

Optimization and assessment of waste bin locations using Geographic Information System

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Abstract

This study presents a Geographic Information System (GIS) method for finding the optimum location of municipal waste bins in a typical developing city based on existing spatial organization and infrastructure. The optimum locations of one to ten waste bins within potential service areas were determined by the built-in solver for p -median problems in TransCAD v. 5.0 (Caliper, Corp.) software. The social impact of the waste bins in terms of the amount of solid waste collected and waste generation points served within 200m walking distance, improved as the number of waste bins was increased from 1 to 5. As the number of sited waste bins were greater than 5, 100% service coverage and public satisfaction was achieved while some waste bins became underutilized. The results of the study also showed that the GIS optimized waste bin locations tend to be more accessible to waste generators than empirical waste bin locations.

Keywords: Municipal solid waste, Geographic Information System, waste bin, optimum location, impact

Introduction

Municipal solid waste management across the world has evolved from the need to protect public health and the environment. Spatial organization and existing infrastructure of cities in developing pose challenges for solid waste management programs. The urban spatial structure of developing countries is characterized by high density, unplanned settlements that have limited

road access, because most cities developed before the Land Use Act and rural-urban migration keeps increasing (Cohen, 2006). Consequently, most urban centers in developing countries like Nigeria are witnessing environmental degradation and the burden of diseases associated directly or indirectly with improperly managed solid wastes (Imam et al, 2008).

In order to minimize the adverse impacts of solid wastes and improve service coverage, city authorities in Nigeria now place large moveable containers at designated service points along the shoulders of accessible roads for the storage of municipal solid wastes. The system takes a shared responsibility dimension; one aspect requires the waste generator to place the generated solid wastes into the waste bin provided by the municipal authority at a designated service point. The second aspect requires the municipal authority to allocate waste bins to different parts of the city, collect the waste bins, dispose the contents and return the empty waste bin to the service point. In this role, the municipal authority is faced the challenge of efficient siting of waste bins in order to achieve maximum service coverage and public satisfaction.

Geographic Information System (GIS) has over the years been used as a decision support tool for planning and modeling of various systems covering social, economic and technical aspects by coordination of complex spatial and non spatial data. Spatial modeling in GIS offers one approach for solving facility location that service some kind of demand distributed in space. A location-allocation problem is a variant of the facility location problem which includes the assignment of demand locations to the facilities, taking into account certain constraints (Hillsman, 1984; Miller and Shaw, 2001). The application of location-allocation 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). This study is aimed at determining the optimum location of several numbers of waste bins and assessment of the spatial performance each waste bin.

Methodology

The GIS-based optimization technique was applied to a part of Ilorin metropolis, Kwara State, Nigeria which was downloaded from www.googleearth.com. The study area 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. The downloaded satellite image of the study area was digitized (Figure 1) and all the information relevant to the study were geo-referenced.

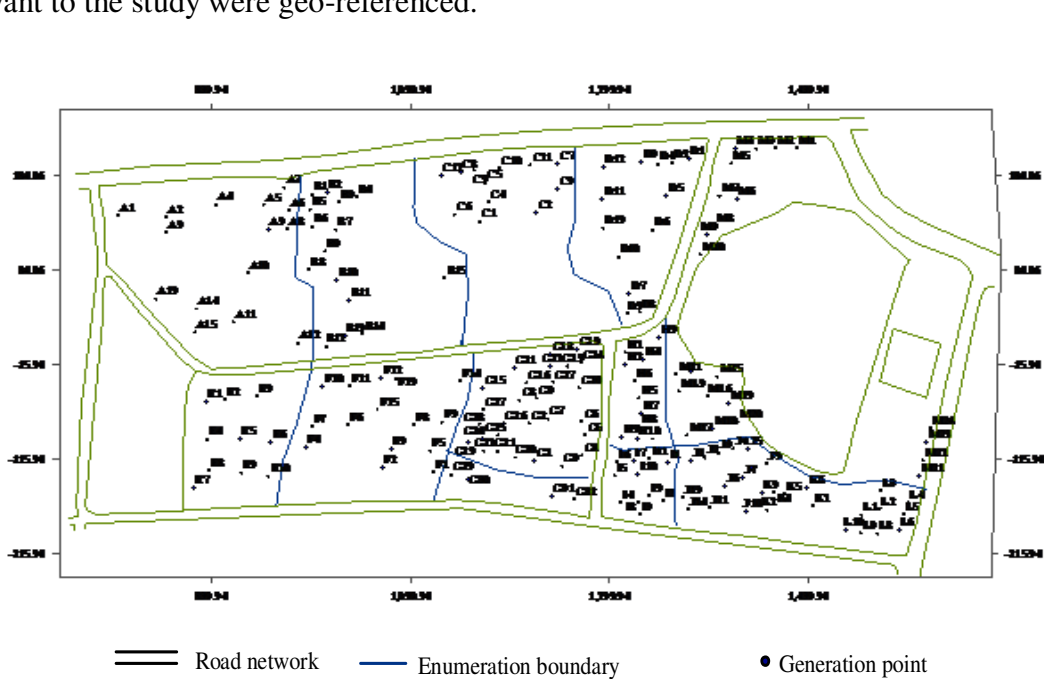


Figure 1. Digitized map of the case study showing solid waste generation points and the road network

Field study was carried out to obtain demographic, solid waste, and collection operation data. Waste bins were located at the shoulders of the major road after eliminating unsuitable areas. The processed information was stored in a spatial database which is a combination of vector spatial data and attributes data with unique identifier for the referenced spatial objects.

The Facility Location Function in the GIS package TransCAD, was used to solve the p - median problem.

Results and Discussion

A total of 187 waste generation points were identified within the case study, including 113 residential buildings, 30 commercial buildings, and 44 mixed dwellings while a total of 269 potential waste bin locations were identified along the accessible road network. The spatial performance of the waste bins (Table 1) was measured in terms of the percentage of waste generation points served within 200m walking distance, the percentage of solid waste collected, and the utilization of the individual waste bins for each scenario. The amount of solid waste collected (service coverage) and generation points served (public satisfaction) improved as the number of waste bins was increased from 1 to 5 while 100% service coverage was achieved with 6-10 waste bins. The average walking distance to the waste bins decreased as the number of waste bins increased as shown in Table 2.

Table 1 Spatial performance of several waste bin quantities

No. of waste bins	1	2	3	4	5	6	7	8	9	10
% Served	50.27	74.87	86.63	94.12	99.47	100	100	100	100	100
% Solid waste collected	55.83	62.64	78.09	93.5	98.2	100	100	100	100	100
No. of waste bins underutilized	0	0	0	0	0	2	2	3	6	7

A comparison between empirical waste bin location and GIS optimized waste bin location for $n = 10$, is shown in Figure 2. The GIS optimized waste bin locations tend to be more accessible to waste generators than the empirical waste bin locations. For example, 30% and 16% of waste generation points were within 0-50m walking distance to the waste bins for GIS optimized waste bin locations and empirical waste bin locations respectively.

Table 2 Number of solid waste generation points within each range of walking distance to the waste bin

No. of bins	1	2	3	4	5	6	7	8	9	10
Walking distance to waste bin (m)	No. of solid waste generation points covered									
0-50	10	16	17	28	33	37	46	42	51	57
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
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

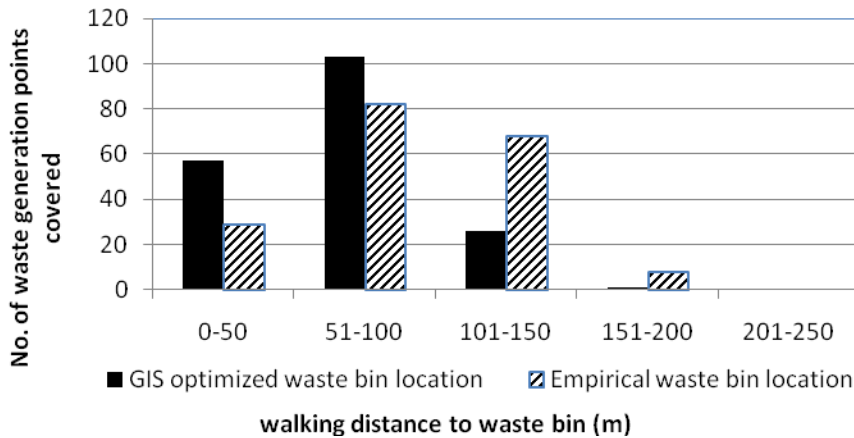


Figure 2. Number of waste generation points within walking distance ranges for GIS optimized waste bin location and empirical waste bin location

A waste bin is underutilized if the amount of solid wastes captured by it in a week is less than 70% capacity of the bottom trapezoidal section of the waste bin. In the GIS optimized waste bin locations, two waste bins became underutilized when $p=6$ and progressively increased to 7 when $p=10$ (Table 1). In empirical waste bin location for $p=10$, seven waste bins were equally underutilized while one waste bin would be extremely underutilized because its spatial location was comparatively far from any waste generation point.

Conclusion

This study has shown how GIS can be used to determine the optimum location of municipal waste bins based on waste generation points and existing spatial infrastructure. The analysis of the attribute table from the result of TransCAD software showed the social impacts of waste bin locations. Service coverage and public satisfaction improved as the number of sited waste bins increased. More importantly, the GIS optimized waste bin locations are more accessible to waste generators than empirical waste bin locations. Some waste bins became underutilized when the number of waste bins sited was greater than 5, indicating a negative social impact and greater economic impact. Evaluation and tradeoffs between decision variables such as impacts of waste bin locations could assist municipal solid waste management authorities in averting failure of solid waste management services.

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