A Spatial Decision Support System for Waste Management in Municipal Society of Lahore City

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***Abstract*— The paper discusses waste management issues in urban regions, which is an area of concern in highly populated cities of developing countries. Lahore, being the second most populated city of Pakistan, is also facing waste management issues, with both private and public organizations struggling to cater to it. A government operated housing society in Lahore named WAPDA (Water and Power Development Authority) Town is facing this issue due to improper waste dumping by residents. To resolve this problem, a door-to-door survey was conducted in the G5 block of the housing society. The survey results showed that most of the residents were not satisfied with waste management services and reported that absence of waste bins was a major reason for inappropriate waste dumping. Identifying the best possible location for placement of new waste bins made this a spatial decision-making problem. The required spatial data was collected using physical street surveys and mapping in ArcGIS 10.2 software. The existing waste dumping locations were taken as alternatives. Additionally, multiple criteria were chosen for evaluation which were given weights using pairwise comparison method, while various geo-processing tools were used to evaluate the criteria. Finally, alternatives were scored in terms of their appropriateness using Analytical Hierarchical Process (AHP), a multi-criteria decision-making technique. The proposed solution will help in minimizing improper waste dumping, leading to a positive environmental impact on the housing society.**

Keywords- GIS; Multi-criteria Decision Making; Waste Management; Spatial Modeling.

I. INTRODUCTION

Massive population rise, unmanaged urbanization and uplift of living standards have greatly contributed to the increasing rate of solid waste generation in developing countries [1]. For urban planners, waste management in municipal areas has become a major problem. Its severity is manifold in developing countries because of inadequate urban planning and scarcity of resources [2].

This is the case in Pakistan as well, where poor planning in cities and high rate of urbanization have led to many problems [3]. One of the major issues in urban areas is waste management, which has adversely affected Lahore, the second most populated city in Pakistan. Even one of the best housing societies in Lahore, like WAPDA Town are no exception. The waste management issue in the housing society is primarily caused by residents disposing of waste at inappropriate locations including open plots, near electricity poles or at street corners. Open garbage dumps, which are exposed to stray animals and rain, lead to waste-related diseases in the society. To handle rising concerns over this matter, WAPDA Town management recently ran a campaign with the title “Clean WAPDA Town”. The campaign aimed to educate residents about proper disposal of waste by placing banners bearing motivational cleanliness messages throughout the housing society. Unfortunately, this campaign did not have any positive impact on the issue. Meanwhile, the residents raised complaints about waste spreading due to severe lack of waste bins.

The passiveness of the society administration to solve this issue was mainly due to budget constraints. Hence, the administration was unable to figure out the appropriate count and location for placing waste bins in any block of the housing society. To solve this problem, firstly a relatively small but congested block of G5 was selected. Then, through research, a detailed methodology was developed with the proposition that lack of waste bins was the main issue behind improper disposal of waste by residents. Finally, the survey data coupled with Geographical Information System (GIS) and multi-criteria decision-making techniques helped in identifying the optimal locations for placement of waste bins. The proposed methodology of waste bin placement can improve the cleanliness of the block and eventually can play a significant role in city-wide waste management.

The rest of the paper is organized as follows: Section II discusses in detail the methodology used for evaluating the locations for waste bin placements. Different alternative locations for bin placement were chosen using a Global Positioning System (GPS) survey. Finally, using a multi-criteria evaluation technique, the alternatives were ranked depending on how appropriate they were considered. Section III describes the results obtained from the methodology in terms of spatial context. At the end, Section IV lists the benefits gained through this work and briefly proposes a validation approach as future work.

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II. METHODOLOGY

This research work aims at solving the waste management issue in WAPDA Town, for which a door-to-door survey was carried out in G5 block. The approximate area of this block is 67000 m^2 which includes 337 houses and 18 empty plots. The survey questionnaire results from 80 households showed that almost 96% of residents of the block were unsatisfied with waste management. Moreover, 65% of residents pointed out that the issue of waste management was due to lack of waste bins in the block. Through street survey, it was found that only one large bin, provided by the management, was placed in the block near a commercial area. Placement of new bins was seemingly the obvious solution, but due to the budget constraints, the management could place only a limited number of such bins.

This transforms the issue under consideration into a decision-making problem, where a selected number of options are to be chosen from a set of available alternatives (bin placement locations) based on certain factors. Being a spatial problem, GIS can facilitate this process. GIS combines spatial data with quantitative and qualitative information [4] and it has been quite extensively used in solving municipal solid waste management issues [7][8][12]. Some highly unstructured social problems require decision making by the municipal administration. For such cases, the fusion of GIS with decision making has formed the domain of Multi Criteria Spatial Decision Making (MCSDM) [13]. The MCSDM has been effectively used in solving various spatial waste management issues [5][6]. The application of MCSDM for waste management is mainly focused on the following matters:

i decision making for the selection of most appropriate landfill site selection [5][6]

ii optimizing waste collection procedures [7][12]

iii reallocation of existing waste bins [7]

The major shortcoming in existing research work is that these waste management practices have been focused primarily on dumping of garbage after collection from waste bins. Nothing substantial has been discussed about cleanliness issues of the study area due to improper waste dumping by the residents. Moreover, the study areas in prior works have been mostly quite large in geographical extent [5][6][7], and hence the specific issues at the block level of a municipal society are overlooked. This has led to the selection of less than optimal criteria for decision making related to waste management. Our research work attempts to fill in these shortcomings by working on a relatively small area of G5 block and focusing on waste disposal issues caused by residents. Through multiple surveys, the root cause of improper waste dumping was found to be lack of available waste bins. With this finding, the primary objective of the current work has been to improve waste management of WAPDA Town at the grass root level by proposing the most appropriate locations for placement of waste bins.

After narrowing down the problem, a GPS survey was done in the G5 block. The Android application GPS Logger [14] was used for surveying and the results collected 14 GPS points of improper waste dumping. The collected GPS points were converted into shapefile and visualized in ArcGIS Desktop 10.2 [9]. These GPS survey locations were taken as alternatives for placement of waste bins. For the evaluation of alternatives, seven different criteria were selected, as listed in Table 1. The choice of criteria was dependent on the sources of garbage generation and dumping specifically for the G5 block. Primary sources of garbage generation include houses and commercial areas. Moreover, the primary target locations for garbage dumping by residents includes empty plots, poles, roads, and existing bins. Another criterion named ‘proposed bins’ considers the distance between the bin under consideration and the nearest proposed bin. This criterion is of vital importance, since too close or too far placement of new bins would significantly affect the waste dumping practices of the block’s residents.

For the evaluation of criteria, data was prepared by the combination of GPS surveys and digitization over geo-referenced satellite imagery, as shown in Figure 1. The data for criteria C1 (Houses), C3 (Roads and streets), C4 (Empty plots) and C5 (Commercial areas) was prepared by digitizing in ArcGIS Desktop 10.2. There were 337 houses, 18 empty plots, 3 commercial points and 17 road segments. The data layers prepared using ArcGIS Desktop were stored in Shapefile format. The data for C2 (Poles), C6 (Existing bins) and C7 (Proposed Bins) was prepared using GPS survey points. There were 56 poles, 14 points of improper waste dumping and only one existing bin. The improper waste points were considered as proposed bin locations (alternatives). The average accuracy of GPS points was 5-7 meters. The GPS points acquired were in Keyhole Markup Language (KML) format, which were then converted into Shapefile format to be used in ArcGIS Desktop. The geometry type of data layers for C2, C5, C6 and C7 was set as point, for C3 as polyline, and for C1 and C4 as polygon. The coordinate system for data layers was set to World Geodetic System 1984 (WGS84) [15].

After the data preparation, a pairwise comparison technique was used to assign weights to the criteria [10][11]. The criterion C1 (Houses) bear the highest weight because G5 being a congested block has a high ratio of garbage generation per unit area. For waste dumping, the places found to be most prone were roads, empty plots and poles. Hence, their weights are comparatively high. All the selected criteria, their reasoning and calculated weights are given in Table 1. It is noteworthy to mention that the higher the value of a criteria, the more it favors the alternative.

The next step was to define an appropriate coverage area for each alternative. For this purpose, the Thiessen polygon tool in ArcGIS Desktop was used. The Thiessen polygon takes as input the alternative points and outputs the polygon enclosing each alternative. Polygons are generated in such a way that any location within a specific polygon is closer to the alternative within the polygon than to any other alternative point (as shown in Figure 2). In other words,

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Figure 1. Block G5 detail map.

these polygons partition the available area according to alternatives and hence serve as base service area for evaluation of selected criteria.

For the most accurate ranking of waste bins (alternatives), the well-known multi-criteria decision-making technique of AHP was used, which focuses on ranking alternatives based on specific criteria with assigned weights [11]. Finally, different geo-processing tools from ArcGIS Desktop were used to evaluate the value of each criteria.

For determining the values of C1-C5, the Spatial Join tool in ArcGIS Desktop was used. It counted the value of specific criteria (e.g. no. of poles) within the geographical extent of base service layer and assigned it to the alternative enclosed within it. Then, the value of the criteria (for each alternative) was normalized to fall between 0 and 1. To calculate the values of C6 and C7, the Near tool in ArcGIS Desktop was used. It calculated the distance from each alternative to the nearest existing bin and proposed bin (alternatives), respectively. The values of all criteria are finally represented as individual attributes in the alternative data layer.

Lastly, using the formula of Weighted Sum Model (WSM), the final value of each alternative was calculated.

$$WS(Ax) = \sum y \, (Ax(Cy) * W(Cy)) \quad (1)$$

where,
WS(Ax) = Total weighted score of Alternative x
Ax (Cy) = Score of Alternative x for Criteria y
W(Cy) = Weight of Criteria y

Sorting the value of alternatives in descending order lists the optimal locations for waste bin from best to worst. Figure 3 summarizes the proposed methodology in terms of three phases namely, exploratory, empirical and analysis, while Figure 4 briefly depicts the phases of decision making.

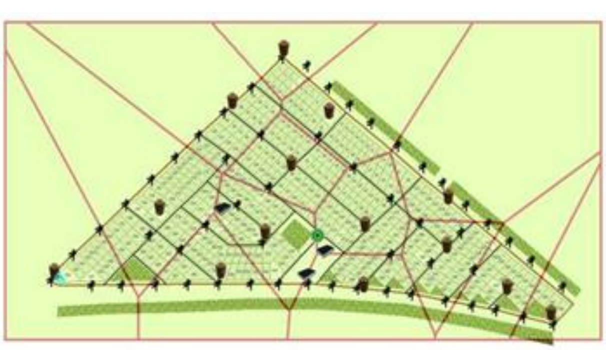

Figure 2. Thiessen polygon map.

III. RESULTS

The final weighted score of alternatives was used to spatially visualize waste bin locations with symbols of different sizes. The size of the symbol is proportional to its importance. The larger the size of an alternative (yellow circles), the better location it represents for waste bins, as shown in Figure 5. Moreover, each alternative location is serially labeled (in descending order) based upon its final weighted score. From the Figure 5, it can be analyzed that the alternatives which are spatially near the center of the block are better for being selected as waste bin locations i.e. alternatives labeled 1, 2, 3 and 4. On the other hand, alternatives labeled 12, 13 and 14 are the least optimal locations. It can be inferred from this analysis that the G5 block is affected by improper waste dumping mostly at the center, caused by congested housing and narrow roads. Hence, priority should be given to bin placements at these locations that are highly prone to improper waste dumping by the residents.

IV. CONCLUSION AND FUTURE WORK

Waste management is a major environmental issue in developing countries including Pakistan. Limited maintenance budget has adversely affected WAPDA Town residents, due to lack of available waste bins. GIS in collaboration with multi-criteria decision-making techniques helps the management in efficiently determining the location of waste bins. The proposed solution has a two-fold advantage. Firstly, due to the generic nature of the required dataset, this spatial decision solution can be applied to other blocks of the society or in various metropolitan areas of Lahore city. Secondly, altering the criteria and their weights, various outputs can be retrieved. This helps in achieving flexible decision making. According to the budget constraints of a specific area, management can choose the top locations for bin placement. The goal achieved through this work is a well-researched solution to the cleanliness issue in WAPDA Town. All previous efforts have been in

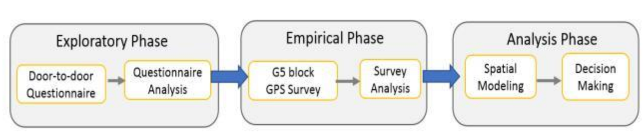

Figure 3. Proposed methodology chart.

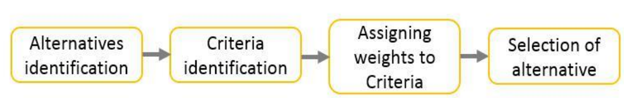

Figure 4. Decision making process.

Figure 5. Decision making result.

vain due to lack of any statistical data and analytical calculations, while the current research work includes both, the surveyed data and spatial analytics.

In the next phase of this research work, actual placement of waste bins is expected at locations retrieved through the proposed solution. Upon placement of bins, further analysis would be carried out to measure any improvement in improper waste dumping by residents in the vicinity of the bin. Reduction of improper waste dumping will authenticate the selection of criteria and their weights; else brainstorming would be done for altering these parameters. This iterative process will eventually mature the spatial decision-making procedure for waste management. Lessons learned from these outcomes can be used to cater waste management issues in other blocks or municipal societies of Lahore city.

Since the final weighted score is a direct measure of the importance of the waste bin location, another future prospect could be to place waste bins of different sizes depending upon the calculated score. This will, in turn, help in efficient utilization of the financial resources of the administration.

TABLE I. CRITERIA DESCRIPTION

Code	Criteria	Weights	Description
C1	Houses	0.42	Each house represents specific amount of daily waste.
C2	Poles	0.09	Waste dumbing is done by residents near electric poles.
C3	Roads and streets	0.12	Accessibility of alternative through main road and streets
C4	Empty plots areas	0.18	Waste dumbing is done by residents inside empty plots.
C5	Commercial areas	0.04	Commercial areas generate more waste as compared to houses
C6	Existing bin	0.06	Distance from the nearest existing waste bin.
C7	Proposed Bin	0.09	Distance from the nearest proposed waste bin (alternative)

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