of SWM groups and various KPIs and consistency index (CI). The calculated consistency ratio (CR) of each PCJM is well below the rule of thumb value of CR equal to 0.1. The values of global weights for each KPI was obtained using Eq. (5).

$GW_{ij}=WSWM_j \times LW_{ij}$ (5)

Where GW_{ij} is the Global weight, j= indicator 1,2,3……….n

$WSWM_i$ is weight for SWM group, i= C&T, ENV, AW, FD, FIN, PL, INS.

LW_{ij} = local weights for KPIs.

The global weights for the KPIs in order of importance are shown in ("table 3").

Table 3: Key performance indicators and their global weights

Rank	Solid waste management group	Performance indicator	Global weight
1	Finance	Expenditure of solid waste services	0.1109
2	Finance	Optimization of expenditure	0.0617
3	Institutional	Legislations on waste treatment & disposal	0.0504
4	Policy &management plans	Development and implementation of transition plan from simple landfills & (or) establishing new sanitary landfills	0.0487
5	Policy &management plans	Development and implementation of a hazardous medical waste management plan	0.0452
6	Policy &management plans	Overall cleanliness of city	0.0451
7	Institutional	Community participation	0.0431
8	Policy &management plans	Implement development of transfer stations in accordance with policy plan	0.0427

Table 3: Key performance indicators and their global weights (continue)

Rank	Solid waste management group	Performance indicator	Global weight
9	Policy &management plans	Improvement of service delivery	0.0415
10	Institutional	Supervision	0.0368
11	Policy &management plans	Development and implementation of Schools awareness and education plan	0.0357
12	Policy &management plans	Development and implementation of a plan to address waste (organic, recyclables, energy recovery).	0.0355
13	Policy &management plans	Development andimplementation of a waste information management system	0.0307
14	Environment	Flies density	0.0276
15	Final disposal	number of machinery	0.0268
16	Collection & transport	Coverage	0.0267
16	Collection & transport	Frequency of collection & street sweeping	0.0267
18	Collection & transport	Readiness of fleet	0.0232
19	Final disposal	Labor condition	0.0218
20	Final disposal	land	0.0215
20	Final disposal	Dust layer at cell	0.0215
22	Collection & transport	Number of physical resources	0.0203
23	Final disposal	Waste disposed to landfill	0.0183
24	Collection & transport	Labor condition	0.0176
25	Final disposal	Support facilities	0.0175
25	Final disposal	Workers in service	0.0175
25	Final disposal	Capacity of cell	0.0175
25	Final disposal	Fires	0.0175
29	Collection &Transport	Sanitary Workers	0.0168
30	Awareness	Awareness programs	0.0165
30	Awareness	Behavior of individuals	0.0165

4.3 Input data and benchmark

The input data for the year 2013 ($X_{variable}$) and the minimum (min) and maximum (max) benchmark values are presented in ("table 4").

Benchmark values were defined from governmental organizations responsible for cleaning Khartoum state which are the following: Supervisory Authority for Cleaning Khartoum(SACKH), cleaning projects, and Higher Council for Environment & Urban Promotion in Khartoum State (HCEUPK). Benchmark values were also taken from :experts and citizens, reports and literature review. It must be noted that the **output measurement for an indicator was chosen according to the bench mark value available.**

It must be noted that the indicators- improvement of service delivery and coverage has similar output measures but they are both included so that not to affect the global weight. Benchmark data for the indicators development of an information management system and waste entering landfill were not available.

Table 4: Input data, minimum and maximum benchmark values for the KPIs

No.	Indicator	Output measure& benchmark reference	unit	$X_{var-iable}$	min	max
1	*Expenditure of solid waste services (collection, disposal and treatment facilities)	Expenditure on Collection per total expenditure [13]	%	90	10	80
2	*Optimization of expenditure	Reductions in costs ([14]-door to door collection system per fixed time – fixed place collection system	%	90	60	10
3	Legislations on waste treatment & disposal	Number of courts for environmental issues (source HCEUPK)	No.	1	3	7
4	Development and implementation of transition plan from simple landfills & (or) establishing new sanitary landfills	Implementation of a sanitary landfill plan [15]	points	0	25	100
5	Development and implementation of a hazardous medical waste management plan	Frequency of medical waste collection	points	0	50(every other day)	100 (daily)
		Frequency of medical waste treatment [16]	points	0	50(on collect-ion days)	100 (conti-nuous)
6	*Overall cleanliness of city	Cleanliness index [17]	No.	1.8	1	3
7	Community participation	Number of activities [18]	No.	0	2/50000 population served	3/50,000popul -ation served
8	Implement development of transfer stations in accordance with policy plan	Number of transfer stations (data from SACKH &HCEUPK)	N0.	3	3	6
9	Improvement of service delivery	Level of waste collection	%	76	60	90
10	Supervision	Degree of supervision of workers;time spend by supervisors in the field to respondent to citizens inquiries and enforcement of laws (data from citizens)	points	#20	50	100
11	Development and implementation of Schools awareness and education plan	Degree of completion of phases (data from experts)	point	0	25	100
12	Development and implementation of a plan to address waste (organic, energy recovery).	Composting-amount of organic waste composed[19]	Ton/ day	0	20	100
		Energy recovery [20]	Ton/ day	0	500	8000

Table 4: Input data, minimum and maximum benchmark values for the KPIs (continue)

No.	Indicator	Output measure& benchmark reference	unit	$X_{var-iable}$	min	max
13	Development and implementation of a waste information management system	No information available				
14	*flies density	Density at net for inspected sites (data from cleaning projects)	No.	#15	11	15
15	Number of machinery for landfills	Number per type of equipment (data From landfill officers)				
	Omdurman landfill	Open truck	No.	4	2	4
		bulldozer	No.	2	1	2
		Heavy loader	No.	0	0	1
		Excavator	No.	0	1	2
		Grader	No.	1	0	1
	Bahri landfill	Open truck	No.	0	2	4
		bulldozer	No.	1	1	2
		Heavy loader	No.	1	0	1
		Excavator	No.	1	1	2
		Grader	No.	1	0	1
	Khartoum landfill	Open truck	No.	0	2	4
		bulldozer	No.	0	1	2
		Heavy loader	No.	1	0	1
		Excavator	No.	1	1	2
		Grader	No.	0	0	1
16	Coverage	Level of waste collection [21]	%	#76	60	90

17	Frequency of collection& street sweeping	Frequency of collection ([22]for min value & data from cleaning projects for max value)	No./ week	#1	1	3
		Frequency of street sweeping & collection [23] Market areas streets-no. of sweeping & collection /day	No	#3	3	5
		City centre main streets-no. of sweeping & collection /day	No	#2	2	3
		Suburban main streets-no. of sweeping & collection /week	No.	#1	1	7
		Residential streets-no. of sweeping & collection /week	No.	0	1	3
18	*Readiness of fleet	No. of years from purchase (data from cleaning projects)	No.	#8	5	10
19	Labor condition at landfill	Salary of sanitary workers in SDG/month (data from workers)	No.	300	1000	4000

Table 4: Input data, minimum and maximum benchmark values for the KPIs (continue)

No.	Indicator	Output measure& benchmark reference	unit	$X_{var-iable}$	min	max
20	Land –landfill Khartoum landfill	Remaining landfill site life in years with year 2002 as reference [24]	No.	13	4	19
	Bahri landfill (for the first 20 ha)		No.	10	4	19
	Omdurman landfill	No information				
21	Dust layer at cell	Length of in cm (SACKH)	No.	0	10	20
22	physical resources for collection & street sweeping	Number of packages for collection /collection vehicle	No.	4	1	4
		Number of packages for street Sweeping/500m/working day (interpretation)	No.	1	1	2
23	Waste disposed to landfill	No. information				
24	Labor condition for collection & transport	Wages for sanitary workers in SDG/month (data from workers)	No.	300	1000	4000
25	Support facilities for landfill	Point for support facilities available [25]	No.	25	80	100
26	Workers in service for final disposal	Points for categories of workers available [26]	No.	80	100	60
27	Capacity of cell	Depth of cell in m (landfill managers	No.	#4	5	10
28	*small scale Fires	No. of fires per year (landfill managers)	No.	#3	0	6
29	Sanitary Workers for collection & transport	No. of workers per vehicle	No.	#4	1	4
		No. of workers for street sweeping /500m/working day (in case the streets were swept) (from cleaning projects)	No.	#1	1	2
30	Awareness programs	No. of awareness programs per year (data from citizens)	No.	3	3	52
31	Behavior of individuals	Individuals paying fee[27]	%	40	80	100

4.4 Calculation of SWMI

In this study, SWMI is evaluated for the year 2013.From (“table 4”), the output measurement values for the indicators were normalized using Eq. (3) &Eq. (4), (Eq. (4) indicated by *),(# indicates an average value of data). Each normalized value was multiplied by the evaluated global weight for each indicator (“table 3”) and the summation model is used to obtain sub-indices for each SWM group (Eq.(2)). The final SWMI was obtained by the summation of the sub-indices.It is important to note that if the value of an indicator is not known the SWMI attributed the value 0 for the indicator normalized to penalize the lack of information about a significant performance indicator (indicators 13,23). If the value of an indicator is 0 (indicators 4,5,7,8,14, 17,23,30) or if it represents a bad value, i.e.,if its value is equal or exceeds the worse benchmark limit (indicators 1,2,3,6,10,11,12,19,21,24,25,27,31) , it does not contribute to the SWMI simulation. As for indicators, 15, 17,20 and 22, an average value was obtained for each indicator from the several normalized values.

The final SWMI and sub-indices for collection & transport performance, Environment performance, awareness performance, final disposal performance, finance performance, policy & management plan performance and institutional performance are summarized in ("table5").

Table 5: Summary of sub-indices and final SWMI

Collection & transport	Environment	Awareness	Final disposal	Finance	Policy & management plans	Institutional	SWMI
0.042	0	0	0.035	0	0.022	0	0.099

4.4 Interpretation of Results

SWMI can be used for performance evaluation of SWM. Sub-indices can be evaluated every year and compared. If a graph is drawn for SWMI or sub-indices with respect to year, the slope of line indicated the incremental growth / decline in the SWM performance of SWMI or sub-indices. Decision makers can assess the trend of SWM. The global weights of each indicators form a basis for prioritizing management issues. Based on weights, targets are set and action plans are made for achieving sustainable development.

V. Conclusions

This paper focuses on improving the SWM system in Khartoum state. This was done by exploring the most important indicators for measuring SWM performance and to formulate a composite index for comparison and decision-making. Thirty-one indicators consistently perceived as being highly important was used to build a model for evaluating the performance of SWM. Analytical hierarchy process was used to weight and prioritize KPIs so that objectives and targets are set to address SWM issues. Attempts have been made to aggregate the indicators in a more scientific manner. Composite indicators are valued for their ability to integrate large amount of information into easily understood formats for a general audience. SWMI enables to assess the performance of SWM and hence fulfilling its role of helping decision makers.

Acknowledgment

The authors would like to thank the Institute of building and Road Research-University of Khartoum, and the National Center for Research for the financial support. Special thanks to the following: Khartoum state cleaning projects, Supervisory Authority of Cleaning Khartoum, Ministry of Environment, forests and Physical Planning, the Higher council for Environment and Urban Promotion State and the Ministry of Health for providing information for conducting this study.

References

[1]. Li, Y.P., Huang, G.H., " An inexact two-Stage mixed integer Linear Programming Method for Solid Waste Management in the City of Regina, J. Environmental Management, Vol. 81, (2006), pp. 188-209.

[2]. US EPA- United State Environmental Protection Agency ," Solid Waste and Emergency Response", available at www.epa.gov/globalwarming, (2002).

[3]. O. Manni, "Design and Develop a Monitoring and Evaluation System to Track Municipal SWM Sector Performance in Amman", A project for Greater Amman Municipality , Hashimate Kingdom of Jordan, available at www.gamtenders.gov.jo, (2010).

[4]. G.D. Atkinson, R.Dubourg, K. Hamilton, M. Munasignhe, , D.W. Pearce, , C. Young, " Measuring Sustainable Development: Macroeconomics and the Environment", Cheltenham, Edward Elgar, (1997).

[5]. I Abdul Rahman, A. H. Memon and A.T. Abd Karim " Significant Factors Causing Cost Overruns in Large Construction Projects in Malaysia" , J. of Applied Science, Vol13, No. 2, (2013), pp. 286-293.

[6]. T. L.Saaty, The Analytical Hierarchy Process, New York :McGraw-Hill, (1980).

[7]. T. L. Saaty, Fundamentals of decision making and Priority theory, second ed., Pittsburg: PA RWS Publications, (2000).

[8]. [8] T. L. Saaty, L. G. Vargas, Models, Methods, Concepts & Applications of the Analytic Hierarchy Process, LLC: published by Springer Science + Business Media, (2001).

[9]. H. M. G. Coelho, L. Celina Lange, L. M. G. Coelho, "Proposal of an environmental Performance index to assess solid waste treatment technologies", J. of Waste Management Vol. 32, (2012) pp. 1473-1481,.

[10]. UNDP- United Nations Development Program, " Human development report 1996", Oxford University Press, New York, (1996). pp. 106-108.

[11]. A.M. Al-Mahasheer and A. A. Al-Salman. " Assessment of Risks Management Perception and Practices of Construction Contractors in Saudi Arabia". Study thesis, King Fahad University of Petroleum and Minerals, (2005).

[12]. T. L.Saaty, The Analytical Hierarchy Process, New York :McGraw-Hill, (1980).

[13]. UNEP- United Environmental Program"Developing Integrated Solid Waste Management Plan" , ISWM Plan-Training Manual, (2009), Volume 4.

[14]. A. ISHII, B. Hamid and A. Hassan, " The Solid Waste Management Master Plan in Khartoum" , A report, Clean Khartoum Master Plan, (2013).

[15]. US EPA-United State Environmental Protection Agency, " Decision maker's guide to solid waste management, (1995).

[16]. [16] MLGPC –Ministry of Local Government and Provincial Councils, " Solid Waste collection and Transport", Service Delivery Training Module 1 of 4, Sri Lanka, (2008).

[17]. US EPA- United State Environmental Protection Agency, " City of Miami ; Public Area Cleanliness Index" , available at www.epa.gov/miamibeachfl.gov.

[18]. N. Georgia Metropolitan Water Planning District, " Water supply and water conservation management plan", found at documents.northgeorgia-water.org, (2009).

[19]. A. ISHII, B. Hamid and A. Hassan, “ The Solid Waste Management Master Plan in Khartoum” , A report, Clean Khartoum Master Plan, (2013).

[20]. J. Margarida Quina, C.M. João Bordado and M.Rosa Quinta-Ferreira ,“Air Pollution Control in MunicipalSolid Waste Incinerators, The Impact of Air Pollution on Health, Economy, Environment and Agricultural” available at www.intechopen.com(2011).

[21]. A. ISHII, B. Hamid and A. Hassan, “ The Solid Waste Management Master Plan in Khartoum” , A report, Clean Khartoum Master Plan, (2013).

[22]. UNEP- United Nations Environmental Program “ Integrated Waste Management Scoreboard- A tool to measure performance in municipal waste management “(2005),

[23]. UNEP-United Nations Environment Program , found at www.Unep.or.jp

[24]. US EPA-United State Environmental Protection Agency, “ Decision maker`s guide to solid waste management, (1995).

[25]. UNEP- United Environmental Program”Developing Integrated Solid Waste Management Plan” , ISWM Plan-Training Manual, (2009), Volume 4.

[26]. US EPA-United State Environmental Protection Agency, “ landfill manuals – landfill operation practices” (1997).

[27]. A. ISHII, B. Hamid and A. Hassan, “ The Solid Waste Management Master Plan in Khartoum” , A report, Clean Khartoum Master Plan, (2013).