GIS Application in Coordinating Solid Waste Collection: The Case of Sinza Neighbourhood in Kinondoni Municipality, Dar es Salaam City, Tanzania

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ABSTRACT

Rapid urbanisation has inevitably increased pressure on urban infrastructure and services, much of which have not sustainably been provided to muddle through with rapid urban growth; thus, resulting to poor urban service delivery including uncollected solid waste in most urban locations in developing countries. The city of Dar es Salaam including its three municipalities has no exception. On one hand, solid waste has high ability of threatening and degrading environmental resources e.g. polluting air through noxious smell, polluting surface and underground water through seepage of deposited and decomposed wastes if not properly managed and above all deterring investments in settlements. On the other hand, waste collection and disposal are very challenging elements in waste management. These issues are also critical in Dar es Salaam, due to increased waste generation and low collection capacity of the actors involved. In the year 2005, about eighty per cent of the solid waste generated in Dar es Salaam was uncollected. Although the situation had improved a bit by 2007, solid waste management is still a problem in Dar es Salaam due to many factors that include: 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. Geo Information System (GIS) is a tool that can provide spatial and non spatial information for urban planning and management. It can also link this data for various uses. Therefore, this paper examines and brings knowledge on how GIS can assist in increasing information and efficiency of solid waste collection system in an urban settlement in a developing country such as Tanzania. Sinza neighbourhood in Kinondoni Municipality in Dar es Salaam City is taken as a case for knowledge sharing.

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1. URBANISATION VERSUS SOLID WASTE MANAGEMENT IN DEVELOPING COUNTRIES

Over the past five decades or so years, urbanisation - that is the proportional change between the population living in rural areas and that living in urban areas - has become one of the most important trends in human settlements development (Kironde, 2000). Unlike Western countries where urbanisation was fuelled by industrialisation, in many of the developing countries, especially those of Sub-Saharan Africa including Tanzania, the type of urbanisation depicts rapid population increase and uncontrolled expansion of cities with limited economic or productive base (Aligula 1999, Lupala 2002, Kyessi 2002). The main features that characterise urbanisation in the Tanzania include sprawling urban centres beyond the limits and capacity of local authorities to provide basic infrastructure and social amenities (Ngware *et al*. 2000). A typical example is the pressure on adequate shelter, urban facilities and basic infrastructure such as solid waste collection, brought about by fast urbanisation in major cities such as Dar es Salaam, Mbeya, Arusha and Mwanza.

In the circumstances, managing solid waste is a critical problem in all cities in the world especially in Developing Countries including Tanzania (Majani, 2000, Kaseva *et al*. 2003). Due to the rising demands of increasing urban population coupled with urban management deficits in cities, the quality of infrastructure services has deteriorated including solid waste management which often receives the lowest priority (Bolaane, 2004). In Tanzania, it has been estimated that only 20-30% of the urban solid waste generated is collected and deposited off (Chinamo, 2003). The uncollected waste accumulates in various places such as on the housing compounds or on open spaces, on streets, and thrown in ditches. This waste pollutes the surface and in many cases directly enters into the stormwater drains or river streams. In other situations, people throw waste directly into the stormwater drains and streams which not only pollutes the water but also clogs drainage and increases the risk of flooding. Dar es Salaam city faces similar situations of rapid population and increasing demand for waste management especially solid waste collection.

2. SOLID WASTE MANAGEMENT IN DAR ES SALAAM

Urban solid waste management in Tanzania and in Dar es Salaam City in particular, has been a serious environmental problem and a challenge to the City Council. The rapid population growth rate of about 4.3 percent per annum in Dar es Salaam, 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 in the region of 3,400 tones per day with an average domestic solid waste generation rate estimated at between 0.50 to 0.79kg/cap/day (Mwakalinga, 2005). In average, only about 40% of the waste generated is collected and deposited off (*ibid*.). This has led to the situation whereby large amounts of uncollected waste

are dumped on open spaces, along streets and roads, in stormwater drains and manholes or even on house compounds, which resulted in dirty streets and roads, unsightly conditions in the city, surface and ground water pollution and flooding during rain seasons (Kassim, 2008).

The main source of waste is household waste; it is estimated that more than 50% of waste generated is from households (*ibid*.). In densely populated urban centres like Dar es Salaam, appropriate and safe solid waste management is of utmost importance, in order to create a healthy environment for the population.

Traditionally, the government was the sole provider of almost all basic services such as water supply, electricity, roads, health services including solid waste management, etc. The adoption of such a conventional approach led to inadequate infrastructure services delivery ((Majani, 2000, Kyessi, 2002).

Although several intervention measures were taken since the early 1990s, such as partnership with private contractors and civil societies' organisations, yet several problems are experienced in solid waste management that include:

- *Inadequate waste collection:* Waste collection is inadequate, in which a large percentage about 60% remains either in the places where it originates or staying longer in the collection points leading to a number of environmental and health hazards e.g. dust, smell, smokes from burning etc. Furthermore, the mounds of waste stored become breeding grounds for disease carrying flies, cockroaches, mosquitoes and rats (Halla and Majani, 1999) and thus creating health risks.
- *Accumulation of garbage on streets, on open spaces and on compounds:* Despite of some interventions that were intended to improve solid waste management in many urban centres in Tanzania, there are still high rates of uncollected solid waste. This situation has been posed by many factors such as poor accessibility, lack of household information, low management skills of contractors and other stakeholders interested in solid waste management and poor equipment (Mwakalinga, 2005).
- *Lack of waste treatment and disposal sites:* The waste dumped in various parts of Dar es Salaam does not undergo any treatment; hence a threat to the environment and pose health risks to the inhabitants. For this reason, the selection of sites where to dispose the waste has to be done scientifically with a number of feasibility studies. Despite of this fact, the selection of dumping sites in Dar es Salaam has not been so successful and thus taking advantage of existing quarried sites as potential areas (Majani, 2000). In general, landfill sites are not common in Dar es Salaam and the one available is about 30 kilometres way from the city centre. One trip could cost about one hour or so to reach the site.
- *High operational costs and poor cost recovery for solid waste management:* This is another issue pertaining solid waste management. There is high operational cost in solid waste collection. The main causes being long distances to main roads, poor design of the routes and scattered location of collection points. In addition, cost recovery is highly affected by the household characteristics and low incomes. Often some households cannot pay refuse collection charges due to household poverty (spending less than one

USD per capita per day) while others are discouraged by the low level of service provision.

- *Poor or inadequate resources for solid waste management:* The Dar es Salaam City council including its three municipalities of Ilala, Kinondoni and Temeke have inadequate resource capacity for solid waste management. In addition, although solid waste collection is outsourced in most parts of Dar es Salaam, those contractors {including community-based organisations (CBO's) and other civil societies' organisations} engaged in solid waste collection lack resources in terms of equipment, finance and technical expertise in solid waste and information management. The use of ICT is hardly being used. On the other hand, many contractors are unable to provide quality service since they are not paid promptly to enable them meet the operational costs.
- *Poor routing systems:* Apart from absence or improper locations for transfer stations for solid waste collection, the routing system for trucks in neighbourhoods has a lot to be desired. Some areas of the city are extremely difficult to access by refuse collection trucks; waste is transported to a collection point. In other neighbourhoods, the routes for trucks are very long, resulting to higher transaction costs between waste producers and waste collectors. Due to higher cost between these parties, the efficiency decreases in the fact that producers cannot afford the fees while the contractors cannot afford operational cost. In those situations, the trucks make one trip or two instead of three times a week as per contracts. Thus, much waste remains uncollected (Chinamo, 2003).
- *Inappropriate Information Management System:* Lack of management information system (MIS) contributes to a complicated process of setting for proper waste storage, suitable routes assignment for trucks, etc. (Mwakalinga, 2005 citing UNCHS, 1997). The routes and collection points are not mapped (Mwakalinga, 2005 citing DCC, 1998). In general there is lack of skills and knowledge on the adoption and use of appropriate ICT in solid waste collection.

The ensuing sections discuss the adoption of ICT in infrastructure service delivery with application of GIS in route assignment in order to increase efficiency in solid waste collection in urban neighbourhoods taking the example of Sinza in Dar es Salaam, Tanzania.

3. ADOPTION OF GIS IN SOLID WASTE MANAGEMENT

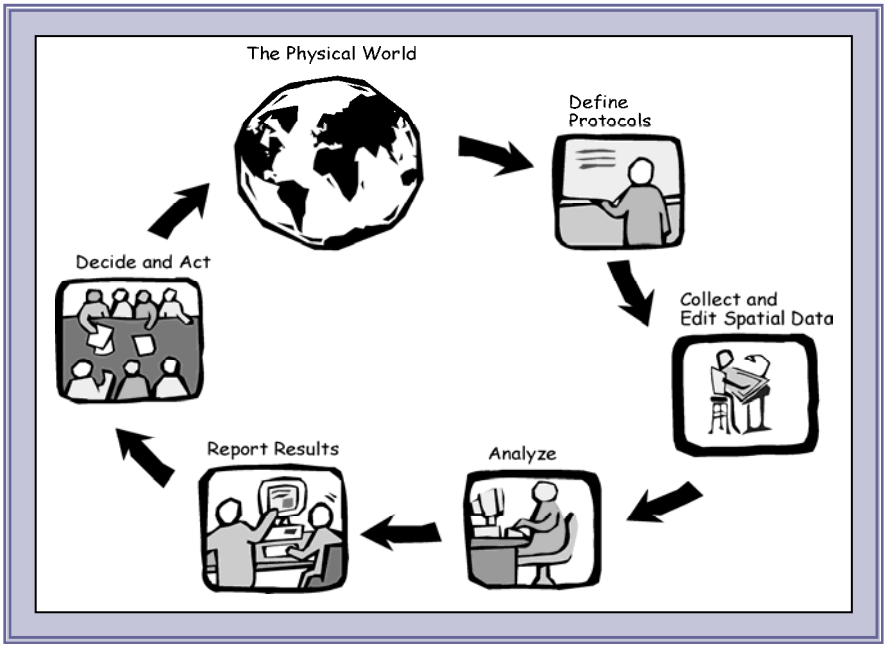
GIS is among Management Information Systems (MIS) and part of the Geo information technology (GIT) adopted in solid waste management in many countries. Experiences may be obtained from developed countries such as the USA, France, Britain, etc. and other developing countries such as Mexico, China, Ghana, South Africa, Kenya, Nigeria; etc. (*ibid*).

GIS has demonstrated to strengthen the functioning of infrastructure service delivery and to enhance sustainable development in the cities (*ibid*.). This technology works for spatial and attribute data acquisition, storage, analysis and visualisation (see Figure 1). It has proved success in assisting planners to give suitable location for transfer stations for solid waste storage, designing short routes for waste collection, creating databases for households that pay

and those who have not paid for the services, arranging time tables for trucks to collect waste, etc. (Bylinsky, Gene, 1989).

Previous experiences in developing countries show that poor spatial and non-spatial data linkage is the main cause for almost all problems in solid waste management. The issues like high waste piles on streets, inadequate waste collection, high operational costs, long routes, scattered location of collection points and failure to pay for service due to high cost, etc., are pronounced to be applicable under poor linkage of spatial and non-spatial data in solid waste management.

Figure 1: GIS for Decision Support and Spatial Data Management



Source: Batty and Howes, 1996

The state of solid waste management in Dhaka city was a serious concern; only 42 % of the solid waste generated in Dhaka city was collected by the Dhaka City Corporation (Anwar, 2004). It was also revealed that 50% of the households did not use waste bins to store wastes, rather they throw it either in drains, on the roadside or in any other improper manner. Besides the health problem, solid waste blocked the drainage systems and created flooding in the streets leading towards mosquitoes, bad odour and inconvenience. The geographical and climatic condition of Dhaka city is favourable for flood; hence, solid waste in streets and drains multiplies the impacts and miseries. Rotten and decomposed garbage make neighbourhoods filthy, foul smelling and unhealthy. Flies, cockroaches and rodents thrive in such filth, and they are the known sources of many diseases. Uncontrolled and open dumping also caused frequent floods and threatened the contamination of water supply. Uncollected solid waste in Dhaka city was increasingly posing health risks to its residents (Anwar, 2004).

Since 2004, Dhaka city saw the importance of utilising GIS in determining optimum locations of solid waste collection places at the neighbourhood level (Anwar, 2004). The ultimate goal was to find out for the suitable location of waste collection points in order to improve the solid waste collection system of the community. On the other hand, a sustainable solid waste management system depended highly on the level of participation of key stakeholders in the city.

In the circumstances, GIS as a tool was used in the analysis of the existing situation and then selected some suitable locations of the waste bins in the area. This situation assisted to improve the service efficiency.

The questions requiring reply is how GIS could be applied in solid waste collection in Dare es Salaam to reduce the amount of waste left uncollected? How GIS could be used to reduce operational cost through reduction of route distance? And, will the use of GIS in solid waste collection in Dar es Salaam increases the efficiency of the service?

4. ADOPTION OF GIS IN DAR ES SALAAM

Urban growth in Tanzania can be well elaborated using Dar es Salaam city. The city has been experiencing high population increase (Table 1) leading to high pressure in urban housing, water supply, electricity, roads and other utilities (Kironde, 1995). Consequently the urban management bodies in the city have inadequate resource capacity to meet the increasing demand of the population (Kyessi 2002, Mwakalinga 2005).

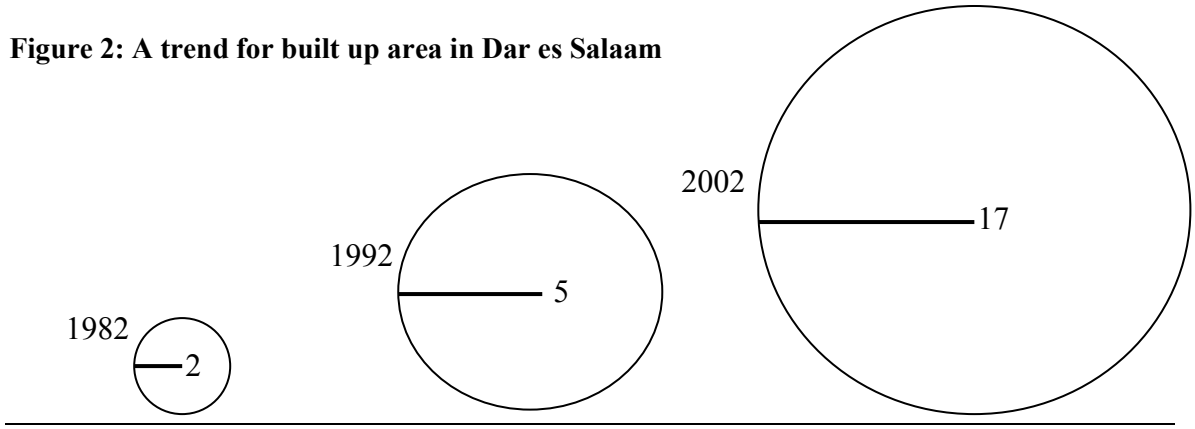
Table 1: Dar es Salaam Population Growth 1957 – 2002

Year	Population	Growth Rate (%)
1957	128,742	
1967	272,821	7.1
1978	843,090	7.8
1988	1,360,850	4.8
2002	2,497,940	4.3

Source: URT, 2003

Likewise, with an area of about 1,350 square kilometres of land area the city has been growing fast spatially. For instance, in 1992 the built–up area had expanded more than twice of the 1982 whilst the expansion in 2002 exceeded that of 1992 by more than three times. In 2004 the built up area was about 698 square kilometres (DCC, 2004).

Figure 2: A trend for built up area in Dar es Salaam



Scale: 1:5,000 (Distance in kilometre)
Source: Mwakalinga, 2005

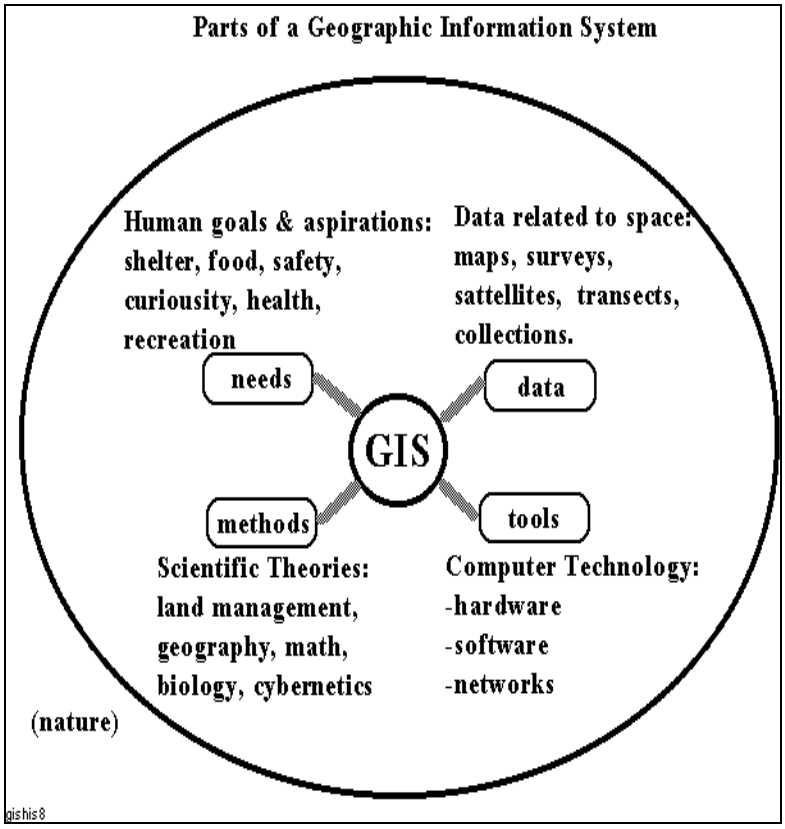
Due to the above situations, of fast demographic and spatial growth, strong and capable urban governance equipped with modern data management system is required. The governance should be able to utilise modern technologies to manage the information, in order to cope with the speed of spatial expansion and increased population needs. This is crucial since every actor and sector would require a special technique to manage the huge population and spatial data (Kyessi, 1990, 2002).

5. CONCEPTUALISING GIS IN SOLID WASTE COLLECTION IN DAR ES SALAAM

Geographic information system (GIS) software uses geography and computer-generated maps as an interface for integrating and accessing massive amounts of location-based information. Information on the spatial dimension of many urban indicators is expected to provide policy and decision makers with a better picture of the magnitude of issues before hand. Indicators on poverty, environmental degradation, lack of urban services, degeneration of existing infrastructure, lack of access to land and adequate shelter have a spatial dimension. Given the ability of GIS to combine both spatial and socio-economic data, more meaningful information can be generated. Outputs from GIS analysis inform the decision-maker on where and to what extent the problem lies.

Geographic Information Systems (GIS) are one of the most exciting technologies available to geographers today. They have also evolved into essential tools of urban planning and administration, business planning, natural resource management, and other areas (see Figure 3). In order to use GIS to its potential, it must be understood as involving more than software. Success or failure of GIS projects is also dependent on users' understanding of the relative merit of the various data models, on a consideration of metadata issues, and on the ability to apply algorithmic thinking to complex modeling tasks.

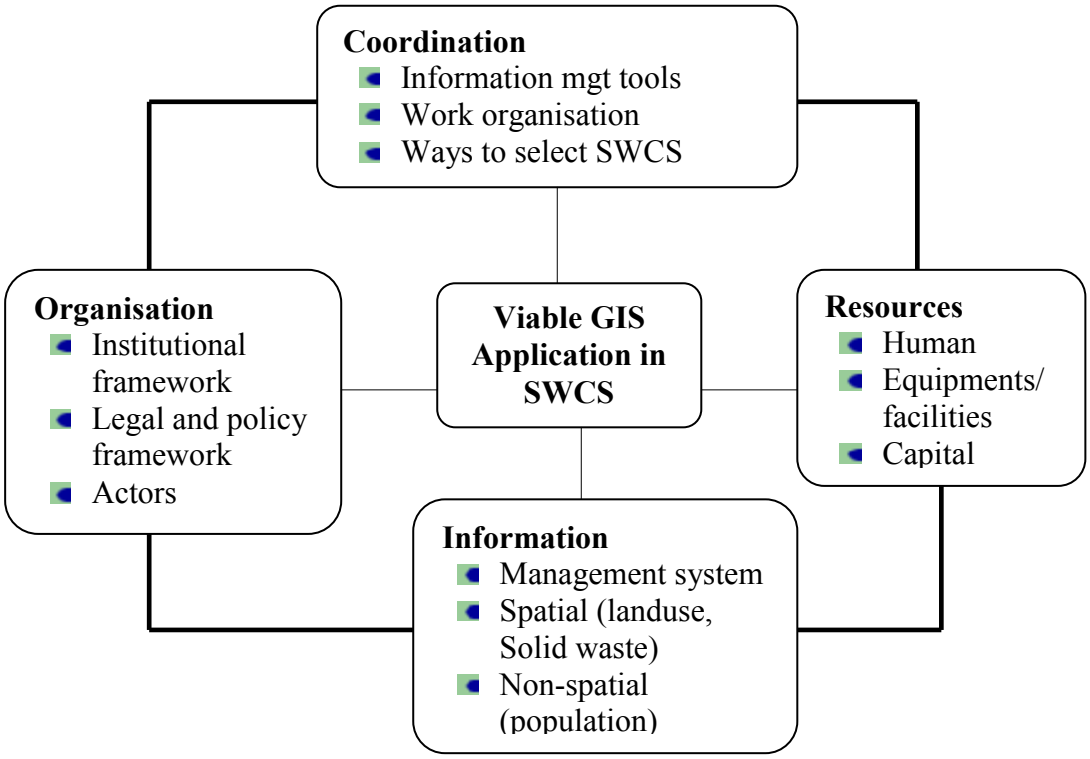
Figure 3: GIS Concept in Information Management



Source: Mwakalinga, 2005 citing Mitchell, 1999

GIS starts to be applied when there is a *need*. After knowing what you want GIS to do, there should be *data* sources e.g. data related to space, peoples' views, aerial photos, etc. In order for the data to be processed, GIS needs *tools* i.e. hardware and software. Lastly, the GIS user should decide on the *method* to use depending on the nature of work.

Figure 4: Conceptual Model for Solid Waste Collection System



Source: Adopted from Morgan, 2004 and modified by Mwakalinga, 2004

As shown in Figure 4 above, it is implicit that in order to have a viable GIS in a solid waste collection system, a number of elements are required; they include: organisation, resources, information and coordination. If all these elements are available and well performing, GIS becomes a viable and applicable tool in solid waste collection.

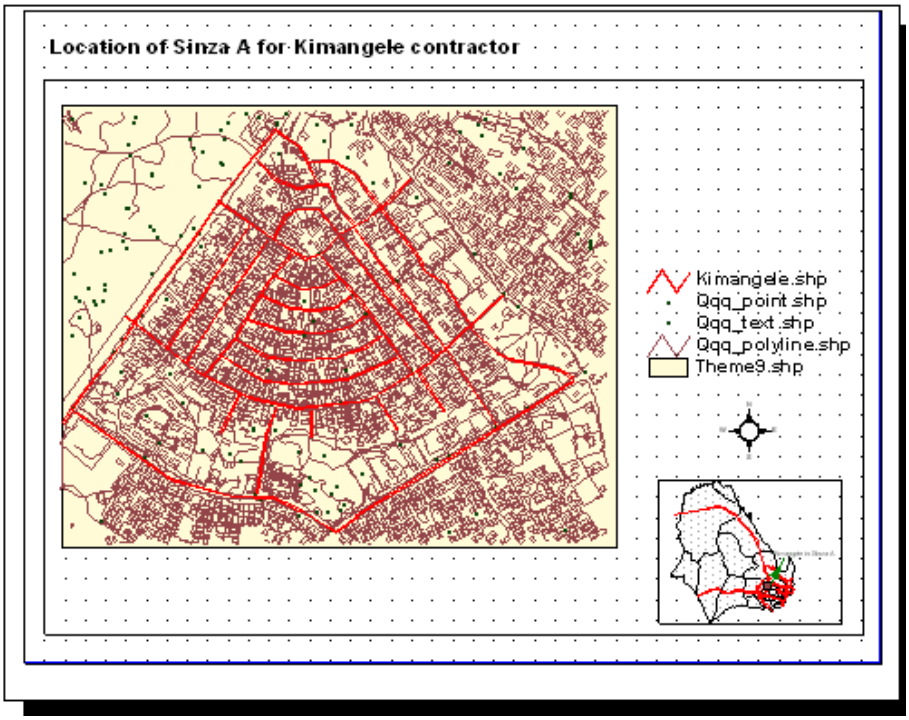
6. ROUTING EFFICIENCY ANALYSIS FOR SOLID WASTE COLLECTION IN SINZA "A" NEIGHBOURHOOD IN DAR ES SALAAM: FINDINGS AND DISCUSSION

6.1 Location

Sinza "A" is one of five residential neighbourhoods of Sinza ward in Kinondoni Municipality in Dar es Salaam. Accommodation about 5,000 people, the neighbourhood is located about 12 kilometres from the Dar es Salaam city centre. The Kinondoni Municipal Council had contracted private companies and civil societies' organisations in the collection of solid waste in residential neighbourhoods. Kimangele Company Limited is one of those private contractors.

The routing system for Kimangele Company was studied in detail to assess the solid waste collection efficiency as shown in Figure 5 and 6.

Figure 5: Location of Sinza "A" area for Kimangele Contractor



Source: Mwakalinga, 2005

Kimangele plies from house to house to establish a solid waste collection system known as *bring system* in Sinza "A". The *bring system* is done in big catchment areas i.e. above 50 metres in radius.

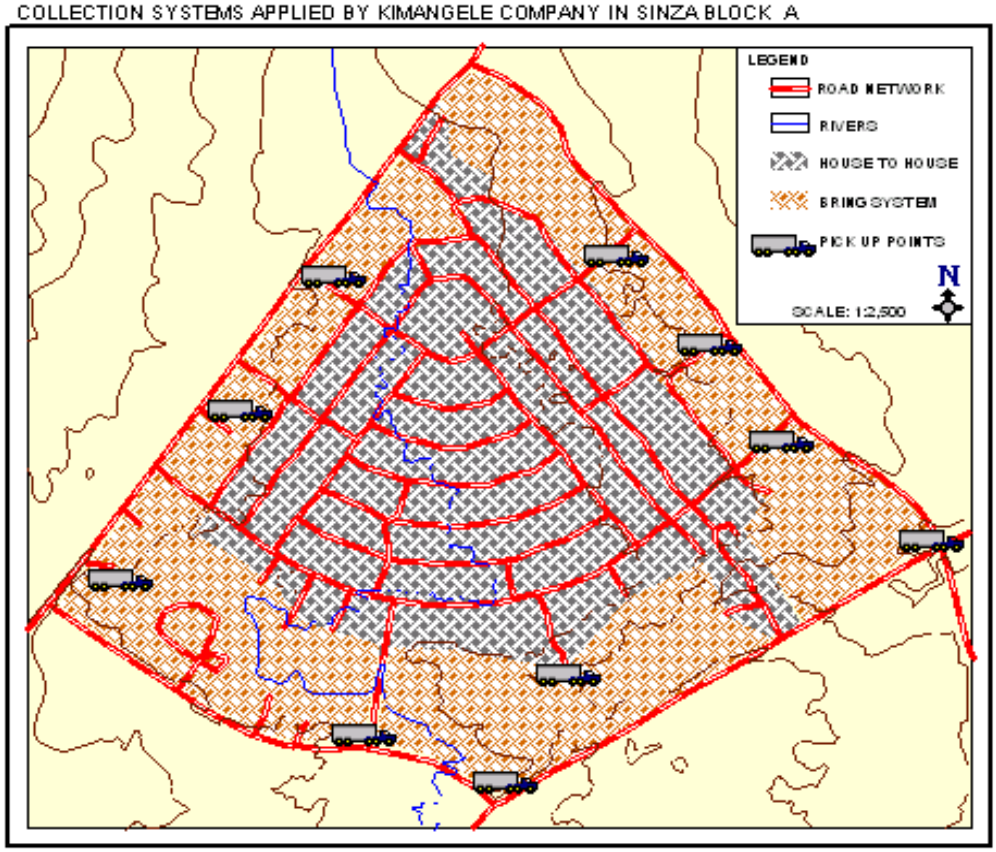
6.2 Waste generation and collection

Sinza "A" consisted of 876 households (Mwakalinga, 2005). Generally the area generates about 14.5 tonnes of waste per day. The waste composes of plastics, tins, organic food waste, packaging materials, clothes, metals and bottles.

Out of the waste generated, the contractor collects 8.4 tonnes from households. The rest About 5.1 tonnes (47.7%) of waste are collected by informal collectors (using wooden carts) to designated collection centres. The rest (about 1 tonne) is haphazardly dumped in rivers, on roads sides, burnt or buried.

About 160 households are not members of house to house collection service; they prefer using the informal collectors instead of the contractor's trucks. When interviewed, these households complained of ineffective collection system by the Contractor. One of the given reasons was that the truck was not following the rout as agreed. Others households said the collection charge of TShs. 2000/= per household was too high. They were ready to pay only TShs. 500/= per house regardless the number households in the house.

Figure 6: Collection Systems as applied by Kimangele Company in Sinza "A"



Source: Mwakalinga, 2005

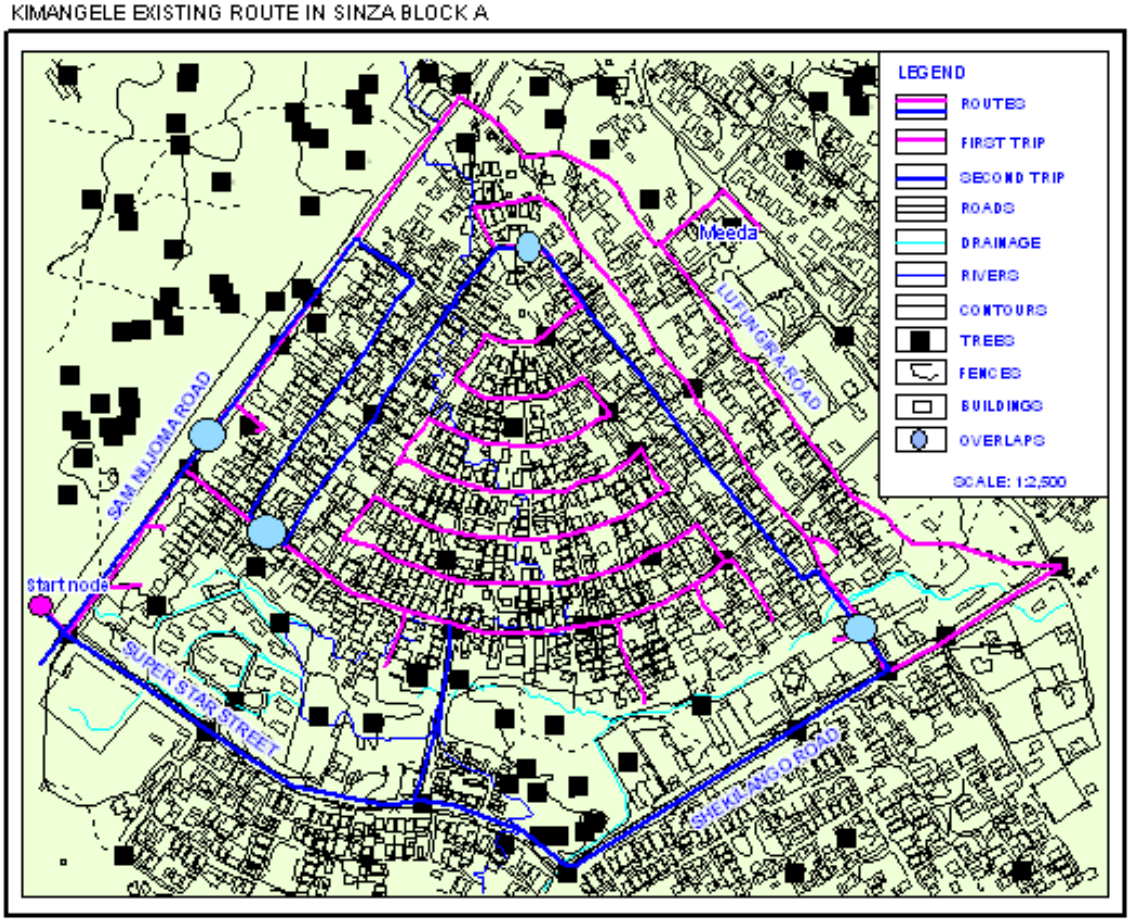
When the Contractor was interviewed in 2005, he replied that, out of 716 households he was serving only 70% paid the refuse collection charges (Mwakalinga, 2005).

According to Figure 8 below, there are some areas where the truck drives twice creating overlaps. Normally, a truck stands at a pick-up point, about 50 meters from the other. In other circumstances, the distance is more than 50 metres, and as a result more waiting time by the truck is needed indicating that the whole system of waste collection was foiled.

6.3 Work Organisation

The collection frequency by Kimangele was done twice a week i.e. Wednesdays and Saturdays. The service starts at 6.30 am to 5.30pm. The truck was making two trips on each day due to the amount of waste generated and the ability of the truck to carry the waste. The route for the first trip starts at Superstar area and ends at Kivulini through Sam Nujoma road to Mtoni kwa Kabuma dump site, about 30 kilometres away (see Figure 7). The route for the second trip passes through Morogoro road via Shekilango road; the first point in this trip is Super Star Street ending at café Latino Street. Thereafter the route enters Sam Nujoma road to the main dump site, Mtoni kwa Kabuma.

Figure 7: Existing Route for Kimangele Company in Sinza "A" Neighbourhood



6.4 Distance Covered and Cost of Solid Waste Collection

The distance covered for the two trips is 10,920 metres. The first trip covers 7,270 metres while the second one covers 3,650 metres. The time spent per day is 11hours, from which 6 and 5 hours are consumed by the first and second trips respectively. The analysis shows that much time is spent on waiting for waste brought from a distance of above 50 metres in the area where the *bring system* is applied.

Apart from that the contractor employs 4 labourers (only during the collection days). Each of them is paid TShs. 5000/= per day; their job being to bring waste from long distant areas to the pick up points where the truck stands. Additionally, the contractor uses 20 litres of diesel costing 18,000/= in each collection day.

In the analysis, there are some costs which the Contractor could avoid if the routing system is rearranged and reassigned. For instance, the action of the labours to bring waste to the pick-up point could be eliminated while the fuel spent by the truck could be reduced if the catchments and overlapping are controlled.

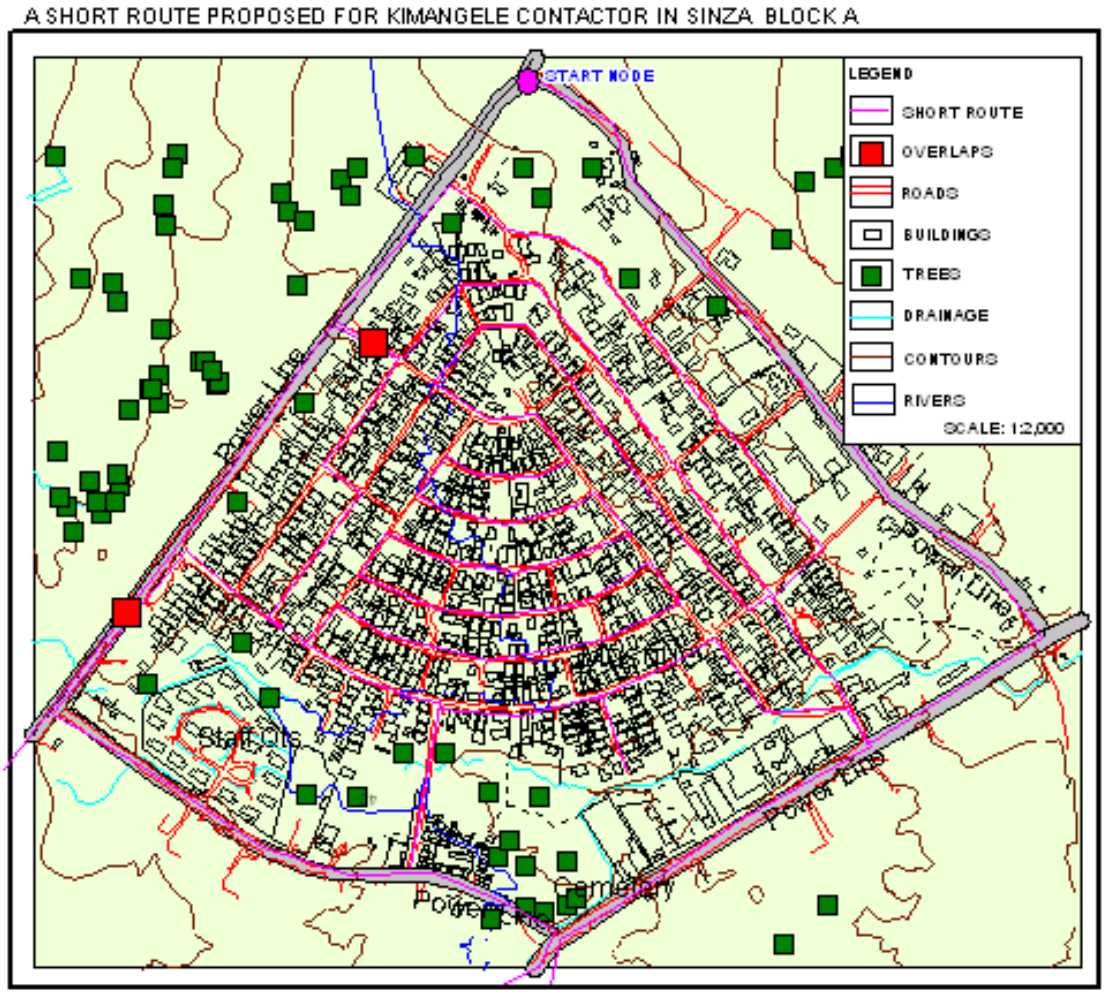
One of the basic criteria for a least cost route is to start from furthest point when the vehicle is empty. As the load increases, the vehicle should be moving to the point near the main route

on the way to the dump site. This criterion was not considered by the Contractor. The existing road network was used arbitrary with no prior studies.

6.5 GIS in network design

A least cost route is obtained through considering various criteria as per the Network Theory (.Mwakalinga, 2005). These criteria include topography, distance, landuse type, road condition, cost involved, time spent and population. In the case of Sinza, only one contractor's route was assessed; the area is small relatively flat, thus there were no constrains of topography, landuse or population. In that regard, only two criteria were applied i.e. cost and distance. In consideration of the two criteria the GIS as a tool was applied to establish the least cost route (Figure 8).

Figure 8: A least cost route for Sinza "A" Neighbourhood.



Source: Mwakalinga, 2005

6.6 Comparison between existing route and the established least cost route

The new route prepared covers the distance of 9,140 metres, about 5,430m less that the old route. Additionally, the new route has got less overlaps; only two while the old had four. The catchment area in the new route is within accepted limits i.e. the contractor will not employ many labourers for the *bring system,* but only one labourer will be required.

Table 2: Efficient analysis between the existing and proposed route

S/N	Criteria	Old route	Least cost route
1.	Overlaps (pick-up point)	4	2
2.	Distance (metres)	14,570	9,140
3.	Labourers	4	1
4.	Time (hours)	11	6.5
5.	Fuel per day (litres)	20	12.5
6.	Cost per day (TShs.)	58,000/=	29,908/=

Source: Mwakalinga, 2005

As the cost reduced the contractor can afford to deliver the service by charging fees per house instead of household. If this is applicable people will be willing to pay for the service and the service delivery will be improved. According to information on Table 2 above, new route is cheaper by almost 50% of the old route.

7. EMERGING ISSUES

There are several issues that have emerged in the application of GIS as tool for coordinating solid waste collection in residential neighbourhoods, they include:

- *Factors related to establishing a GIS database*

There was no database for solid waste management system established for Kinondoni municipality. This computer based collection system was established in a study of establishing the least cost route. Information on waste generators (households) and performance of the contractors was not readily available.

(a) Waste composition in most (75%) of the collection points was not known. There were recycled materials like plastic, metal, tins, etc. which could be traded while creating employment. However, there was no an established figure that could attract buyers although sorting at source (see Plates 1 and 2) of the waste could have assisted in reduction of cost of solid waste management at the municipal level.

(b) Catchments areas of most of the collection points along the designated routes are often too large i.e. majority were of a distance of between 500 to 1000 metres instead of 50 to 150 metres. This led to under estimate of the required trucks and collection points for the waste collection. As a result, some households resorted to private hand push carts (see Plates 3 and 4), thus undermining the private contractor. Often, the hand cart pullers do not normally take waste to the collection points due to long distances. Instead, they dumped it on the streets or roads, in valleys or open spaces and in ditches.

Plate 1 and 2: Selling sorted plastic materials at collection points in Kinondoni

Source: Mwakalinga, 2005, Field Observation, 2005

Plates 3 and 4: Hand push carts used to bring waste from households to collection points

Source: Mwakalinga, 2005, Field observation, 2005

(c) Waste generation rates were not yet established in most of the settlements including Sinza "A". This situation contributed to under estimation of the collection points, trailers needed and number of trips to be made per week, resulting to high piles of waste at collection points necessitating crude dumping (see Plate 5).

Plate 5: Overwhelmed Trailer at a Collection Point

Source: Mwakalinga, 2005, Field Observation, 2005

(d) Burning is one of the crude methods performed at some collection points, leading to air pollution posing health risks to people (see Plate 6).

Plate 6: Burning waste at a collection point

Source: Mwakalinga, 2005, Field Observation, 2005

- *Factors related to locational suitability analysis of collection points*

The collection points were found to be arbitrarily located while the traditional method of selection them was not a scientific one. There was no background information collected to support the sitting of the collection points. In general, the collection points were on an inefficient route.

- *Factors related to routing efficiency*

The existing routes were long and expensive due to lack of awareness and skills on how to apply the geo-information technology (GIT) in route planning. The Contractors would like to maximise profits by minimising operational costs, however, they lack the technical know-how to do so. As a result the service delivery becomes inefficient and thus making the households not to have trust on the Contractors.

8. CONCLUSION

The application of GIS in route planning and designation of collection points in Sinza "A" has brought up a number of lessons. First, GIS is capable and can help improve waste collection in residential neighbourhoods in urban areas. Secondly, in order to have an efficient solid waste management system, GIS may be adopted because it is capable of handling both spatial and non-spatial data necessary for effective solid waste collection system. Thirdly, solid waste collection Contractors prefer routes which are short and cheap, with high rate of return within a short period; however, traditional methods of handling data are incapable of identifying the least cost routes for solid waste collection. Fourthly, GIS has been proved to be a tool that provides the alternative method of minimising operational costs for Contractors, although neither the urban councils nor the designated solid waste collection Contractors are utilising it.

Other issues like organisation setup, legal framework and ways used to select the SWCS add to complicated waste management issues in the city.

9. RECOMMENDATIONS

Based on the foregoing findings and discussion, there are three recommendations to make:

- *Aspect regarding information*

GIS for solid waste collection needs to be institutionalised. It needs to be introduced to the Contractors, municipal and city councils officials in order to ease information management for both spatial and non-spatial data. GIS can be used as a planning tool for sold waste management. On the other hand, the spatial and non-spatial data should be updated from time to time in order to support decision making. In addition

- *Aspect related to capacity building*

Private contractors and civil societies organisation involved in solid waste management, as well as practitioners, need to be trained in the use of GIS as a toll for planning in solid waste collection. Short courses, seminars and workshops need to be conducted to build their capacity in waste collection. The focus should be based on empowering the stakeholders about importance of information, information needs, collection, storage, analysis and use.

- *Aspect related bring system in built-up areas*

The bring system is suitable for large and high density areas since it is proved to be more efficient and least cost than the house to house system. The optimal distance should be 150 metres from the furthest dwelling/housing unit. GIS should therefore be utilised to plan for the bring system.

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