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MODELLING SPATIAL VARIATION OF COLLECTED WASTE IN URBAN ENVIRONMENTS USING GIS

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Abstract:
Municipal solid waste collection constitutes one of the most pressing issues in developing countries. In recent years the continuous increase in solid waste has been observed with the increase in population growth. Several studies have applied Geographic Information Systems in waste management. Existing research has however concentrated on waste generation and disposal and a few studies focused on collection systems. In this study we determine how collected waste varies using GIS. The relationship between collected waste and other variables such as affluence, population and road density were also tested. We found that collected waste does vary in urban environments and the variation is significantly related to affluence (r=-0.3382, p=0.009) population (r=0.536, p=0.001) and road density (r=0.391, p=0.07). We recommend that in the future resource allocation for solid waste collection should also incorporate the variables tested in this study.

Keywords: Solid waste collection, Population growth, Geographic Information Systems(GIS).

1.INTRODUCTION

Globally, municipal solid waste has generally increased especially in less economically developed countries (Kinnaman, 2009). The major factors contributing to the increase in municipal solid waste include the increased population growth in urban areas , rapid industrial growth, increase in informal trading as well as the rise in the standards of living (Kamran, Chaudhry, & Batool, 2015). Increased informal trading as well as the continuous growth of industries results in increased waste generation from packaging material as well as from producing goods. Municipal solid waste is usually not properly handled in developing countries and causes several problems with respect to storage, collection and disposal (Burnley, 2007; Morrissey & Browne, 2004). Improper storage, collection and disposal of solid waste is of major concern (Batool & Chuadhry, 2009). This is because less economically developed countries lack enough resources for collection of waste (Masocha & Tevera, 2004) .Awareness of the dangers of poor handling of solid waste is sometimes not well spread .

One of the major factors highlighted in studies contributing to the generation of huge quantities of waste is related to rural urban migration an informal trading (Tsiko & Togarepi, 2012). Africa has generally had a 10% increase in population between 1990 and 2013 as a result of rural to urban migration which has led to a general increase in population. Rural to urban migration has contributed a 3% increase in population of Harare between 2002 and 2012 (Zimstat, 2013). The challenges of waste management have therefore been felt in Harare, Zimbabwe as a result of poor waste handling due to the pressure on resources caused by a growing population. Due to the increase in solid waste, the city has been failing to cope with regards to meeting its obligations which includes making sure the waste is collected and disposed of at appropriate sites.

Studies on GIS modeling of municipal waste generation have been carried out to estimate the future generation of waste (Beigl, Lebersorger, & Salhofer, 2008; Karadimas & Loumos, 2008). The aspect of disposal has been covered in several studies especially with reference to proper landfill site selection (Al-Ansari, Al-Hanbali & Knutsson, 2012; Karsauliya, 2013; Nas, Cay, Iscan & Berktay, 2010). However, to the best of our knowledge, the application of GIS on collection of waste management is still not well documented in literature. The only studies on waste collection that can be traced are those related to optimization of transport routes using GIS (O'Connor, 2013; Tavares, Zsigraiova, Semiao, & Carvalho, 2009). Furthermore, a few studies have quantified the spatial variations in collected waste based on residential areas. The use of spatial statistics tools such as hot spot analysis in assessing the variation of municipal solid waste collection is one of the key approaches which however remain unexplored.

Thus, in this study we investigate whether collected waste varies spatially in Harare using spatial statistics. We also want to investigate how population density; road density and affluence explain collected waste. We hypothesis that collected waste in urban environments varies in relation to affluence, population density and road density.

Solid waste management involves four main aspects which are generation, collection and disposal. Several studies have been carried out highlighting the application of GIS and analysis of variation in solid waste generation and disposal. However, the application of GIS in analyzing how waste collection varies spatially in urban environments based on variables such as affluence, road density and population density is unclear. In this study we want to test using GIS application whether collected waste varies spatially in an urban environment. We want to test the relationship between collected waste and variables such as affluence, population and road density.

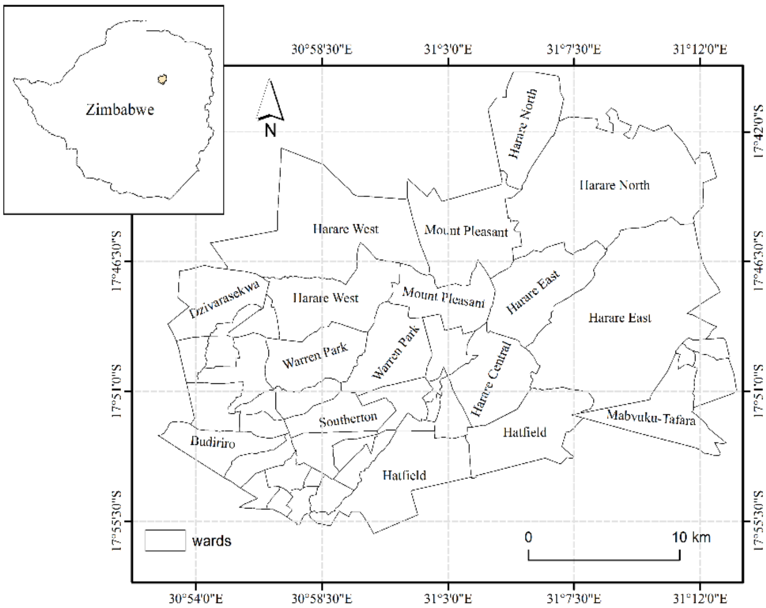

Fig. 1: The Study Area, Harare, Zimbabwe

2.STUDY AREA

The study was conducted in Harare, the capital city of Zimbabwe. It is located -17.83 latitude and 31.05 longitudes and it is situated at elevation 1494 meters above sea level. It has a recorded population of 1.485 million (Zimstat, 2013). According to the Harare City Council statistics obtained from the 2013 Amenities status report the annual municipal waste generation is approximately 150 300 tons .The City is divided into 8 collection zones (Northern, Western, Eastern, North Western, North Eastern, South western, South Eastern and Central) and 45 collection wards, (Fig. 1) The Amenities report stated that the City has a total of 23 solid waste collection vehicles responsible for servicing the 8 waste collection zones comprising of 45 wards. It has 8 Cleansing inspectors for each zone to monitor collection efficiency.

3. METHODOLOGY

3.1 DATA COLLECTION

3.1.1 POPULATION AND ROAD DENSITIES

Ward population data for Harare Metropolitan Province was obtained from ZIMSTATS. We used the ward population data to calculate population density. Population density was used because it is a standardized measure of population as it incorporates area. The population density was calculated because it will be used as a predictor variable of collected waste. Population density was calculated by dividing the ward population by area of each ward. The Harare road network was downloaded from DIVA GIS http://www.diva-gis.org/datadown . The road network was overlaid with the population wards. We calculated the total length of roads for each ward using the field calculator. We divided the total length of roads for each ward by its area to get the road density. Road density was used because it is a standardized measure of the roads in the wards and it was used as a predictor variable of collected waste.

3.1.2 AFFLUENCE

The high low and medium density suburbs were used as a proxy measure of affluence. This is because we could not obtain the employment or income data. These were represented by values 1, 2, 3 with 1 being high density representing the least affluent, 2 being the medium density representing the average and 3 being the low-density suburbs representing the most affluent, Affluence was used for further statistical analysis of variation in collected waste, population and road density as well as a predictor variable of collected waste.

3.1.3 COLLECTED WASTE

The zonal solid waste data was obtained from the City of Harare, Department of works, Cleansing and Amenities Services section. The zonal solid waste data we obtained for the 8 zones was recorded as the number of loads carried by each compactor. A compactor is a garbage vehicle that is automated to compress solid waste. It has a maximum capacity of 10 tons and is designed in such a way that the maximum is not exceeded. We multiplied the number of loads per day for each zone by 10 tons to get the total amount of waste collected in a particular zone per day. The total waste collected per day was then multiplied by 365 days to get the value for annual waste collected in a year. The collected waste was calculated so as to show how waste varies spatially based on road density, population density and affluence. Waste collection Zones were digitized using data obtained from 2013 status report on waste management.

3.1.4 MERGING POPULATION DATA AND WASTE DATA

We merged the ward population and waste data collection zones because our population data was in wards were as our waste data was in zones. This was done in order to have our data in one shape file with more than thirty wards for hot spot analysis to be feasible. The collected waste data, population density and road density data were manually added to the attribute table of the population wards. This process was done so as to run zonal statistics on waste data which would enable us to get continuous average data values for the wards. The zonal statistics was added and executed under the raster toolset. Output columns of the summary statistics were generated in the vector file of the population ward. The vector file was exported into ARCMAP and used to run Hot Spot analysis.

3.1.5 GETIS ORD-GI* HOT SPOT ANALYSIS

Getis Ord-Gi* is the tool we used for assessing the spatial variation in solid waste collection among the suburbs. The tool was run in Arc map under spatial statistics. The resulting maps showed variation of road density, population density and collected waste. The tool analyzes hot spots, explaining whether high or low values cluster spatially. It calculates z-score values. Clustering of high z-score values above +1.96 show significant hot spots. This explains high spatial clustering. Cold spots are represented by low z-score values below -1.96 which show significant cold spots. This explains low spatial clustering. A z-score near zero means there is no spatial clustering.

4. STATISTICAL ANALYSIS

SPSS 16.0 was used for data analysis. The Kolmogorov Simonov normality test showed that our data was normally distributed. The results showed that our data was normally distributed therefore we carried out the Analysis of Variance (ANOVA) test to assess variation of the collected waste, population and road density within the high, low and medium densities. Box plots were used to show further comparison of the collected waste; road and population density. To test how affluence, population and road density correlate with collected waste scatter plots were built and the Pearson's correlation test was run to test for significance of the correlation.

5. RESULTS

Results show that the population density for Harare city ranges between 419 (Harare North) to 21388 (Mbare) people/km2. The road density tends to increase generally from west to East with Glen Norah having the highest density of 48, 79 km 2 and Harare East having the lowest road density of 10km2. Our results also show that the amount of waste collected ranges between 7000 and 21000 tons per year with the Southern collection wards having the highest and the Northern wards having the lowest amount of collected waste

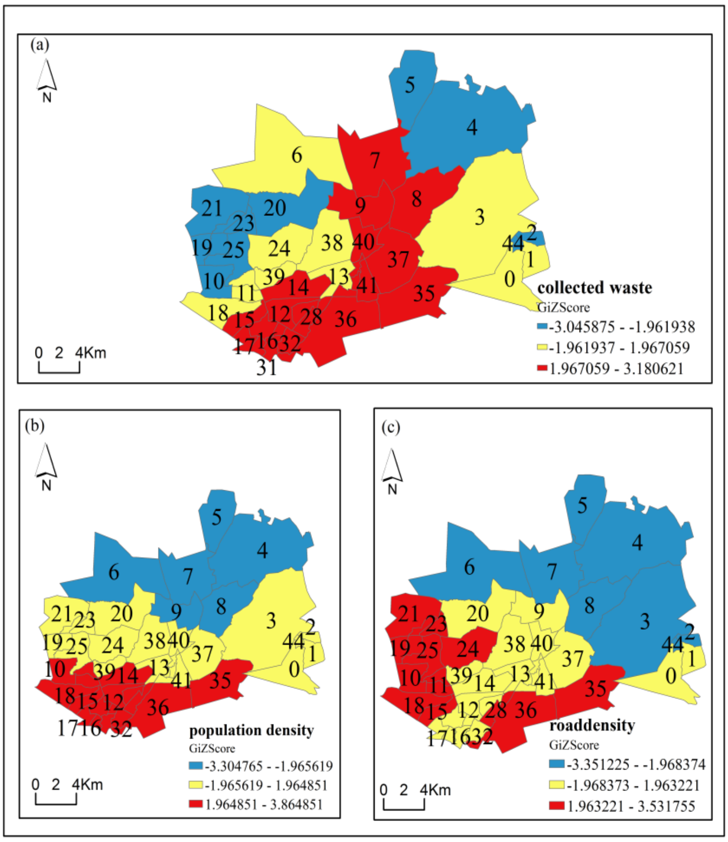

Fig. 2. Hotspot analysis of solid waste collection wards (a) collected waste (b) road density(c) population density

6. HOT SPOT ANALYSIS

Results from the hotspot analysis show that collected waste generally increases from North to South and from West to East. Road density and population density also tend to increase as collected waste increases from North to South (Fig. 2).

46% of the collection wards show a significant hotspot of collected waste with the most significant hotspots being in the Southern suburbs. Cold spots are particularly observed in the Northern (26%), Western (17%) as well as part of the North Eastern (4%) of collection wards. A remainder of 7% of the collection wards shows no clustering (Fig.2. (a)).

Hotspots of population density are shown to be most significant in the Southern wards (22%). Significant cold spots are observed in the Northern collection wards (13%). 65% of the wards do not show significant clustering of population density (Fig.2 (b))

The Northern wards show a significant cold spot for the road density and a hotspot for the Southern and Western Suburbs.26% of the collection wards also show a significant hot spot of road density with 20% in the west and 6% in the Southern wards. (Fig.2(c)).

7.STATISTICAL ANALYSIS

The collected waste, population density and road density showed a significant difference within the high low and medium suburbs ($p<0.05$). Road density $F(2,42) = 3.634$, $p=0.035$, Population density $F(2,42) = 6.965$, $P=0.002$. Collected waste $F(2,42) = 4.563$, P=0. 0016.Box plots results also demonstrate that collected waste, population density, and road density tend to vary with affluence. (Fig. 3) shows how collected waste varies within these suburbs as a measure of affluence

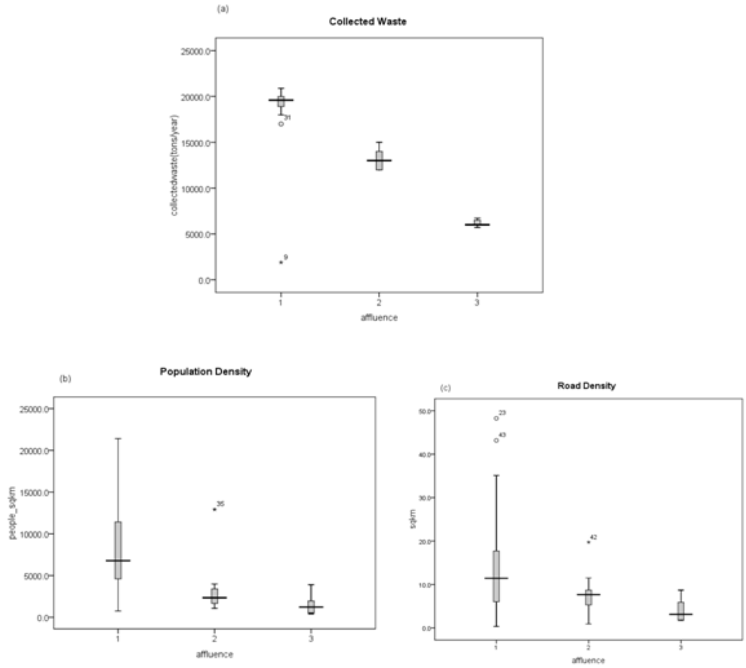

Fig. 3. Waste Collected waste population and road density variation in suburbs 1, 2, 3

Fig. 3. shows variation of collected waste, road density and population density against affluence. The high-density suburbs show the highest volumes of collected waste, median (20 000 tons/year per suburb) and the low density show the lowest volumes of collected waste (5000 tons) (a). Road density shows a higher median in high density suburbs (12km2) and the least median in the low-density suburbs (3km2) (c). Population density is highest in the high-density suburb (5000 people/km2) and lowest in low density suburbs (<1000 people/km2) (c).

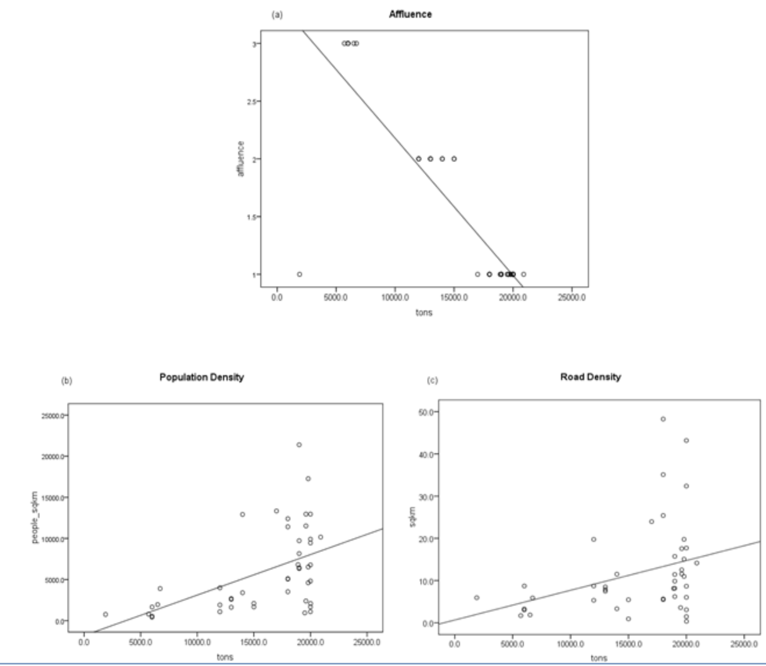

Fig. 4. Relating collected waste to affluence, population and road density

Further analysis relating affluence, population density and road density to collected waste showed that the three variables significantly correlated with collected waste. Affluence showed a negative significant relationship to collected waste (r=-0.382, p=0.009). Road density showed a positive correlation to collected waste (0.391, p=0.07) and population density showed a significantly stronger correlation with collected waste, (r, 0.536, p=0.001).

8.DISCUSSION

Our hypothesis tested for the variation of waste in an urban environment as well as the relationship between collected municipal solid waste and affluence, population density and road density. Our study showed that there exists a significant variation in collected waste across Harare based on the variation of road density, population density and affluence. Results further demonstrated that road density, affluence and population density are determinants of collected waste, these results agree with the results that (Karadimas et al., 2008) found pertaining to determinants of waste generation. The results showed that affluence and demographic factors are among the most contributing factors in waste variation.

High volumes of collected waste observed in the Southern suburbs particularly the Budiriro, Glenview and Glen Norah areas are as a result of high waste generation which is influenced by a high population density. The fact that there are many people per unit area (21388km2) means that more waste is generated in these environments. Another reason for high volumes of collected waste in the high-density suburbs is that the first priority in allocating waste collection vehicles is given to the high-density suburbs as means of minimizing dumpsites. In the absence of waste collection vehicles people in high density suburbs resort to dumping. Dumping sites create breeding conditions for mosquito and bacteria which may result in the outbreak of infectious diseases such as cholera.

Low volumes of collected waste were observed in the Northern parts of Harare particularly the Borrow dale area, which showed a significant positive relationship with population density. Possible explanations for low levels of collected waste in low density suburbs could still be due to the fact that the affluent use private vehicles to collect their own waste thus absence of collection does not cause an increase in the volume of waste

A higher road density obtained in the high-density suburbs also explains high volumes of collected waste because there is a high likelihood of having more bins in an area with high road density then there is in an area of low road density. The reason for having more bins is because of the high number of households.

One key focus of this study was to analyze solid waste collection using GIS particularly Getis Ord, a spatial statistical tool of ARCGIS. The strengths of this tool is that it assesses areas of high and low values based on z values which explain significant clustering of high and low values .This study is in line with the findings of (Kesser, 2010), whose results showed chloropleth maps that explained spatial variation of waste generation though he did not make use of the Getis Ord Gi* tool to asses clustering .The study however does not pick up the seasonal variation of waste collection yet collection may also vary depending on time as generation also varies. Another issue which was not addressed in this study was the amount of waste generated and collected in other land uses such as industries and the commercial sectors. This could help further explain spatial variations in waste generated and collected. Thus, future studies should include other land uses to model the spatial variations in the amount of waste generated and collected in urban environments.

The use of high, low and medium densities as a measure of affluence also needs to be refined. We therefore recommend that future studies gather income data and employment status as a measure of affluence. Future studies should also consider the temporal aspect in assessing variation in waste collection.

This study is important to the Municipality of Harare and other municipalities as it helps in identifying areas of high and low collected waste which will help in resource allocation. The identification of areas of high and low collected waste is important for collection efficiency which is a step in reducing emerging dumpsites thus reducing the risk of diseases such as cholera, typhoid and malaria.

9.RECOMMENDATIONS

We recommend that in the future, factors such as population density, road density and affluence should be considered when allocating resources for waste collection as these have an influence on collection. Industrial and commercial solid waste collection should also be assessed since these land uses tend to contribute significant volumes of waste.

10.CONCLUSION

The study aimed at testing whether collected solid waste in Harare varies in relation to population density, road density and affluence. Based on our study we observed that collected waste varies spatially with waste increasing from Northern to the Southern suburbs. It shows that collected waste varies positively with population density and road density because areas of high collected waste also show high road and population density. The results also show that affluence explains collected waste as low volumes of collected waste are found in the affluent areas and the high collected waste volumes are observed in the less affluent areas.

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