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RESEARCH ARTICLE

MANAGEMENT OF SOLID WASTE IN KHARTOUM STATE

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ABSTRACT

Khartoum, the capital of Sudan, has a serious problem with solid waste management and treatment because of the huge amount of generated wastes. Thousands of tons are generated daily, generally, uncollected wastes accumulate at roadsides and burned by residents, most of it ends up in open dumps and wetlands, contaminating surface and ground water, posing major health hazards. Land filling has started in Sudan since 2008 but not properly engineered, most amount of the region's waste is disposed in open dumps or semi-controlled unlined landfills with no gas collection system, groundwater protection, leachate recovery, or treatment systems. 5,100 tons are generated daily in Khartoum state;almost 70% (3,570 tons/day) must dispose to landfill after separation of 30% of recyclable materials (plastic, metals, glass, etc.). Approximately, 180,000 m3/month of MSW generated from three parts of Khartoum state, Khartoum, Bahri and Omdurman. It needs to be dumped on three proper designed landfills. On the basis of "monthly" Cells for the purpose of easy design and management problems if occurred in any Cell (e.g. containment of fire or isolation problems), cells will have 60,000 m3 capacity with 1800m^2 surface area. The waste depth is 10 meters to achieve sufficient depth for feasible gas production and extraction. Site excavation can be up to 4 meters below existing ground level. The total landfill area for period of a year equal 97,200 m^2, and cells must have isolated by HDPE (high density poly ethylene) to prevent ground water from leachate. This paper describes the recent situation of MSW in Khartoum state and proposed a proper design of landfill to receive waste and the generated gases.

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INTRODUCTION

The paper concluded with a summary of the social and environmental sustainability benefits that can be realized. Wastes can be defined as those materials which are no longer required by individuals, institutions or industry. Wastes are thus regarded as by-products or end products of the production and consumption process respectively and it refers to the following:

Garbage: should be collected at least two times weekly in residential sections in summer and winter. On the other hand, commercial establishment should be accorded daily collection service throughout the year.

Dead bodies: should be collected immediately.

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Rubbish: is generally collected weekly in residential areas and daily in business sections. Solid waste includes any garbage, refuse and any discarded materials including solid, semi-solid, liquid or contained gaseous material resulting from industrial, commercial, mining and agricultural operations, and from community activities. Solid waste has become a global common problem to all countries; whether these countries are advanced or developing. The situation in Sudan is not much different from that in other countries with similar circumstances. Knowing the sources and types of solid wastes, along with data on the composition and rates of generation, is basic to design and operation of the functional elements associated with the management of solid wastes. The materials that are collected under the term solid wastes include many different substances from vary types of sources. The different types and sources of solid waste are shown in the table 1.1 below:

Table 1. Different types and sources of solid waste

Source	Types of solid waste
Residential	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes.
Industrial	Housekeeping wastes, packaging, food wastes, construction and demolition materials, hazardous wastes.
Commercial	Papers, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes.
Institutional	Same as commercial.
Construction & Demolition	Wood, steel, concrete, dirt, etc.
Municipal services	Street sweepings, landscape & tree trimmings, general wastes from parks, sludge.
Process (Manufacturing, etc.)	Industrial process wastes, scrap materials, off-specification products, slay tailings.
Agriculture	Spoiled food wastes, agricultural wastes, hazardous wastes.

*Source: Integrated solid waste management; 1993

Table 2. Landfills already exists in Khartoum state

Landfill Name	Location	Total Area	Full capacity	Used Capacity
TAYBA Landfill	25 km from Khartoum center	40 acre	1,651,000 m^3	840,000 m^3
HATAB Landfill	25 km East of Khartoum	80 acre	2,724,000 m^3	200,000 m^3
ABU WLIDAT	30 km North of Khartoum	6000 km^2	16000 m^3	2,274 m^3

*Source:Khartoum state cleaning corporation (KSCC)

Table 3. Landfill gas composition

Component	Percent by volume	Characteristics
Methane	45-60	Naturally occurring gas. It is colorless and odorless.
Carbon dioxide	40-60	Naturally found at small concentration in the atmosphere (0.03%). It is colorless, odorless and slightly acidic.
Nitrogen	02-May	It comprises approximately 79% of the atmosphere. It is odorless, tasteless and colorless.
Oxygen	0.1-1	It comprises approximately 21% of the atmosphere. It is odorless, tasteless and colorless.
Ammonia	0.1-1	Amonia is a colorless gas.
Non-methane organic compounds	0.01-0.6	$NMOC_s$ are organic compounds (i.e., compounds that contain carbon).
Sulfides	0-1	H_2S are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. It can cause unpleasant odors even at very low concentrations.
Hydrogen	0-0.2	It is an odorless and colorless gas.
Carbon monoxide	0-0.2	It is an odorless and colorless gas.

*Source: LFG primer (**ATSDR**) 2016

Khartoum state the capital of Sudan; is located at the confluence point of the White Nile and the Blue Nile. It lies at the margin of sahara desert and its climate is arid with hot summer and cool dry winter. Like all countries in the sub-Saharan region, Sudan is experiencing movement of its population from rural to urban areas, giving rise to new issues relating to the management of increasing volumes of municipal solid waste (MSW). MSW management involves various steps, namely collection, transportation, sorting,processing and disposal. Landfill is the most common method adopted. Indeveloped countries proper landfills exist along with proper construction and maintenance of the same. However, in developing countries such as SUDAN properly designed and maintained landfills are seldom found. Khartoum state today has population of more than 7 million; the generated solid waste is 5,100 tons/day, the waste transferred to landfills is about 2000 tons/day which is much less than expected, while the remaining quantity is disposed of in open dumpsacross large areas of desert in a largely uncontrolled fashion.Landfills have been the most widely adapted practice for municipal solid waste management worldwide. Khartoum state has three landfills for three areas; Khartoum, Bahri and Omdurman with uncontrolled dumping system and not properly engineered showed in the table 1.2 below:

There are five environmental management principal's techniques for landfills which a landfill occupier must consider in order to achieve the best environmental outcome:

- Site selection;
- Design and construction;
- Monitoring;
- Site operation management – remediation; and
- Closure management.

Typically, operators of landfills for non-hazardous wastes meet predefined specifications by applying techniques to:

- Segregate recyclable materials from landfilled wastes.
- Confined wastes to small area as possible.
- Compact wastes to reduce volume.
- Cover waste (usually daily) with layers of soil.

Daily operation of landfill site includes the application of manpower, plant and materials, with increased demands being placed on all of these. Site management required much better understanding and control of the site. The problems facing solid waste management in Sudan is absence of solid waste treatment plants, unsorted waste at the collection stage, limited financial resources, obsolete machines and equipment and poor maintenance operations. The land fillg as results from the biodegradation of wastes, it is a significant Greenhouse Gas (GHG) and canals oposea risk to site users and any nearby residents. The LFG will initially be flared but maybe used productively for power generation or local energy purposes in the future. It is currently hoped that the gas can be utilized for electricity generation which will supply the local grid. The total LFG composition detailed in table 1.3 below:

AsLFGrecovery, flaring and/or productive use are reliable technologies that are already widely commercially employed, the technical risks from this project are fairly low. The main project risk will be the rate of land fillgas generated, which is largely dependent on the biodegrade ability and moisture content of the waste. This risk will be minimized –and the rates of landfill gas generation maximized – through the management of the incoming waste and segregate the recyclable materials. Tominimize the risk, maximize as recovery, and improve waste management practice in Sudan, it must to create materials recovery facility (MRF) at the site. Incoming waste will be selected and passed through the MRF. The MRF will seek to recycle metals, plastics, wood, glass, paper and card board. From the waste. There area high percentage of plastics in Sudan waste must develop processestore-engineer this waste to get commercially benefits from it. The major waste in Sudan can be considered as municipal waste and it consists of the following components.

Table 4. Waste Composition Analysis in Khartoum state

Waste type	Recycling	%
Paper and cardboard	Recyclable	11.8
Plastic	Recyclable	12.7
Organic material	Non-recyclable	49.5
Dust & ash	Non-recyclable	13.4
Metals	Recyclable	1.7
Wood	Recyclable	0.2
Leather	Non-recyclable	0.4
Glass	Recyclable	3.5
Cotton & jute	Non-recyclable	4.6
Couch	Non-recyclable	0.3
Others	Non-recyclable	1.9

*Source: Khartoum state cleaning corporation (KSCC)

This result shows that almost 30% of wastes of Khartoum states are recyclable materials that should not dumped and disposed to landfill and must be segregated and recycled. The recent scenario is the disposal of the waste on a landfill without capture of the landfill gas where decomposition of biodegradable fraction of the waste under anaerobic conditions leads to methane generation. The objectives of the project are to show best ways to manage solid waste problem in Khartoum state and calculate and reduce the percentage of recyclable materials to landfill then Design Landfill Cells commensurate with the actual amount of waste in Khartoum State. The other objective is to produce compost from municipal solid waste collected from households around Khartoum region.

METHODOLOGY

Khartoum City needs to apply an integrated complete approach, that takes into account key factors, that affecting waste generation, storage, and final disposition. Establish stable financing and ensure funds are used appropriately, carefully design, develop and implement privatization systems after assessing the potential costs and benefits. Involve the community in waste-management decision making, and build capacity of administrative and technical staff in government and/or the private sector. A well-designed waste management plan can minimize illegal dumping and mitigate severe environmental damage that affect the environment.

Khartoum State data were collected from Khartoum state cleaning corporation (KSCC) and Khartoum localities centers. The results of census in Khartoum state and the total amount of wastes collected from seven localities in Khartoum state for the years 2008, 20012 and 2016 are showed in the tables below.

Figure 2.1. An illegal dump in Khartoum state

Design of the dumper

Cell design: From previous results:
The total amount of generated solid wastes in Khartoum state = 5,100 tons/day.
70% will disposed to landfill = 5,100 * 0.7 = 3,570 tons/day.
Since: Volume = Weight / Density
Then: The total volume of waste = 3,570 / 0.36 = 9,916.67 m^3/day.
The solid waste density = 0.36 ton/m^3.(according to KSCC)
The total Volume of wastes generated per month:
= 9,916.67 *30 = 297,500 m^3/month.
This amount will be segregated to three landfills, equals to 99,166.7 m^3/month for each.
:. The cell volume = 99,166.7 m^3.
Where: The cell volume = Mean area * total height.
And: The cell total height = 10 m.
So: The cell mean area = 9,916.67 m^2.
Assume square shape for each cell:
The cell's mean length (width) = approximately 100 m.
So: The basal cell area = 90*90 = 8,100 m^2.
And the surface area over ground level = 110*110 =12,100 m^2.

Slope calculations

The maximum slope allows for each cell = 30°.
The maximum depth of the cell under ground level = 4m.
The slope angle with tan = 0.4
$\Theta = \tan^{-1}(0.4) \rightarrow \Theta = 22^o$. (Acceptable)
For one year it needs 12 cells by surface area 12,100m^2 located in one line.
The total area = 12,100*12= 145,200 m^2.
:. The total area for a landfill needed for disposal of wastes for one year = 145,200 m^2.

Landfill Design: The landfill project has to include installation of a landfill gas collection system comprising vertical gas collection wells, connection pipework, and a gas extraction and flaring system. The wells have to be installed within the wastes once final tipping levels have been attained within individual cells and will collect the landfill gas that will be produced as the wastes degraded. The gas will be extracted from the site along inter-connected pipework laid within the surface capping layer of the landfill cells and will be drawn to a gas flaring compound.

Table 2.1. Census in Khartoum state for 2008, 2012 and 2016*

Statement	Khartoum	Bahri	Jabal Awlyaa	Karary	Omdurman	ShrgElnil	Umbda	The Total
Population of 2008	639,598	608,817	942,429	714,079	513,088	868,147	988,163	5,274,321
Population of 2012	758,420	720,812	1,121,959	846,171	607,989	1,344,208	1,178,371	6,577,930
Population of 2016	837,153	794,589	1,238430	934,013	671,104	1,483,753	1,300,699	7,259,741

*Source: Khartoum state cleaning corporation (KSCC)

Table 2.2. The amount of waste generated per day in 2016*

Statement	Khartoum	Bahri	Jabal Awlyaa	Karary	Omdurman	Shrg Elnil	Umbda	The Total
Amount of collected waste ton/day	1,500	600	600	500	700	700	500	5,100
Waste discharge rate Kg/Person/day	2.00	0.94	0.47	0.54	0.89	0.60	0.46	0.70

*Source: Khartoum state cleaning corporation (KSCC)

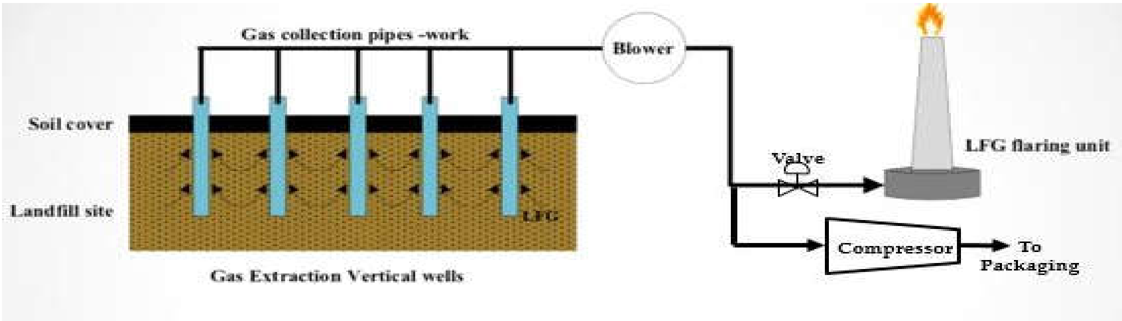

Figure 2.2. The LFG collection and treatment procedures

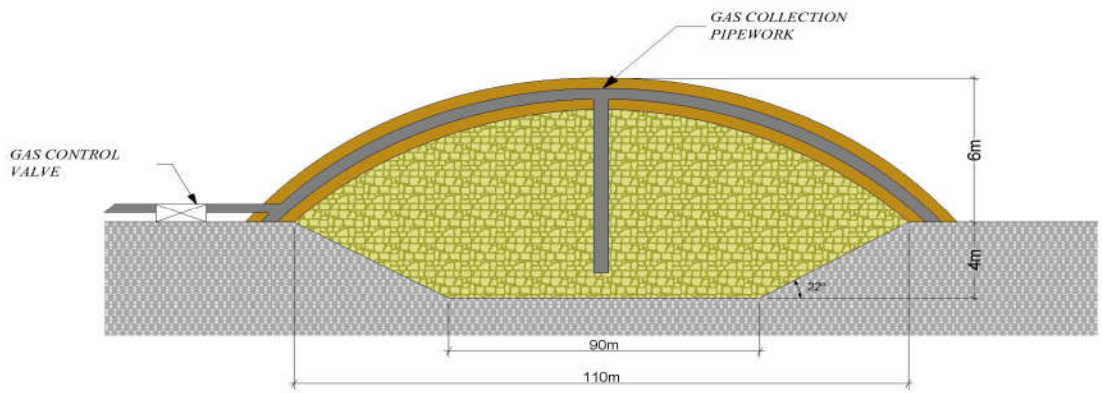

Figure 2.3. Typical cross section of the proposed Cell

Efficient high temperature combustion of the gas mixture within the flare chamber will destroy the harmful trace components of the gas and convert the methane component to carbon dioxide prior to release to the atmosphere. Any leachate or rainfall collected at the site will be recirculating back into the waste mass in order to increase the moisture content of the waste and optimize gas production conditions. The landfill must be developed with new phases on a monthly basis, with 12 phases in preparation for annual receiving, other 12 phases being landfilled and other 12 phases being restored at any time.

Specifically, the following technology must be installed

- Gas Extraction wells: Vertically driven gas wells must be constructed to extract the landfill gas as it is produced;
- Gas collection pipework: These pipes, constructed using High Density Polyethylene (HDPE) will collect and transport the gas from the wells to the extraction plant where the gas will be safely flared;
- Gas extraction plant (blower): A centrifugal blower is required to extract landfill gas from the wells and supply this to the flare unit. The blower creates lower pressure inside the wells than in the landfill, thereby sucking the gas from the landfill into the wells and from there to the extraction plant;
- Condensate management: Measures such as self-draining wells has to be included within the system to minimize condensate build-up and hence reduce the likelihood of pipe blockages from liquid, which should help maximize the efficiency of the gas extraction system. The moisture content of the waste must be monitored and managed to optimize the generation of gas; and
- Flare unit: Enclosed (high temperature) landfill gas flaring units has to be installed to safely treat the extracted gas. Figure 2.2 bellow shows the landfill gas collection and treatment procedures. This is the disadvantages of this method is the environmental impact on the atmosphere.

However, the design will be set-up for collection of generated gases for commercial uses and will be covered in the next paper.

Table 2.3. K & L0 suggested values*

Variable	Range	Wet climate	Medium Climate	Dry Climate
L_0 (m^3/Mg)	140-180	140-180	140-180	140-180
K (1/yr)	0.003-0.4	0.1-0.35	0.05-0.15	0.02-0.10

*Source: Conference and project Expo, 2007

Outline design of gas management system

Although engineered as separate cells, as the landfill develops and expands, the gas management system within each initial landfill cell must be interconnected with the extracted gas piped to a single compound housing a suitably sized gas control and flaring system. As the landfill expands further and the feasibility of utilizing the landfill gas increases, the gas management plan for the site need to be fundamentally reviewed and revised as appropriate. However until that point, the initial outline design suggests to Grade waste surface and cap with 1.5 meters of local soils and Place further 1.5 meters of surface soils above collection pipework to protect from harsh climatic condition, graded to fall to encourage run-off of any surface water during short but intense periods of heavy rainfall.

Estimation of methane gas generated from Khartoum State landfills

$$Q_T = \sum_{i=1}^{n} 2K\,Lo\,Mi\,e^{-Kti} \longrightarrow \quad \textbf{Eq}$$

1St Order Decomposition Rate Equation
(Vasudevan, 2004)

Where:

Q_t= Total gas emission rate from landfill.
K = Landfill gas emission constant, time^{-1}
L_0 = Methane generation potential, volume/mass of waste.
T_i = Age of i section of waste, time.
M_i = Mass of wet waste, placed at time i.
n = Total time periods of waste placement.

From Table 2.3 assume:

K = 0.1 yr^{-1}
L_0 = 160 m^3/Mg, = 0.16 m^3/Kg
From previous studies:
M_i = 310,250× 10^3 Kg/yr
t_i= 1yr

$$Q_t=\sum_{i=1}^{1} \frac{(2*0.1)1}{yr} \times (0.16)m^3\ /kg \times (*\ 10^3)kg \times e^{-(0.1\frac{1}{yr}\times 1yr)}$$

$$Q_t = (0.2\frac{1}{yr}) \times (0.16\frac{m^3}{kg}) \times (310,250 \times 10^3 kg) \times (0.9)$$

Q_t = 7,818,300 m^3/yr
Q_t= 297,095.4Gj/yr

Where: 1m^3 = 0.038 Gaga J (given).
The percentage of methane gas generation is almost 7%(V/V)

RESULTS AND DISCUSSIONS

Khartoum state has a high rate of waste generation with a high percentage of organic materials approximate to 50%. The studies showed that, 30% of Khartoum state's wastes are recyclable materials and should not be disposed to landfills. Segregation of recyclable materials would minimize the amount of materials should be disposed to landfill which can also minimize the areas needed to be used for landfilling. Cells will be designed on monthly bases to make design easily and to manage problems perfectly. The total volume of one cell adequate for waste generated for one month equal to 99,166.7 m^3. The service area for the cell equal to 12,100 m^2. The total area for the landfill appropriate for one-year waste generation is equal to 145,200 m^2. The total amount of methane gas that would be generated from Khartoum solid waste's landfill is equal to 297,095.4 gaga joules/year. From literature, the percentage of generated methane gas is 5%-15%. For Khartoum state landfill it is 7% because of it's dry climate. The local social and environmental benefits of the project will be:

- Reduction of local's oil and water pollution;
- Reduction in the greenhouse gas emissions and climate change that would otherwise occur through uncontrolled release of land fill gas to atmosphere;

- Reduced angers to site operatives and site sorters/recyclers.
- Aesthetic value (disappearance of plentiful accumulated waste);
- Decrease in insect vector diseases which willbe reflected positively in the general health of the community;
- Less cost of control and cure of many diseases; provision of a number of employment opportunities relating to the operation and maintenance of the site and equipment.

CONCLUSIONS AND RECOMMENDATIONS

Municipal solid waste is a serious problem that facing Sudan government, and the situation is deteriorating every day, this a result of uncontrolled solid waste management. Khartoum state needs a proper waste management plans which can minimize illegal dumping, open burning and mitigate severe environmental damage. Organic materials in Khartoum state wastes, could be converted to compost that will have great local benefita soil improver or to generate methane gas which is financially feasible. The process will also segregate materials that can be reused or recycled, whilst significantly reducing the volume of material landfilled.It is a significant opportunity to move towards more sustainable waste management practice in a country where no other mechanism currently exists to drive such improvements.

The Authour recommended:

Improvement of waste collection system and include segregation at household level. Also to improve the participation of private sector which would increase the effeciency of waste transportation and disposal. Municipals has to increase waste storage tanks an containers, raise up the public awareness about the consequences of mismanagement of solid waste disposal to decrease illigal dumping and stop open burning. The use of methane gas as an energy source maximizes the extraction of useful resources from landfills and minimizes the global warming.

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