A logistics framework to reduce the number of landfills in the North West province of South Africa

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Abstract

This study reviewed the landfill practice in the 21 local municipalities of the North West (NW) province. The projections of the province's domestic waste load and the underlying factors were analysed by Kadama and on that basis it was assumed that the municipal solid waste load (MSW) of the province was likely to increase in a similar trend. The landfill practice was deemed unsustainable and needed to be re-engineered. It was noted that in order to minimise the capital outlay required for the re-engineering process, it would be necessary to landfill the provincial MSW load in the sanitary landfills existing in the province. To achieve this goal, the study developed a logistics framework for the transportation of MSW in the province.
Keywords: commercial waste, domestic waste, municipal solid waste, landfills, waste management.

1 Introduction

This study defined a landfill as a site in which waste is deposited for the purpose of waste management and the term was interchangeably used to refer to the action of disposing of waste in a landfill. Landfilling is the oldest form of waste management and is still the most practiced form of organised waste management in most parts of the world (Wikipedia [2]). Landfilling involves the deposition of waste onto land and this occupies space that could have been used for other purposes. Thus in this world of finite resources, exponential population growth and the associated increase in waste generation, landfilling is bound to result in a stiff competition for space.

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A number of negative impacts may result from landfill operations. These include:
1. Fatal accidents resulting from landslides or fires at landfills.
2. Damage to existing infrastructure by heavy earthmoving machinery and trucks.
3. Changes in the landscape and visual discomfort.
4. Pollution of ground and surface waters.
5. Soil contamination and possible loss in soil fertility.
6. Emission of greenhouse gases such as methane.
7. Nuisance problems such as harbouring vermin, flies, bad odour, dust and noise.

Source: EGSSAA [3], Wikipedia [2].

Because of these impacts, in many countries, the establishment and management of landfills are state controlled activities (Pierce [4]). In South Africa, the Department of Water Affairs and Forestry (DWAF) is responsible for regulating the establishment and operation of landfills. DWAF has compiled a reference framework of standards for waste management in a set of manuals known as the Waste Management Series. This series also provides for the enforcement of the landfill permitting system prescribed in Act 73 of 1989 [5]. Section 156 (1) (a) of the constitution of the Republic of South Africa, Act 108 of 1996 [6], empowers municipalities to be in charge of waste management related activities in their areas of jurisdiction.

1.1 Background

The North West province (NW) of South Africa is located on the fringes of the Kalahari Desert and lies in the Southeast quadrant between longitudes 22º 30′ and 28º 30′ and latitudes 24º 30′ and 28º. It borders the Republic of Botswana in the north and the provinces of Limpopo, Gauteng, Northern Cape and Free State (Readers Digest [7]). The NW covers a surface area of 116 320 km^2 and has 21 local municipalities (Statistics SA [8]). Kadama [1] notes that 87% of the local municipalities in the NW are rural and have small revenue bases. Most of them depend on funding from the central government to finance their capital and operational budgets.

Except for the municipalities of Kagisano, Ratlou and Tswaing, each of the others in the province operated at least one landfill. Kadama [1] classifies the operational landfills in the NW into three categories viz. open dumps, controlled landfills and sanitary landfills. This classification was based on the following criteria:

1. Open dumps are, as the name suggests, open field onto which waste is indiscriminately disposed. They do not have any infrastructural development.
2. Controlled landfills have infrastructural developments like roads, offices, ablutions and are demarcated into cells. Waste is disposed in designated areas and is compacted and periodically covered with soil.
3. Sanitary landfills are modern facilities with infrastructure that includes leachate and gas management systems. Waste is compacted and on a daily basis, covered with soil.

Investigations in Kadama [1] reveal that of the 38 landfills in the province:

1. The majority (61%) were controlled landfills, 29% were open dumps while 10% were sanitary landfills. All open dump landfills did not have permits and while the controlled landfills had permits, their operations did not comply with the permit requirements.
2. In so far as operational time left before the landfills were due for closure was concerned, there were no records available for 13% of the landfills, 11% were due for closure but were still operational, 66% were left with 10 years or less and 10% were left with more than 10 years.
3. 82% of the municipalities had plans to construct at least one landfill in the next 10 years.
4. 16% of the municipalities had conducted the necessary studies and identified suitable sites for construction of new landfills.

Kadama [1] also notes that the construction of modern sanitary landfills requires massive capital outlays which are far beyond the means of the majority (87%) of the local municipalities in the province.

According to NEMAI and SBA [9], landfill management is the second goal of the NW waste management strategy. In the NW waste management strategy, the landfill management targets are stated as follows:

1. 80% of the landfills in the province should be licensed by 2012.
2. The number of operational landfills should be reduced to the bare minimum.
3. All landfills should fully comply with landfill license conditions specified by DWAF.
4. Establish regional landfill facilities where feasible.

NEMAI and SBA [9] argue that operating a licensed landfill can be very expensive in so far as plant, machinery and human resource are concerned. They further argue that it would be environmentally desirable and economically logical to close unnecessary landfills and rather transport waste to a few landfills that are operated in line with environmentally accepted procedure.

1.2 Problem statement

From the foregoing discussion, it emerges that:

1. The activities in 90% of the landfills in the NW do not comply with international best practice and are therefore a peril to the people of the province and the environment at large.
2. The number of operational landfills in the province is not sustainable and their continued operation will not only harm the environment but also deplete the meagre resources of the local municipalities.
3. The majority of local municipalities need to urgently develop alternative landfill sites. However, they lack the capacity and resources to establish landfill facilities that comply with the provisions of Act 73 of 1989.

1.3 Aim of the study

Considering the problem at hand, this study deemed it imperative to develop a framework for sustainanble landfill management in the NW that would ultimately reduce the number of landfills in the province.

1.4 Objectives of the study

The objectives of this study were to:
1. Estimate the quantity of municipal solid waste (MSW) generated and destined for landfills in the NW.
2. Determine the distance between the towns with existing sanitary landfills and the main towns of the other local municipalities in the province.
3. Develop a framework that optimises the location of waste management facilities and ultimately reduces the number of landfills in the province.

1.5 Assumptions

Some of the information required in this study was not available since other relevant studies had not yet been conducted. It was therefore deemed necessary to make the following assumptions:
1. Each of the local municipalities has at least one potential site for the establishment of a sanitary landfill.
2. That funds are available for local municipalities to implement the statutory remedial procedures prescribed for the closure of landfills, to build transfer stations and to acquire the neceassary vehicles and equipment.
3. Commercial waste generated as a result of provision of services to individuals was generated in the local municipalities where they reside.
4. Commercial waste generated in respect of an individual in a population will be 20% of the domestic waste per capita of that population.
5. Municipal solid waste transported to landfills in the NW consists of domestic waste and commercial waste only.
6. The existing sanitary landfills in the province can accommodate the province's municipal solid waste load for the next 15 years.
7. On long trips, waste transportation trucks move at an average of 70 km per hour.
8. The domestic waste per capita in the NW would remain at 0.572 kg as was determined in Kadama [1].

2 Literature review

Modern landfills are constructed to be the ultimate disposal sites for municipal solid waste. For that purpose, they are constructed as highly engineered containment systems designed to isolate solid waste from the environment and minimise its environmental impact (OSU [10]). Sanitary landfills are contained bioreactors and attenuation structures designed to promote the biodegradation of compacted waste (Cointreau [11]). The design of a landfill should be based on the outcome of site investigations and the environmental impact assessment (EIA). Generally, a landfill should be designed with the objective of providing a cost effective and environmentally acceptable disposal facility. According to DWAF [12], landfills should be designed to meet the following specific objectives:

1. Mitigation of the adverse impacts identified during site investigations and EIA.
2. Prevention of solute pollution of adjacent ground and surface water.
3. Provision for appropriate leachate management and treatment.
4. Provision for sufficient cover material that shall ensure an environmentally and aesthetically acceptable landfill operation.
5. Ensure that minimum quality assurance requirements are met during selection, design and installation of liners and capping layers.
6. Ensure proper scheduling of activities during the stages of; designing, development, operation and closure of landfills.

Sanitary landfills are cost-effective systems of solid waste disposal for urban areas that should be the preferred choice in developing countries. According to Cointreau [11], studies have shown that sanitary landfills may be 2-3 and 5-10 times cheaper to operate than composting and incineration respectively.

2.1 Criteria for determining landfill sites

A number of statutory requirements are in place to ensure that the specific objectives of landfill designing cited in section 2 are complied with. These requirements relate to infrastructure specifications, life-span and to the geo-hydrological conditions that ought to be met prior to the establishment of a landfill. However, whereas this study fully acknowledged the importance of the statutory requirements, it opted to emphasise the economic aspects that provided guidance in development of the framework to optimise the location of waste management facilities. These include:

1. To ensure maximum productivity of the delivery trucks, prevailing road and traffic conditions should allow for trucks to deliver from source to landfill within 30 minutes time. Cointreau [11] advises that where travel time exceeds 30 minutes, it would, from the economic perspective, be advisable to invest in transfer stations with large capacity delivery trucks (greater than 20 tonnes).
2. Where transfer stations are used, the landfill should be accessible within two hours of travel time (one-way) by trucks from the the transfer station. For longer distances, train haulage to landfills should be considered. However, railway connections to landfill sites may be expensive to construct (Cointreau [11]).
3. Double handling by truck or rail transfer should be avoided due to cost escalation (Cointreau [11]).
4. The population and MSW generation potential of the catchment area (OSU [10]).

2.2 Composition of municipal solid waste

According to UNEP [13], the composition of municipal solid waste depends on a number of factors that include:

1. The standard of living of individuals.
2. The level of education for members of a given community.
3. The level of urbanisation.
4. Energy choices available to the community.
5. Consumption patterns of the community.

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A survey by ETC/RWM [14] indicates that municipal solid waste is in the main composed of:

1. Waste originating from households.
2. Waste originating from commerce and trade, manufacturing sector, office buildings and institutions (schools, hospitals, government buildings).
3. Bulky waste (e.g. white goods, old furniture, mattresses).
4. Garden waste; leaves, grass clippings and tree branches.
5. Market cleansing waste.
6. Waste from selected municipal services, i.e. waste from park and garden maintenance.

3 Research method

In order to achieve the objectives, this study had to gather information on the following variables:

1. The amount of municipal solid waste generated in each of the local municipalities.
2. The distances between the main towns of individual local municipalities and the towns where the sanitary landfills in the province were located.
3. The one-way travel time of waste transportation trucks from points of origin to their destinations.

To compute the amount of municipal solid waste produced on a daily basis in the local municipalities, one needed to know the current population in the individual local municipalities and the domestic waste per capita (DWPC) in the NW. The last official population studies conducted in South Africa were the census of 2001 and the Community Survey of 2007. Using the population figures from the two studies, the differential equation (1) (Cooper and Schindler [15]) was applied to estimate the population growth rate (r) of the NW and thereafter the estimate population in 2011was computed.

$$P_2 = P_1 e^{rn} \tag{1}$$

where:

e = 2.718 (a constant exponential function)
P_1 = population in 2001
P_2 = population in 2007
ln = natural logarithm
n = the time interval between 2001 and 2007
r = the population growth rate

Solve for r as follows:

$$\frac{P_2}{P_1} = e^{rn}$$

Apply natural logarithms

$$\ln\left(\frac{P_2}{P_1}\right) = \ln(e^{rn})$$

given that:

$$\ln e = \ln 2.781 = 1$$

then

$$\ln\left(\frac{P_2}{P_1}\right) = rn\ln e$$

$$r = \frac{\ln\left(\frac{P_2}{P_1}\right)}{n} \tag{2}$$

Having established the population growth rate (r) of the province, equation (1) was applied to estimate the current population in each local municipality (P_3) and the province as a whole. The domestic waste per capita (DWPC) of the province was obtained from Kadama [1] and was applied as follows to compute the daily municipal solid waste (DMSW) load in kilogram (kg)) of the individual local municipalities:

$$DMSW = P_3DWPC + (0.2)P_3DWPC \tag{3}$$

Data on the DMSW load of the local municipalities were captured on an MS Excel spreadsheet and multiplied by factors of 7, 30 and 365 to obtain the weekly, monthly and annual MSW loads of each local municipality in the province. By summation the corresponding MSW loads of the province were obtained.

The following steps were taken to determine the distances between the main towns of the individual local municipalities and the towns where the sanitary landfills in the province were located:

1. A list of the names of the main town in each NW local municipality was compiled.
2. The shortest road distance between each town and the towns where sanitary landfills existed was established using a Tom Tom global positioning satellite (GPS). The routes followed had to be tarred and were either national or major provincial roads.

The approximate travel time taken by waste delivery trucks to transport waste from source to destination was computed using equation (4)

$$Time = \frac{Distance}{Average\ speed} \tag{4}$$

Based on time taken by trucks to travel from a given town to towns that had sanitary landfills, the NW towns were grouped into time based categories described in Table 1. This categorisation informed the process of planning and development of the logistics framework.

Table 1: Truck travel time (t) to nearest sanitary landfill and corresponding action.

Truck travel time (t)	Recommended action
t > 0 ≤ 30 minutes	Use compactor trucks ranging from 10 to 15 tonnes to transport waste to the nearest sanitary landfills.
t > 30 minutes ≤ two hours	Establish transfer stations in those towns and use delivery trucks of 20 tonnes or more to deliver waste to the nearest sanitary landfills.
t > two hours	Select a town to serve as a collection point from where waste could be transported by rail to the nearest sanitary landfills.

4 Presentation of results

The total annual MSW load of the province was computed to be approximately 841044592kg. The distances between the main towns in each local municipality and the towns where the nearest sanitary landfills in the province are located are presented in Table 2. The distance, in kilometres (km) and the time in hours, are for the shortest route between the specific places and do not necessarily reflect the best or fastest route connecting them. To read the distance between two towns in Table 2, find their names on the horizontal and vertical lists respectively. Follow the row in which one name is listed to the point where it

Table 2: Distance and time of travel between towns.

Town	Carltonville		Potchefstroom		Rustenburg	
	km	Hours	km	Hours	km	Hours
Brits	118	1.69	173	2.47	66	0.94
Christiana	301	4.30	246	3.51	356	5.09
Delareyville	229	3.27	115	1.64	245	3.50
Ganyesa	381	5.44	330	4.71	390	5.57
Klerksdorp	113	1.61	48	0.69	167	2.39
Koster	93	1.33	112	1.60	53	0.76
Lichtenburg	149	2.13	135	1.93	138	1.97
Mafikeng	215	3.07	202	2.89	212	3.03
Mogwase	154	2.20	195	2.79	59	0.84
Moretele	334	4.77	278	3.97	373	5.33
Schweizer Reneke	252	3.60	197	2.81	296	4.23
Setlagole	278	3.97	236	3.37	264	3.77
Taung	330	4.71	275	3.93	376	5.37
Tosca	466	6.66	415	5.93	475	6.79
Ventersdorp	68	0.97	54	0.77	95	1.36
Vryburg	311	4.44	260	3.71	319	4.56
Wolmaranstad	183	2.61	127	1.81	238	3.40
Zeerust	196	2.80	215	3.07	128	1.83

crosses at a right angle with the column in which the other name is listed. The figures in the cells at the point of intersection reflect the distance in km between the two places and the average time taken for trucks to move from one town to the other.

5 Discussion

The results in Table 2 reveal that all the major towns in the local municipalities that need to transfer their MSW are more than 30 minutes away by trucks from the closest sanitary landfills. Therefore, as was discussed in section 2.1, it would be necessary to establish transfer stations in these towns from where MSW would be hauled to the sanitary landfills either by trucks with capacity of 20 tonnes or more, or by rail. Waste sorting facilities should be established at each transfer station. In the sorting facilities, re-usable and recyclable items and compostable material will be separated from MSW destined for landfills. Waste sorting facilities will be beneficial for waste management for the reasons that they will help to reduce the amount of MSW destined for landfills and encourage the practice of recycling and re-use of items. The establishment of waste sorting facilities will result in the following socio-economic benefits:

1. Job opportunities will arise from the recycling and re-use of items.
2. Funds saved as a result of reduced MSW transportation costs will be available for municipalities to use in other priority areas.
3. Important waste management information such as type and quantity of recyclable material sorted and quantity of MSW destined for landfills, will be recorded for planning purposes.

In section 2.1 it is noted that rail haulage should be considered where truck delivery time exceeds two hours. From the results presented in Table 2, rail haulage has to be planned for 13 towns which are far apart in time and space. The geographic dispersion of these towns does not allow for one to plan a one-way route that connects all affected towns to the sanitary landfills. In planning the transportation of MSW, double handling by truck or rail transfer should be avoided as it results in cost escalation. However, considering that the majority of the local municipalities that need rail haulage have low MSW loads, it was felt that the construction of rail sidings to the transfer stations in each of the towns would be costly. For that matter, it was decided that three collection centres should be established for the aggregation of MSW. Each of the collection centres would be provided with rail sidings to facilitate rail haulage to sanitary landfills. By so doing, the following benefits would accrue:

1. Economies of scale would be realised from the aggregation of MSW.
2. The construction of only three rail sidings as opposed to 13 would save on costs.

The following criteria were applied to develop the logistical framework for the transportation of MSW to existing sanitary landfills:

1. Major towns from which truck travel time to the nearest sanitary landfill was at most two hours were identified. In these towns, provision was made to have MSW transported to the nearest landfill by road using trucks of 20 tonnes or

more. The towns identified under this criterion and their associated landfills are shown in Table 3.
2. Towns that were best positioned to serve as MSW collection points and the associated feeder towns were identified and are shown in Table 4.

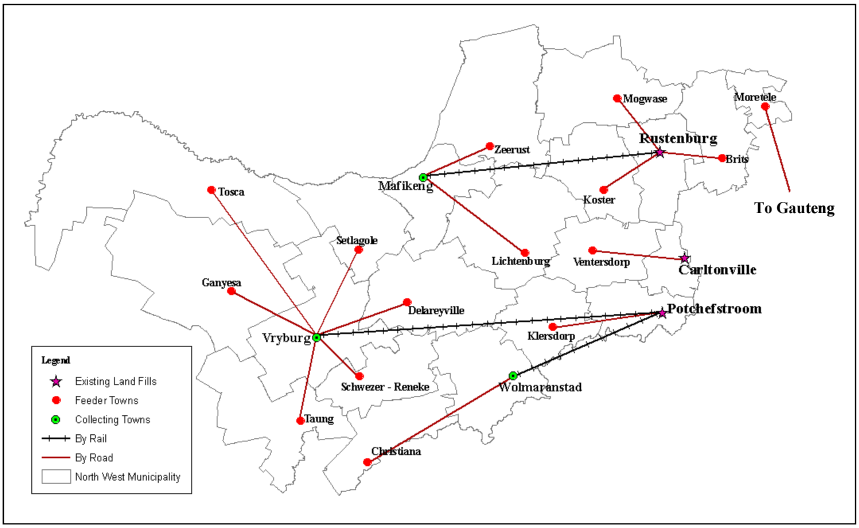
Table 3: Towns from which MSW will be transferred using trucks of at least 20 tonnes

Town	Truck travel time in hours to nearest sanitary landfill		
	Carltonville	Potchefstroom	Rustenburg
Brits			0.94
Klerksdorp		0.70	
Koster			0.84
Mogwase			0.84
Ventersdorp	0.97		

Table 4: MSW collection points and truck travel time to nearest landfill.

MSW feeder towns	Truck travel time in hours to nearest MSW collection point		
	Mafikeng	Vryburg	Wolmaranstad
Christiana			1.7
Delaryville		1.2	
Ganyesa		1	
Lichtenburg	0.94		
Schweizer Reneke		2.1	
Setlagole		1.2	
Taung		1	
Tosca		2.1	
Zeerust	0.97		

By combining the above criteria, a logistical framework for transportation of MSW to existing landfills in the NW was developed and is illustrated in Map 1. The locations of the towns in Map 1 were purposefully chosen for convenience and as such, they may not be true reflections of the actual positions of those towns. This framework accounts for all the local municipalities of the NW with the exception of Moretele. This particular local municipality is located on the north eastern fringes of the NW and borders with Gauteng province. It is located about four hours' truck travel time from the nearest sanitary landfill in the province and is not connected to the existing national railway network. Rail haulage of MSW from Moretele should not be contemplated as it requires the construction of several kilometres of railway for the sole purpose of transporting a quantity of MSW that could never justify the capital outlay. As such, the most feasible option would be to transport MSW from Moretele by trucks to an appropriate sanitary landfill in Gauteng.



Map 1: A logistics framework for transportation of MSW.

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