ISSN : 0974 - 7451 Volume 10 Issue 10

Environmental Science
An Indian Journal
Current Research Paper

ESAIJ, 10(10), 2015 [347-355]

Application of GIS for effective urban solid waste management: A case of Kirumba ward in Mwanza city, Tanzania

I.J.E.Zilihona*, H.Canute, N.Kasongi
Department of Environmental Planning, Institute of Rural Development Planning, P.O.Box 138, Dodoma, (TANZANIA)
E-mail : innocent.zilihona@irdp.ac.tz

ABSTRACT

Managing solid waste is a major problem in developing countries including Tanzania. Various methods have been used in addressing this environmental problem. Geographic Information System (GIS) is one of the new technologies developed for improving the waste management systems. This paper presents findings from the research carried out in Mwanza city in Tanzania which focused on the application of GIS for effective urban solid waste management. Specifically, the study determined current and future population based on current growth rate in relation to solid waste generation, examined the existing solid waste collection, transportation and disposal systems and identified appropriate solid waste management systems using GIS techniques. Data on population size were collected from Mwanza City Council which was later projected. Household characteristics and wastes generation information was collected using questionnaires from 50 households. A total of 10 key informants who were purposively selected were used to give specific information about solid wastes management in Kirumba ward. SPSS was used to analyze qualitative data while ArcGIS was used to process, manipulate and analyze special data and help to make decision about proper waste management. Amount of solid wastes generated at household level was directly proportional to household size, and will increase as population size increases. Amounts of uncollected solid wastes in some streets reach up to 76% due to inefficient solid wastes collection system. Number of routes made by only one available 5000kg carrying capacity vehicle to collect wastes was irregular and do not put into consideration population size of a specific street. GIS is therefore a powerful tool for decision making in solid waste management. With GIS it was possible to integrate population data, vehicle capacity and amount of wastes generated and computing required frequency of routes to collect wastes from a specific street.

KEYWORDS

GIS;
Urban;
Solid wastes management;
Mwanza city.

INTRODUCTION

Urban solid waste management is a very serious problem in developing countries of Asia and Africa[13]. In Africa, rapid urban growth in particularly from 1950s had posed pressure on the land resources within the area surrounding the cities, and has led to increased generation of waste. The problem is characterized by the open dump nature of disposing waste especially in the slum areas of most African cities[10].

In most of Sub-Saharan Africa, solid waste generation exceeds collection capacity. This is in part due to rapid urban population growth, while only 35 percent of the sub-Saharan population lives in urban areas, the urban population grew by 150% between 1970 and 1990[12]. But the problem of growing demand is compounded by broken-down collection trucks and poor program management and design. In West African cities, as many as 70% of trucks are always out of service at any one time, and in 1999, the city of Harare failed to collect refuse from nearly all of its residents because only 7 of its 90 trucks were operational[12].

In Tanzania, urban solid waste is a serious environmental problem particularly in the big cities like Dar es Salaam, Mwanza, Arusha and Mbeya where there is rapid urbanization and industrial activities. For-instance, in 2009 about 61% of the solid waste generated in Dar es Salaam was uncollected. The situation had decreased as compared to 2005, where uncollected solid waste was 50%[6]. The problem is due to many factors including lack of information on the extent of solid waste generated, inadequate data on the number of households generating the waste, poor cost recovery due to non-payment of refuse collection fees and poor collection system within settlements[5].

In Mwanza city, solid waste generated is increasing proportionately with increasing human population and economic activities[7]. The city council has implemented some strategies like privatizing solid waste collection and formation of Community Based Organizations (CBOs) and construction of landfill at Buhongwa. In spite of all strategies in place still solid waste management is a big problem. For instance only 30% of daily solid waste generated in the city is collected. During the rainy season in particular, uncollected refuse is washed away and through stomata drains, dumped into Lake Victoria[7].

Recent data in Tanzania estimates that the quantity of municipal solid waste generated countrywide amount to more than 10,000 tons per day[2]. The indicative solid waste generation rate is 0.1- 1.0kg/cap/day. As the result, more than 50% of the total solid waste generated is not collected by Local Government Authorities (LGAs) in major cities in Tanzania including Mwanza city[2]. Urban solid waste management in Tanzania and in Mwanza City in particular, has been a serious environmental problem and a challenge to the City Council. The rapid population growth rate of about 3.2% per annum in Mwanza, coupled with the increasing growth of commerce and trades, has increased the solid waste generation at a rapid rate. The amount of solid waste generated is estimated to be about 875,400 kg per day with an average domestic solid waste generation rate estimated at between 0.3 to 0.6kg per day[7]. This is due to tradition planning in which no consideration of spatial distribution of waste based on the population size of each locality.

There has been development of new technologies for improving the waste management systems. GIS is one of the new technologies which have been documented to contribute less time span to the waste management society[1]. GIS is therefore a tool that can provide spatial and non-spatial information for urban planning and management. It can also link data for various uses. This planning tool has been widely used in developed nations like United States of America, Britain, Spain, and Netherland and proved efficiency in planning for solid waste management[5].

In some case studies, GIS has been successfully used to select suitable location for dumpsites. For-instance, Qumsieh *et al*.[8] combined aerial photographs and topographic data to select waste disposal sites and facilities for Palestine. In Kaohaiung city, Taiwan, Chang *et al*.[3] combined GIS and mixed integer programming model to analyze several waste selection sites before selecting the final sites.

Having success in applications of GIS in solid wastes management in other countries, the research was carried out in Mwanza city to find out how the problem of solid wastes management in the city could be addressed using GIS as a planning tool. The study put in into consideration real field situation by considering population size, actual amount of solid waste generated and a number of available wastes collection vehicles as well as their carrying capacity.

MATERIAL AND METHODS

Description of the study area

This study was conducted at Kirumba ward in

Mwanza city (See Figure 1). Mwanza city lies at an altitude of 1,140 meters above the mean sea level. Mean temperature ranges between 25.7 ^{0}C and 30.2 ^{0}C in hot season and 15.4 ^{0}C and 18.6 ^{0}C in the cooler months. The city experiences rainfall between 700 and 1000mm per year in two seasons in which season one is between October and December and season two is between February and May[7]. According to 2012 National Population and Household Census[11], the current population of Kirumba ward is 26,765 people. Kirumba ward has 8 streets but only four of them (Kirumba Kati,Ngara,Mlimani and Kabuhoro) are serviced by solid wastes collection track. Kirumba ward has 8 streets but only four of them (Kirumba Kati,Ngara,Mlimani and Kabuhoro) are serviced by solid wastes collection track. Figure 1 shows the location of Kirumba ward in within Mwanza city and the streets within the ward. Kirumba kati serves as a point for solid wastes collection from other streets.

Data types

Primary data

Primary data in this research included X and Y coordinates of solid waste collection points, Google Earth imagery, existing solid wastes collection facilities and frequencies, residents' perception and understanding concern solid wastes management.

Secondary data

Secondary data used in the research included map sheets, aerial photographs and population data from National Population and Household Census data (2012) from respective departments' offices in Mwanza city.

Generally this study focused on examining application of GIS for effectiveness of urban solid waste management. The design of this study was therefore a non-experimental; rather a cross-sectional survey which involved asking questions to a representative sample of the population. The sample size for this study was 60 households. Checklist, physical observation and structural questionnaires were used to collect quantitative, qualitative and spatial data.

Data collected using questionnaires were edited, classified, coded, and entered in a computer using Social Package for Social Science (SPSS) software. The spatial data collected from Google Earth server were saved in KML format. ExpertGPS version 4.0.3 software was used to convert spatial data from KML to SHP format which is compatible with Arc GIS software. The vector data (.shp format) were added in Arc

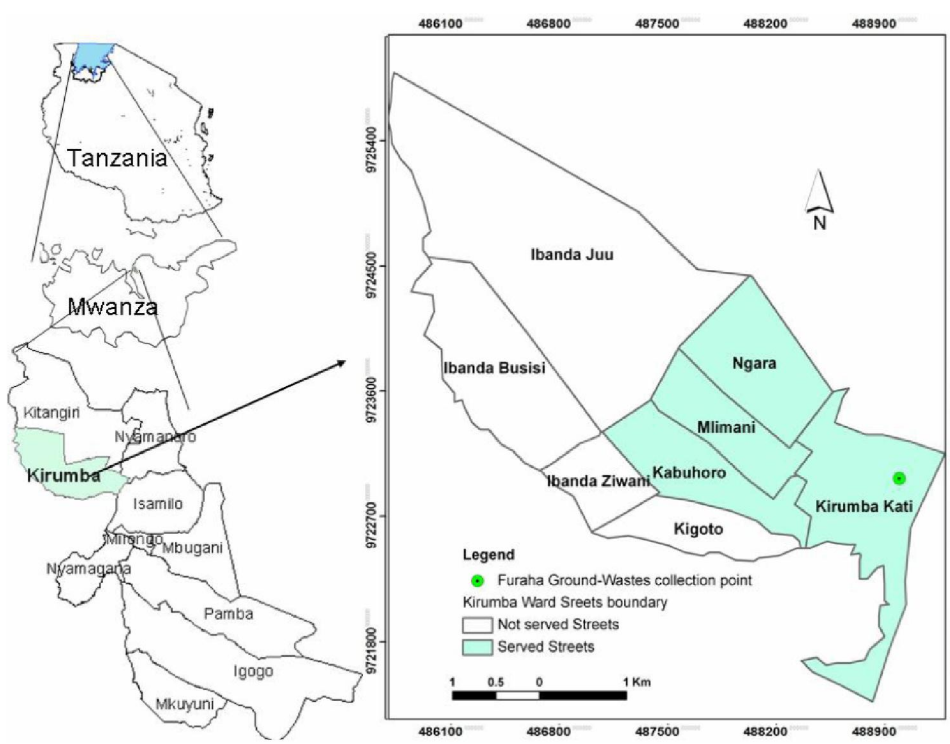

Figure 1 : Location of Kirumba ward in Mwanza city showing served and not served streets and solid waste location point

FID	Shape	LABEL	NAME	pop_2012	waste/day	truck_capa	waste/week	freq/day	freq/week
0	Polygon	kirumba	MLIMANI	4232	1904.4	5000	13330.8	0.38088	2.7
1	Polygon	kirumba	NGARA	4629	2083.1	5000	14581.4	0.41661	2.9
2	Polygon	kirumba	KIRUMBA KATI	4755	2139.8	5000	14978.3	0.42795	3
3	Polygon	kirumba	BANDA JUU	4245	0	5000	0	0	0
4	Polygon	kirumba	BANDA BUSISI	555	0	5000	0	0	0
5	Polygon	kirumba	BANDA ZIWANI	623	0	5000	0	0	0
6	Polygon	kirumba	KIGOTO	1745	0	5000	0	0	0
7	Polygon	kirumba	KABUHORO	5442	2448.9	5000	17142.3	0.48978	3.4

Figure 2 : Screen capture of attribute table of Kirumba ward data as organized in ArcGIS software

GIS version 9.3 and attribute tables were created for storing attribute data namely population size, name of street, waste generation and truck load capacity as shown in Figure 2.

Quantitative data was analyzed using SPSS computer software version 16. The analysis involved computation of descriptive statistics such as estimates of frequencies, percentages and means. Arc GIS software version 9.3 was used to analyze spatial data in different layers including street boundary and collection point were overlaid and field calculator within data management tools was also used to facilitate the spatial analysis. The results of analysis included waste generation per week and waste collection frequency (times/week). Since per capita waste generation per day was known, that is 0.45kg/ day[7], then household waste generation per week was determined by multiplying per capita waste generation per day by the size of household. Then multiply the household waste generation per day by seven days in a week. The methodology adapted for data processing and analysis was as shown in Figure 3.

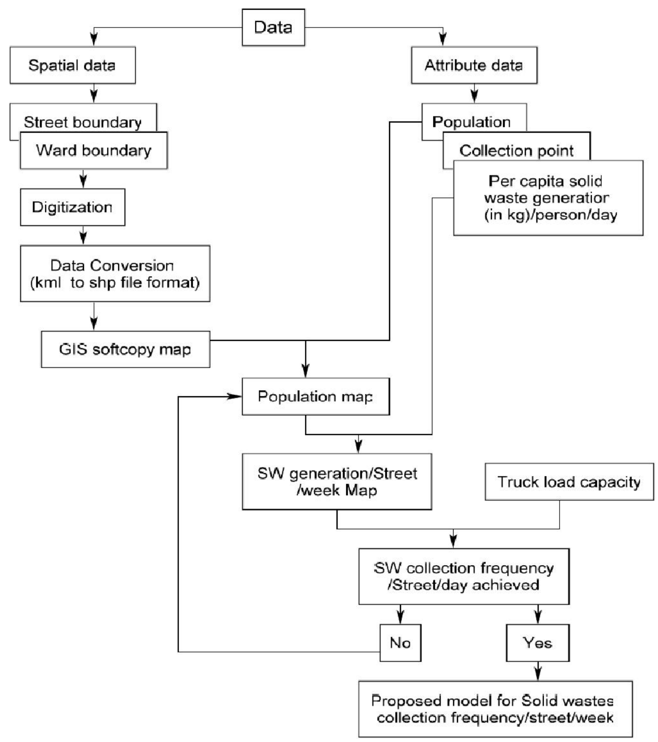

Figure 3 : Flow diagram to show steps followed in determination of effective solid wastes solid wastes management in Kirumba ward.

RESULTS AND DISCUSSION

Waste generation trends based on population growth

Solid waste generation per day in Kiruma ward is directly proportional to the size of a household. According to MCC[7] per capita waste generation is 0.45kg/ day. TABLE 1 shows the relationship between household size and solid waste generated per day.

Based on the results in TABLE 1, if the household has more members also the amount of solid waste generated is larger than household with fewer members.

TABLE 1 : Household size and solid waste generation (in Kg) per day

Household size	Frequency	Solid Waste generation (in Kg) /day
1-5	26 (52%)	0.45 - 2.25
6-10	20 (40%)	2.7 - 4.5
12-15	4 (8%)	5.4 - 6.75

Kirumba ward population of 2012 was projected to 2016 using a population growth rate of 2.53% (popu-

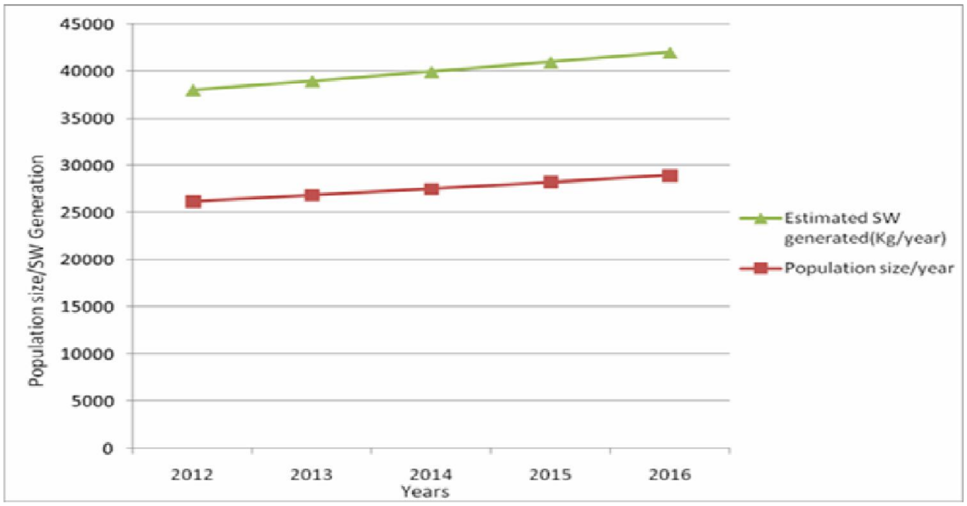

Figure 4 : Projected population growth and waste generation trend of Kirumba ward from 2012- 2016

lation growth rate according to regional and district projection provided by National Bureau of Statistics) to investigate what will be the future trends in waste generation for better waste collection planning. Figure 4 shows the trends of projected population and estimated waste generation from 2012 to 2016.

The trend in Figure 4 shows there is positive relationship between population size and solid waste generation. Population will be increasing from 2012 to 2016 and therefore lead to increases in the amount of solid waste generated. The results are in line with Sivakumar and Sugirtharan[9], who found that the rate of generation of solid waste in the society is increasing with an increase of population. These results are useful for any town planners and authorities responsible for waste collections. They can be used to predict and plan for adequate amount of facilities required to handle the increasing solid wastes generation so as to avoid pile ups of wastes and existence of uncollected wastes in the streets in urban areas.

Existing solid waste collection, transportation and disposal systems

The study found out that solid waste generated in Kirumba at the households level were food waste (remains) (29.2%), plastics (23.4%) used as packing material, papers and box (26.3%), bottle (14.6%) and old textile (6.4%). Large portion of households solid wastes are biodegradable (food waste) that would easily decompose while the remaining portion is recyclable (paper, bottles and plastic) that can be reused to make other products.

The research findings indicate that all respondents in Kirumba ward do not separate solid wastes before disposal to collection points. They are not aware that organic and recyclable wastes should be separated. They regard all wastes to be the same but in fact wastes are different. The study by Ketibuah *et al.*,[4] suggests that waste separation at source is necessary and the residents must be well informed to make such an exercise efficiently and long lasting. Ketibuah *et al*[4] further argued that solid waste separation reduces amount of solid waste disposed at the dumpsite.

Solid wastes collection from households in Kirumba ward is done by a private service provider known as MEMCO. Some residents also take trouble to send the solid wastes to the collection points or make their own open pits for solid wastes disposal. Kirumba ward has four streets serviced by MEMCO, these are Kirumba Kati,Ngara, Mlimani and Kabuhoro. In some streets solid waste collection is done door to door whereby a household pays TSh 800/= per month. A tractor and trailer with a carrying capacity of 5000kg per trip is used to collect wastes from streets to the solid wastes collection point located at Furahisha grounds in Kirumba Kati street waiting for final disposal at Buhongwa damp site (See Figure 5). The solid wastes collection point at Kirumba kati street is partially fenced hence giving possibilities of wastes to spread and pollute the environment in the residential areas.

Solid wastes collection track has four routes as seen in Figure 5. First route includes Mamlaka ya pamba,

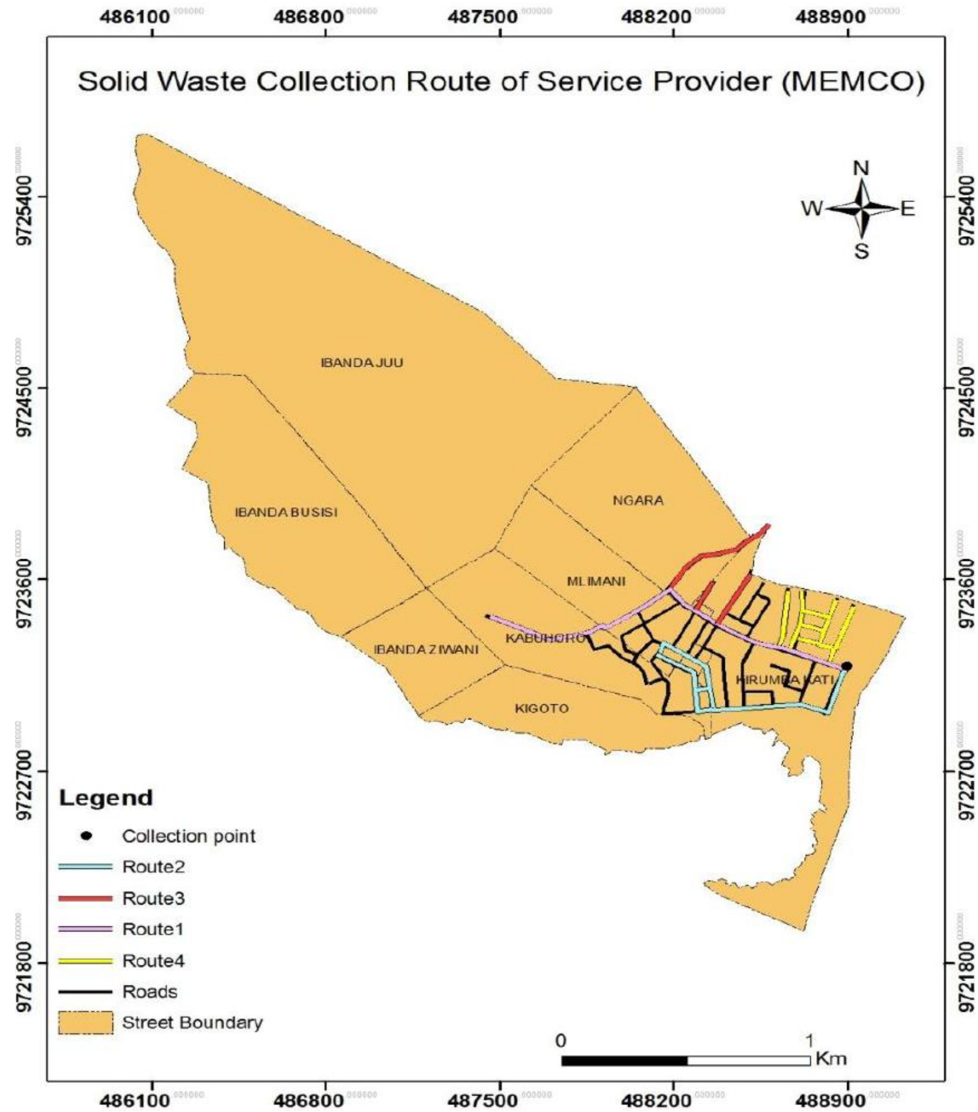

Figure 5 : Spatial locations of solid waste collection routes from served streets within Kirumba ward

TABLE 2 : Solid wastes generated, collected and uncollected in Kirumba ward

Street	Estimated Waste Generation (Kg/Wk)	Collected Waste (Kg/Wk)	Percent (%)	Uncollected Waste (Kg/Wk)	Percent (%)
Kirumba Kati	14978	10000	66.8	4978	33.3
Ngara	14581	10000	68.6	4581	31.4
Mlimani	13331	5000	37.5	8331	62.5
Kabuhoro	17142	10000	58.3	7142	41.7

Genge la Kabuhoro and collection point Kirumba kati. Second route includes Uwanja wa Magomeni, Mwaloni, Check point and collection point. Third route includes Ngara, Kirumba police station and collection point. Fourth route includes Kirumba Kati, Kirumba market and collection point. The interview with service provider revealed that routes were not fixed and changes would be made depending on the prevailing situation in solid waste collection in Kirumba ward.

Applications of GIS techniques to determine appropriate solid waste management practices

It is noted in previous section 3.2 that during solid wastes collection from served streets, solid wastes collection truck owned by (MEMCO) pass in routes at

TABLE 3 : Proposed solid waste collection per street per week

Street	Estimated Solid Waste (Kg/Wk)	Days to fill 5000kg Truck	SW Collection Frequency (Trips/Wk)	Days interval for waste collection
Kirumba Kati	14978.0	2	3	2
Ngara	14581.4	2	3	2
Mlimani	13330.8	3	2	3
Kabuhoro	17142.3	2	3	2

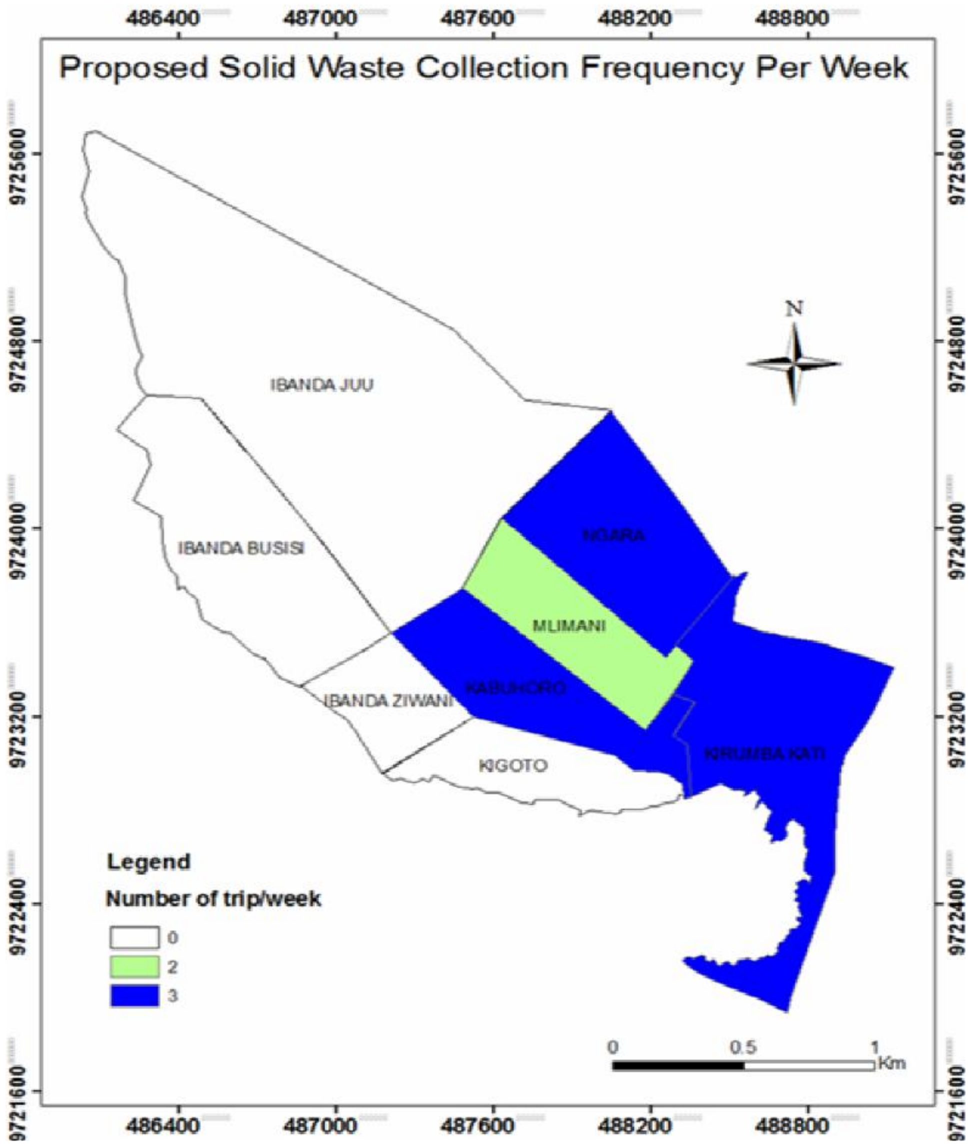

Figure 6 : Proposed effective solid waste collection frequency per street per week

random. Routes were not fixed and changes would be made depending on the prevailing situation in solid waste collection in Kirumba ward. The study found out also that frequency of waste collection at each street in Kirumba ward was set without considering waste generation (in kg) per street and truck load capacity. The disadvantage of existing waste collection frequency per street per week is that wastes are not collected in time causing uncollected wastes to remain in streets for days as shown in TABLE 2. As the result, residents incur addition cost of paying people to take wastes to the collection point at Furahisha ground.

TABLE 2 shows that the amount of solid wastes which remain uncollected in some streets goes up to

62.5% as seen in Mlimani Street. This is due to inefficiency solid waste collection system which do not put into consideration about spatial distribution of population and amount of waste generated in order to determine appropriate frequency of solid wastes specific for each street instead of generalization.

Based on the above findings, several approaches were used in this research in order to deduce and propose appropriate solid wastes management practices. The approaches were based on statistical and spatial capability of GIS software in processing field collected population data, per capita wastes generation and waste collection track capacity (volume). The steps have been briefly shown in Figure 2 which shows the flow diagram used to achieve the required proposed solid wastes management map shown in Figure 6.

Solid waste collection frequency (trip/week) was obtained by dividing estimated solid waste generation (in Kg) per week by number of days to fill 5000kg truck. TABLE 3 shows the proposed waste frequency per street in Kirumba ward per week based on the amount of solid wastes generated.

In addition to frequency of waste collection per week per street, GIS statistical analysis function enabled to produce the required days interval required for waste collection from each street, as seen in TABLE 2.

The proposed waste collection frequency per street per week will help to avoid uncollected solid waste at each street. In addition, unnecessary trip of waste collection will be avoided and hence the exercise will be cost efficiency. The ability of GIS to provide a kind of spread sheet in the attribute table of each street and possibility of calculating other parameters like frequency and days interval for waste collection as well as displaying the data and phenomena spatially was the foundation for the possibilities to address the problem of waste collection in Kirumba ward. Figure 6 show spatial presentation of waste collection frequency (trip) at each street within Kirumba ward per week.

Results in Figure 6 out scores the existing waste collection system from the streets. The figure indicates that since the volume and number of waste collection vehicle is known, the municipal council should see to it that population size which determines amount waste generation specific for each street is put into consideration during planning for frequency of routes for waste collection and days interval for each street. This cannot be generalized; otherwise wastes will remain uncollected as seen in TABLE 2.

CONCLUSIONS AND RECOMMENDATIONS

Amount of solid waste is proportionate to household or population size in a sense that the bigger the household or populations size the large amount of solid waste it generates. Large portion of household solid waste is organic and small portion being recyclable waste but no waste separation is done. Furthermore, not all wastes are collected in time due to low capacity of MEMCO, who has only one tractor and trailer used for collecting waste. Also the ward has only one collection point in which all wastes from the streets within the ward are disposed. The Government has to increase collection points in the ward in order to improve efficiency in solid waste storage and distance from households to the collection point. Waste separation should be promoted in order to influence recycling activities and hence reducing amount of solid waste disposed in the landfill. GIS as a planning tool has proven to be efficient in proposing waste collection frequency per week in Kirumba ward. The proposed waste collection frequency based on solid waste generated per street and truck carrying capacity can help to avoid uncollected solid waste at each street and unnecessary trip of waste collection and thus optimize efficiency in the whole process GIS as planning tool should be used in planning of urban solid waste management due to its ability to integrate spatial and attribute data such as amount of waste generated per street and truck load capacity in order to save time and cost. Mwanza city planners should address the waste management problem by incorporating the population size per each ward, industrial and commercial areas into GIS and determine the required waste collection frequency(times/week). Municipal councils should try hard also to address the challenges facing GIS applications like cost constrains in term of hardware and software, infrastructural, educational and data constrains in terms of existence and accessibility of data.

REFERENCES

[1] A.V.Bhambulkar; Municipal Solid Waste Collection Routes Optimized With Arc GIS Network Analyst. International Journal of Advanced Engineering Sciences and Technologies, **11(1)**, 202–207 **(2011)**.

[2] CAG; General Report of the Controller and Auditor General on the Performance Audit (VFM) reports for the period ending 31st march, 2010. United Republic of Tanzania, **(2010)**.

[3] N.Chang, H.Y.Lu, Y.L.Wei; GIS technology for vehicle routing and Scheduling in solid waste collection systems. Journal of Environmental Engineering, **123(9)**, 901-910 **(1997)**.

[4] E.Ketibuah, M.Asase, S.Yusif, M.Y.Mensah, K.Fischer; Comparative Analysis of Household Waste in the Cities of Stuttgart and Kumasi –Options For Waste Recycling and Treatment in Kumasi, **(2004)**.

[5] A.Kyessi, V.Mwakalinga; GIS Application in Coordinating Solid Waste Collection: The Case of Sinza Neighborhood in Kinondoni Municipality, Dar es Salaam City, Tanzania. Available at: (http://www.fig.net/pub/fig2009/papers/ts04b/ts04b_kyessi_mwakalinga_3219.pdf) visited on 22/03/2012, **(2009)**

[6] E.Mbuya; Solid Waste management in Dar es Salaam: Privatizing and Improving Revenue Collection, **(2009)**

[7] MCC; Mwanza city Profile 2010. Mwanza, **(2010)**.

[8] V.Qumsieh, M.Owewi, J.Isaac; Establishing an environmental information system for Palestine. Paper Submitted to the Sixth International Conference for the Protection of Environment. May 21-23, Alexandria, Egypt, **(1996)**.

[9] K.Sivakumar, M.Sugirtharan; Impact of Family Income and Size on Per Capita Solid Waste Generation: A Case Study in Manmunai North Divisional Secretariat Division of Batticaloa. Department of Agricultural Engineering, Faculty of Agriculture, Eastern University, Vantharumoolai, Chenkalady, Sri Lanka, **(2010)**.

[10] Y.A.Twumasi, A.Manu, T.L.Coleman, B.Schmid, A.Moustapha; Use of Geo-Spatial Data for Sustainable Management of Solid Waste in Niamey, Niger. Journal of Sustainable Development in Africa, **8(1)**, 203-215 **(2006)**.

[11] URT; Population and Housing Census: National Bureau of Statistics, Ministry of Planning, Economy and Empowerment. Dar es Salaam, **(2012)**.

[12] USAIDS; Solid waste: generation, handling, treatment and disposal, **(2009)**

[13] C.Zurbrugg; Solid Waste Management in Developing Countries. SANDEC/ EAWAG, **(2003)**.