



OPTIMIZATION OF WASTE BIN LOCATION AND SIZE FOR ILORIN, NIGERIA

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ABSTRACT

This study illustrates a procedure for selecting optimal locations and size of waste bins for a developing area in Ilorin, Nigeria. For this purpose, relevant data were obtained from field study and the satellite image of the study area was digitized. The Facility Location algorithm in TransCAD v. 5.0 (Caliper, Corp.) software was then used to determine the optimal locations of one to ten waste bins ($p=1$ to 10). When the maximum walking distance to the service points was set at 200 m, only $p=6, 7, 8, 9$ and 10 entirely covered the study area. Consequently, the output from TransCAD software was analyzed to derive the size of each waste bin for $p=6$ to 10. The z-interval statistical analysis of several waste bin sizes showed that at 95% confidence level, the most appropriate size for the study area ranged from 1.47 to 1.8 m^3 . Hence, a normalized size of 1.74 m^3 which was slightly above the median (1.6 m^3) and occupied the 59th percentile is proposed. The remaining 41% of service points would require quantities of this waste bin size according to the volume of solid waste emanating from the service area.

INTRODUCTION

Improving service coverage and efficiency of municipal solid waste collection activities within the urban spatial structure has been a demanding task. This challenge is particularly anticipated in the developing world because most urban settlements are characterized by high density, unplanned expansion of low-income settlements and ineffective control of land development (Cohen, 2006). More so municipalities in developing countries spend as much as 20-50 percent of their available recurrent budget on solid waste management, yet about 50 percent of the population is not served (World Bank, 2009). This calls for stringent measures to effectively manage municipal solid wastes. Fundamentally, proper location of waste bins, estimation of waste generation and their on-site storage capacity are most essential for the effectiveness of a solid waste management system (Vijay *et al.*, 2008).

Proper location of waste bins is a facility location problem. Over the years, facility location problems have been motivated by several practical applications involving provision of services to serve some kind of demand distributed in space (Handler and Mirchandani, 1979). Facility models are basically aimed at determining the most efficient location of a facility according to one or more objectives such as cost minimization and accessibility maximization (Teixeira and Antunes, 2008). However, these objectives are subject to physical, structural, and policy constraints, in a static or deterministic setting (Current *et al.*, 1997). As such, the application of facility location models for spatial decision support in developing countries is mainly within the context of facilities that provide social services such as potable water, healthcare, education, sanitation and security (Oppong, 1996). In the absence of such formal

spatial decision, a political or pragmatic decision is made which is often far from the optimal solution (Smith and Rahman, 2000). The likely resultant effect of this decision on municipal solid waste management particularly in developing countries is insufficient collection and inadequate disposal of solid wastes (Medina, 2005).

Optimization of waste bin locations can be modeled as a p -median problem, which is a variant of the facility location problem. The p -median problem is a *minisum* location-allocation model that simultaneously sites a pre-specified number of facilities and allocates customers to those facilities (Hillsman, 1984). In order to determine the optimal waste bin location for the collection of municipal solid wastes, the p -median problem sites p waste bins among a set of m potential service points along a network to serve n waste generation points. For this purpose, a waste generation point is assigned to a municipal waste bin with the shortest total distance from it. Once a waste bin location is specified, the capacity of container has to be indicated so as to determine the most appropriate collection vehicle.

Due to the increasing costs including the cost of labour, fuel and equipment, there is strong movement by waste management professionals

towards the use of large containers that can be emptied mechanically (Peavy *et al.*, 1985). This system is common in some parts of Nigeria and it requires solid waste generators to provide their own primary storage facilities (plastic bags or small containers) and later dump their stored wastes into large municipal containers provided by the city corporation at designated locations. Agunwamba (2003), Dauda and Osita (2003), and Aremu *et al.* (2010) reported the use of such municipal waste bins in Onitsha, Maiduguri and Ilorin respectively. The municipal waste bins are mainly suitable for areas with high waste generation and accessibility problems, but under utilization may occur if the bins are too large compared to the turnout of wastes. On account of the costs associated with provision and collection of communal waste bins, the size and utilization of these bins are of great economic importance (Tchobanoglous *et al.*, 1993).

Therefore, in order to improve municipal solid waste management in developing areas based on existing spatial infrastructure, there is need to determine the most effective location and specify the size of waste bins. Accordingly, the objective of this study is to determine the location and size of waste bins for a developing area in Ilorin, north central Nigeria.

MATERIALS AND METHODS

The city of Ilorin is the largest urban center in Kwara State, Nigeria and has a population of about 777,667 (NPC 2007). A typical part of Ilorin which is bounded by latitude $8^{\circ}28'45''$ and $8^{\circ}28'55''$ North, and longitude $4^{\circ}32'50''$ and $4^{\circ}33'20''$ East was chosen as the study area. The screen lines of the study area are Taiwo road, Unity road, Yidi road, Stadium road and Otunba Adebayo road (Figure 1).

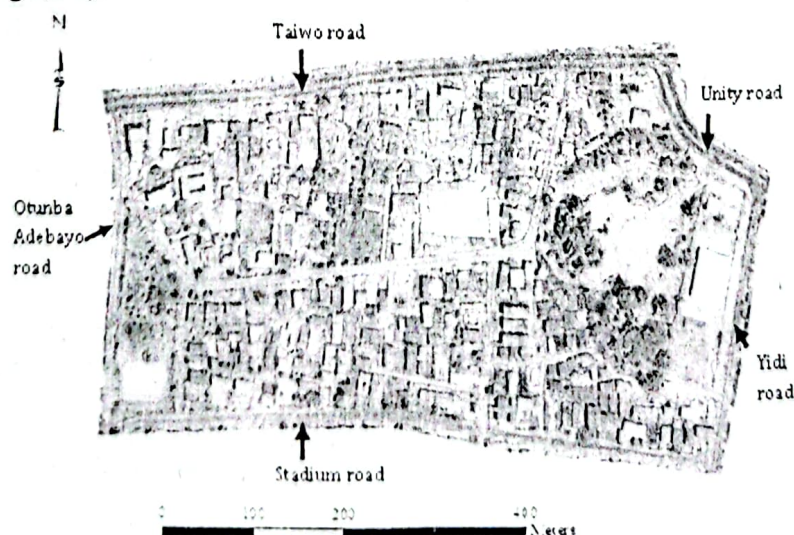


Figure 1: Satellite Image of the study area

Due to the non availability of demographic and solid waste data, field study was carried out to obtain these data from the study area. The *canvasser* method, which is the movement of the enumerator from one building to the other to gather the required information, was adopted for population and housing census after the study area was divided into enumeration areas. In terms of land use, each land/building was classified as residential or commercial or a combination of both (mixed dwelling). The information obtained

from the enumeration process are: land use category, number of people per household, type of business and floor area occupied by the business. This information provided the data which was used to calculate the waste generation rate from each land use type.

The weight of solid waste was taken in triplicates from sixty waste generation points and the mean generation rate in kg/capita/day was determined from the equation (1):

$$W_{pc} = \frac{\sum_{i=1}^n w_i}{\sum_{i=1}^n p_i} \quad (1)$$

Where

W_{pc} is per capita solid waste generation rate,

w_i is amount of solid waste generated from household i

P_i is population of household i

n is number of waste generation points

The approach of Karadimas and Loumos (2008) and WHO (1996) was used to classify solid wastes generated from commercial land use activities. The four classes are shown in Table 1 and the coefficient which represents the intensity of solid waste generation resulting from such commercial activity in kg/m²/day is given in equation (2):

$$W_{pa} = \frac{\sum_{i=1}^n (w_{ai} * A_i)}{\sum_{i=1}^n A_i} \quad (2)$$

Where

W_{pa} is solid waste generation per area for commercial category a ,

w_{ai} is amount of solid waste generated from commercial activity i in commercial category a ,

A_i is area occupied by commercial activity i

n is number of studied commercial areas

Hence, the solid waste from each waste generation point within the study area is based on:

- The per capita waste generation rate multiplied by the population of each household for residential land use type.
- The coefficient of the commercial category multiplied by the land area occupied by such commercial activity for commercial land use type.
- A combination of (i) and (ii) for mixed land use type

Table 1: Classes and related commercial activities

Classes	Typical Commercial Activities
A	Market, food shop, supermarket, restaurant, printing press, fish store, and fast food shop.
B	Butcher store, boutique, bar, business centre, floristry, bakery, workshop and hotel.
C	Book shop, barbershop, pharmacy, post office and worship centre.
D	Hand set store, shoe store, clothing store, jewelry store and compact disc store.

Note: Adapted in part from Karadimas and Loumos (2008)

The components of solid waste generated in percentage by weight were determined by taking measurements from sampled waste generation points for a period of one year. The procedure involves sampling, sorting of the wastes by hand into various categories and weighing individual component. The sorted categories are: food wastes, paper, textiles, plastics, grass/ leaves/wood, leather/rubber/nylon, metals, glass/ ceramics and miscellaneous wastes. The weight of each component was quantified relative to the entire weight of the waste stream (as percentage weight) and the mean percentage composition of each component was determined. The density of a typical solid waste from the study area was calculated from the sum of the density of individual mean percentage composition. Taking a collection frequency of once in every three days, the volume of solid waste from each service area is given as:

$$V_{su} = \left(\frac{\sum_{i=1}^k w_{gi}}{\delta_{mean}} \right) * 3 \quad (3)$$

Where

V_{su} is the volume of solid waste from the service area of a waste bin in three days

w_{gi} is the daily amount of solid wastes from waste generation point i

k is the total number of waste generation points served by the waste bin and,

δ_{mean} is the mean density of solid waste

Data Analysis

Mathematical formulation of the waste bin location problem

The mathematical formulation of the waste bin (facility) location problem otherwise referred to as p -median problem, is given by the equation (modified from Miller and Shaw, 2001):

$$\text{Minimize } Z = \sum_{i=1}^n \sum_{j=1}^m w_i c_{ij} x_{ij} \quad (4)$$

Subject to

$$\sum_{j=1}^m x_{ij} = 1, \quad i = 1, \dots, n \quad (5)$$

$$x_j - x_{ij} \geq 0, \quad i = 1, \dots, n; j = 1, \dots, m \quad (6)$$

$$\sum_{j=1}^m x_j = p \quad (7)$$

where

Z = the total weighted distance between solid waste generation points and service points

$\{1, \dots, n\}$ is a set of solid waste generation points

$\{1, \dots, m\}$ is a set of potential service points where a waste bin could be placed

w_i = amount of solid waste generated at waste generation point i , $w_i > 0$

c_{ij} = shortest distance between generation point i and service point j

$$x_{ij} = \begin{cases} 1 & \text{If waste generation point } i \text{ is assigned to service point } j \\ 0 & \text{Otherwise} \end{cases}$$

$$x_j = \begin{cases} 1 & \text{If a waste bin is located at service point } j \\ 0 & \text{Otherwise} \end{cases}$$

p = number of waste bins to be located

The assumption of the p -median is that the waste generator will patronize the nearest service point. Constraint (5) ensures that a waste generator is assigned only to one service point (the nearest service point). Constraint (6) allows a waste generator to be assigned to a service point if a waste bin is located at that service point. Constraint (7) allows exactly p number of waste bins to be sited. Solution methods for p -median problems include enumeration, graph theoretic, mathematical programming and heuristic procedures (Miller and Shaw, 2001).

Solution procedure for the p -median problem

The Geographic Information System (GIS)-based software; TransCAD v. 5.0 (Caliper, Corp.) was used to solve the p -median problem. TransCAD software fully integrates GIS with facility location algorithms and provides tabular and spatial display of the results. This makes the Facility Location Function in TransCAD exceptionally suitable to solve the p -median problem in this study. To this end, the satellite

image of the study area was digitized and all the information relevant to the study were geo-referenced. The digitized map in TransCAD platform was then queried ten times to give the optimal location of one to ten waste bins along the road network. A screen shot from the Facility Location dialogue box in TransCAD for $p=5$ is shown in Figure 2. The function “# New Facilities” represents the number of waste bins to be sited; “cost” in the objective function represents the distance between the waste generation points and the waste bin(s); “Facility Settings” represents the layer containing potential waste bin locations while “Client Settings” represents the layer containing waste generation points. The Facility Location Function generates several combinations of geo-referenced waste generation points and potential waste bin locations until the optimal solution is achieved for each computer run (specified p -value). The attribute table for each optimal location was then exported for analysis of spatial performance of each waste bin.

Figure 2: Facility location dialogue box in TranCAD software

Statistical Analysis for Determining Waste Bin Sizes

The one-sample z-interval procedure was used to determine the range of waste bin sizes appropriate for the study area given any degree of confidence. To determine this range for medium sized samples, outliers may be removed and an arithmetic probability plot is required to ascertain that the remaining data is normally distributed (Weiss, 2002). The confidence interval for the mean waste bin size falls between $\bar{x} - z_{\alpha/2} \frac{\sigma}{\sqrt{n}}$ and $\bar{x} + z_{\alpha/2} \frac{\sigma}{\sqrt{n}}$ (Weiss, 2002), where $\bar{x}$ is the sample mean, $\alpha = 1 - \text{confidence level}$, $z_{\alpha/2}$ denotes the z-score that has an area $\alpha/2$ to its right, σ is standard deviation of the data, and n is the sample size.

RESULTS AND DISCUSSION

The digitized satellite image of the study area containing geo-referenced waste generation points and the road network is shown in Figure 3 while Table 2 presents the characteristics of each waste generation point. A total of 187 waste generation points were identified within the study area and 269 potential waste bin locations after eliminating unsuitable sites. Out of the waste generation points, 113, 30, and 44 are residential, commercial and mixed land use type respectively. The average solid waste generation per capita from all the sampled residential land use types is

0.22 kg. The mean solid waste generation rate per area for commercial category A, B, C and D are 0.1558, 0.0822, 0.0466 and 0.0382 kg. Residential land use types generated 371.36 kg/day; commercial land use types generated 173.12 kg/day while mixed dwellings generated 298.90 kg/day, hence the total daily output of solid waste from the study area is 843.38 kg. The result of the composition of solid waste from the study area is shown in Table 3. The mean density of solid wastes from the sampled waste generation points is 238.6kg/m³.

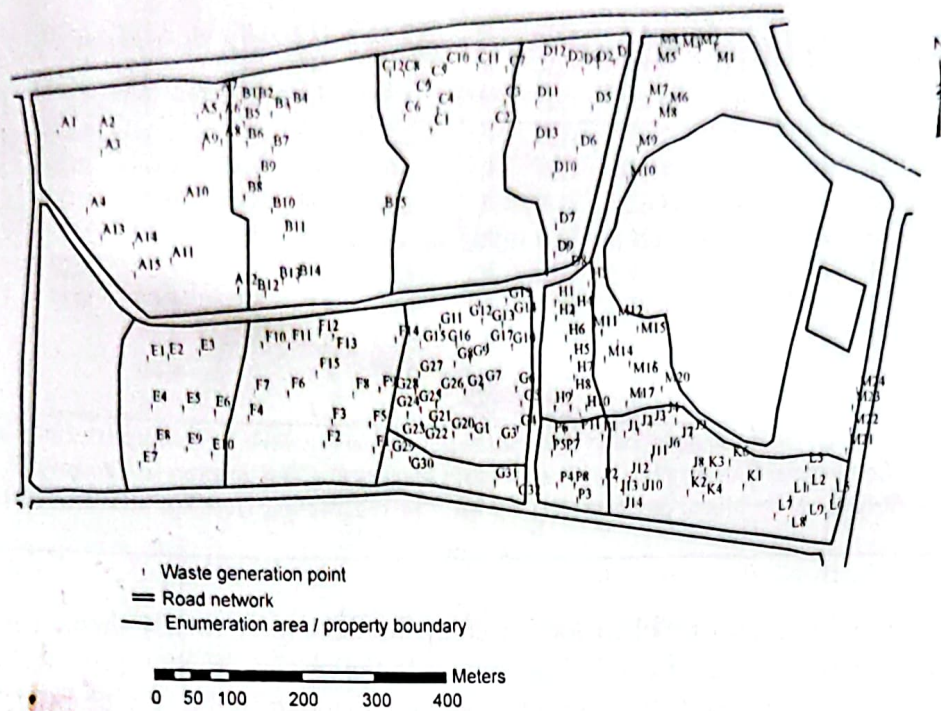


Figure 3: Digitized satellite image of the study area showing waste generation points, property boundaries and the road network

Table 2: Characteristics of geo-referenced waste generation points

Hno	Lut	Swg	Hno	Lut	Swg	Hno	Lut	Swg	Hno	Lut	Swg	Hno	Lut	Swg
A1	MA	15.19	C9	MD	3.10	F12	CC	5.55	H3	MA	6.99	K5	R	2.20
A2	MD	3.07	C10	MA	7.26	F13	MC	5.51	H4	MA	5.45	K6	MB	6.98
A3	MB	3.38	C11	MA	7.82	F14	MA	4.66	H5	R	1.32	L1	R	6.60
A4	MB	5.72	C12	MA	7.66	F15	R	4.4	H6	R	9.24	L2	R	7.92
A5	MB	4.61	D1	CA	19.97	G1	R	0.88	H7	R	4.18	L3	R	4.40
A6	MB	7.91	D2	CA	9.36	G2	R	6.60	H8	R	8.36	L4	CA	3.34
A7	MB	6.70	D3	MA	6.38	G3	R	5.28	H9	R	5.72	L5	MA	9.04
A8	MB	6.70	D4	MA	4.70	G4	R	3.96	H10	R	1.76	L6	R	0.00
A9	MB	3.74	D5	CC	0.56	G5	R	2.42	H11	R	14.08	L7	MA	4.51
A10	R	1.32	D6	CC	1.86	G6	R	2.64	I1	R	2.20	L8	CD	0.50
A11	R	3.52	D7	R	3.52	G7	R	1.98	I2	CC	1.34	L9	CD	0.69
A12	R	2.86	D8	R	1.76	G8	R	6.16	I3	R	7.70	M1	CB	10.52
A13	R	2.64	D9	R	1.32	G9	R	10.56	I4	MA	13.74	M2	CB	1.97
A14	R	3.52	D10	R	2.86	G10	R	2.20	I5	R	1.32	M3	CB	2.14
A15	R	5.06	D11	R	1.32	G11	R	3.52	I6	R	1.76	M4	CB	10.19
B1	MA	15.08	D12	R	2.86	G12	R	4.84	I7	R	5.50	M5	MA	7.82
B2	MD	3.10	D13	R	2.64	G13	R	4.40	I8	CA	4.06	M6	MA	16.88
B3	MA	8.20	E1	MC	3.57	G14	R	1.32	I9	R	2.20	M7	MA	14.09
B4	R	1.76	E2	MA	5.72	G15	R	3.52	I10	R	0.00	M8	CB	0.00
B5	MB	4.83	E3	R	1.10	G16	R	1.76	I11	CB	1.48	M9	CB	4.27
B6	MD	1.78	E4	R	1.98	G17	MD	2.68	J1	R	4.18	M10	CB	9.70
B7	R	2.20	E5	MD	0.94	G18	R	0.88	J2	R	1.76	M11	MA	18.24
B8	R	3.74	E6	R	1.76	G19	R	1.32	J3	CA	1.97	M12	R	1.76
B9	R	1.10	E7	R	5.28	G20	MC	6.07	J4	CB	1.48	M13	R	2.86
B10	R	5.50	E8	CD	1.22	G21	R	3.96	J5	R	1.32	M14	R	1.76
B11	R	3.52	E9	CD	0.92	G22	R	5.72	J6	R	0.88	M15	R	1.32

B12	R	2.86	E10	CC	1.56	G23	R	2.42	J7	R	2.20	M16	R	7.92
B13	R	2.20	F1	CD	4.58	G24	R	1.10	J8	R	2.86	M17	MC	2.44
B14	R	3.08	F2	R	4.84	G25	R	1.98	J9	R	5.50	M18	R	3.08
B15	R	3.52	F3	R	2.20	G26	R	2.20	J10	R	1.10	M19	R	1.76
C1	R	2.64	F4	R	11.00	G27	R	2.64	J11	CC	0.43	M20	R	2.20
C2	R	1.76	F5	R	4.62	G28	R	3.08	J12	CC	0.28	M21	CA	4.68
C3	MA	7.10	F6	R	2.20	G29	R	1.32	J13	R	1.32	M22	CA	9.05
C4	MA	5.14	F7	R	0.66	G30	R	1.32	J14	R	4.62	M23	CB	2.30
C5	R	1.54	F8	R	1.32	G31	R	2.86	K1	R	6.60	M24	CA	5.62
C6	R	2.86	F9	R	1.76	G32	R	6.60	K2	MD	7.31			
C7	R	2.86	F10	R	2.64	H1	MA	8.87	K3	R	4.40			
C8	MD	2.96	F11	R	2.20	H2	MC	5.26	K4	R	1.76			

Hno=House number; Lut=Land use type; Swg= Solid waste generation (kg/day); R=Residential; CA=Commercial Category A; CB=Commercial Category B; CC=Commercial Category C; CD=Commercial Category D; MA= Mixed dwelling (R+CA); MB= Mixed dwelling (R+CB); MC= Mixed dwelling (R+CC); MD= Mixed dwelling (R+CD)

The solution to the p median problem for ten computer runs ($p=1$ to 10) showed that as the number of waste bins increased, the walking distance to the service points (optimized waste bin locations) decreased (Table 4). If the maximum walking distance to the service points is set at 200 m, only $p=6, 7, 8, 9$ and 10 entirely covered the study area. Consequently the size of waste bins for $p=6$ to 10 need to be determined.

Table 3: Mean composition and density of municipal solid waste types from the study area

Waste type	Average composition (%)	*Typical specific density (kg/m ³)	Density (kg/m ³)
Food Wastes	12.24	290.72	3558.38
Paper	19.49	89.00	1734.51
Textiles	8.55	65.26	557.96
Plastics	3.57	65.26	233.05
Grass/ Leaves/wood	4.75	237.32	1126.43
Leather/rubber/nylon	19.24	160.19	3082.07
Metals	4.97	320.38	1592.89
Glass/ Ceramics	3.83	195.79	750.40
Miscellaneous	23.36	480.57	11226.19
Mean density			238.6kg/m ³

*Tchobanoglous *et al.* (1993)

Table 4: Number of solid waste generation points within each range of walking distance to the service points

No. of waste bins	1	2	3	4	5	6	7	8	9	10	
Walking distance to service point (m)	No. of waste generation points covered										
0-50	10	16	17	28	33	37	46	42	51	57	Acceptable walking distance
51-100	28	41	53	65	74	78	76	105	103	103	
101-150	31	52	62	61	59	63	56	37	30	26	
151-200	25	31	30	22	20	9	9	3	3	1	
201-250	27	26	20	10	1	0	0	0	0	0	Unacceptable walking distance
251-300	14	8	4	1	0	0	0	0	0	0	
301-350	19	12	1	0	0	0	0	0	0	0	
351-400	18	1	0	0	0	0	0	0	0	0	
401-450	9	0	0	0	0	0	0	0	0	0	
451-500	5	0	0	0	0	0	0	0	0	0	
501-550	1	0	0	0	0	0	0	0	0	0	

Table 5 presents the summary of results for $p=6$ to 10. The alphanumeric code represents a waste bin identity while the value in parenthesis is the corresponding amount of solid wastes from waste generation points within 200 m walking range. For example 6B1(56.22) represents waste bin number one out of six and the total amount of solid wastes from waste generation points within its reach is 56.22 kg. For each value of p , the required capacity of each waste bin is the accumulated volume of solid wastes from its service area in 3 days. As presented in Table 5, the minimum and maximum required waste bin capacity for the study area is 0.50 m^3 (10B3) and 3.56 m^3 (6B5) respectively. Assuming a capacity utilization of 70%, then the modified minimum waste bin capacity is 0.65 m^3 (1.3×0.50) for 10B3 and 4.63 m^3 (1.3×3.56) for 6B5.

Table 5: Amount of solid wastes captured by waste bins and required range of waste bin size for $p=6$ to 10

p -median value	*Waste bin identity and amount of captured solid wastes (kg)	[†] Required range of waste bin capacity (m^3)
6	6B1(56.22), 6B2(118.05), 6B3(146.05), 6B4(141.28), 6B5(282.75), 6B6(99.03)	0.71 - 3.56
7	7B1(56.22), 7B2(118.05), 7B3(142.53), 7B4(142.33), 7B5(128.89), 7B6(156.33), 7B7(99.03)	0.71 - 1.97
8	8B1(56.22), 8B2(98.03), 8B3(142.53), 8B4(63.05), 8B5(90.83), 8B6(104.34), 8B7(193.31), 8B8(95.07)	0.71 - 2.43
9	9B1(66.19), 9B2(56.22), 9B3(98.03), 9B4(142.53), 9B5(59.31), 9B6(97.74), 9B7(121.41), 9B8(106.88), 9B9(95.07)	0.71 - 1.79
10	10B1(66.19), 10B2(56.22), 10B3(40.11), 10B4(57.92), 10B5(142.53), 10B6(59.31), 10B7(97.74), 10B8(121.41), 10B9(106.88), 10B10(95.07)	0.50 - 1.79

*Alphanumeric code represents waste bin identity while the corresponding daily amount of solid waste captured is in parenthesis

[†]Begins with minimum volume of solid waste in 3 days and ends with maximum volume of solid waste in 3 days

The non-parametric probability plot of the modified volume of solid waste from all the service areas when three major outliers (observations that fall outside the pattern of the data) are removed is shown in Figure 4. The data is normally distributed ($R^2=0.9567$) and the z-interval procedure is appropriate for analysis (Weiss, 2002). Using the z-interval procedure at 95% confidence level, the modified volume of the waste bin was determined to be somewhere

between 1.47 and 1.8 m³ ($\alpha=0.05$, $\sigma=0.52$, $n=37$). Consequently, if a waste bin is to be chosen above the median value (1.6 m³), then it is logical to choose a normalized size of 1.74 m³ which occupied the 59th percentile and provide multiple waste bins for service areas whose generation rate was greater than this value. It therefore implies that for $p=6$ to 10, more than one waste bin would be required in 41% of the service points.

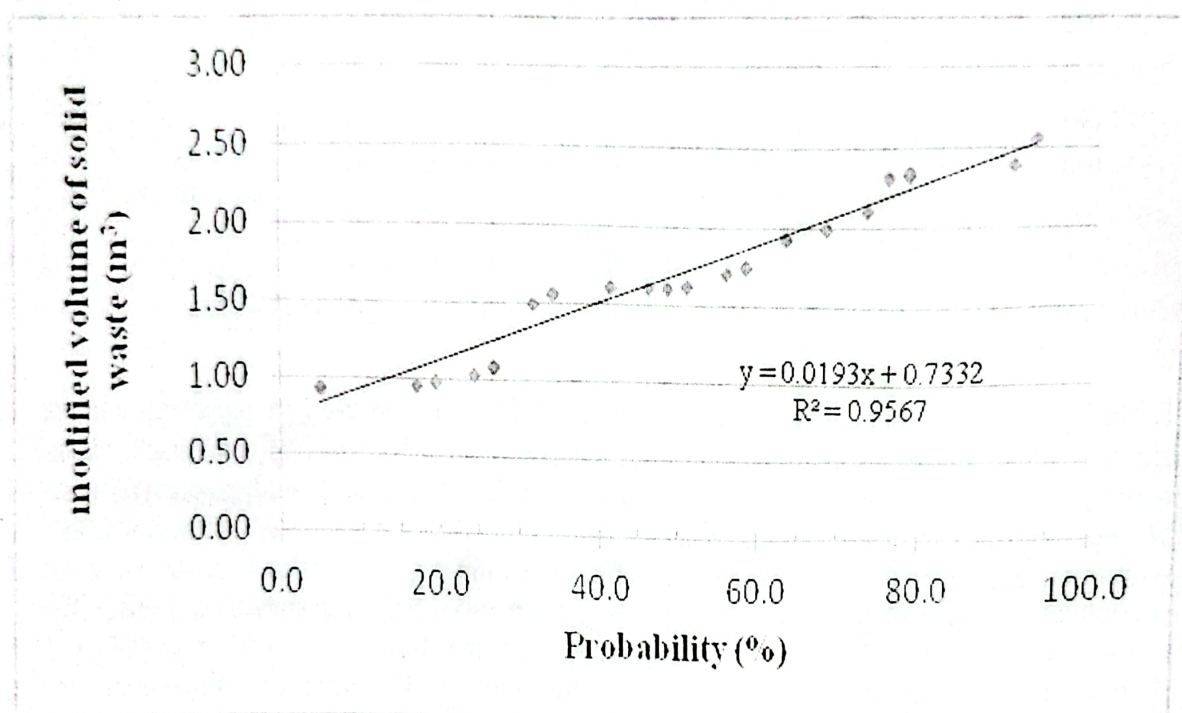


Figure: 4 Non-parametric probability plot of modified volume of solid waste from service areas

CONCLUSION

The procedure for selecting optimal waste bin locations and size in developing areas was illustrated in this study. Optimal locations of one to ten waste bins within the study area was determined by the built-in solver for p -median problems in the GIS-based software; TransCAD v. 5.0 (Caliper, Corp.). The software considered several combinations of geo-referenced waste generation points and potential waste bin locations until the optimal solution was achieved for each computer run. The spread sheet from the p -median solution was analyzed to obtain the

service area and amount of solid waste captured by each waste bin. Consequently, the size of each waste bin was derived from the product of utility factor and accumulated volume of solid wastes from its service area in 3 days. When the maximum walking distance to the service points was set at 200 m, only $p=6, 7, 8, 9$ and 10 entirely covered the study area. The statistical analysis of several waste bin sizes (for $p=6$ to 10) using the z-interval procedure showed that at 95% confidence level, the most appropriate size of waste bin for the study area was between 1.47 and 1.8 m³. Hence, a normalized size of 1.74 m³ which was slightly above the median value of 1.6 m³ and

occupied the 59th percentile was proposed for the study area. The remaining 41% of service points would require the same waste bin size but the quantity for each service point would depend on the volume of solid waste emanating from the service area. Based on the size of the waste bins and recommendation of Tchobanoglous *et al.* (1993), a one-ton medium sized truck with a hook lift mechanism is appropriate for collecting the waste bins

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