MUNICIPAL SOLID WASTE MANAGEMENT AND DISPOSAL SAFETY IN THE CITY OF BEIRA, MOZAMBIQUE

By

JAIME BESSA AUGUSTO NETO

Bachelor of Geography

Pedagogical University

Beira, Mozambique

1996

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2002

MUNICIPAL SOLID WASTE MANAGEMENT AND

DISPOSAL SAFETY IN THE CITY OF BEIRA,

MOZAMBIQUE

Thesis approved:

Thesis Advisor

Dean of the Graduate College

ACKNOWLEDGMENT

First and foremost I would like to thank Dr. Richard Marston, my major advisor, for his immensurable supervision, help and guidance. I would like to extend my appreciation to my other committee members, Dr. Carlos Cordova, my academic advisor, who has been helpful during my years at Oklahoma State University, and to Dr. Mahesh Rao, for providing all critical assistance and guidance. I also would like to thank Father Dr. Michael J. Schultheis and his team from Catholic University of Mozambique, Beira, who helped me conduct interviews in three neighborhoods in Beira. I also want to give thanks to Bruce Battles, Center for Application of Remote Sensing coordinator in Geography Department, Oklahoma State University, and Anil Raghavan for their help in preparing maps. The Africa-America Institute supported my graduate studies at OSU, including travel home (Mozambique) in order to collect data for my thesis. I also want to extend my thanks to the City Council of Beira by allowing me to come to this university to pursue my graduate studies and to Maria Faustina for helping me collect data for my thesis and to all agencies and institutions in Mozambique who provided data for this study.

TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Problem statement

Solid waste collection and landfill disposal in the city of Beira, Mozambique is characterized by a wide range of problems. A significant portion of solid waste generated in the city is not collected, and the portion collected is not handled and disposed in an efficient manner. As a result some environmental diseases (e.g., cholera, malaria, dysentery, and diarrhea) have spread. The landfill disposal in Beira has been operating for about 40 years, in the form of an open dump that has been a source of health and ecological problems, especially for the adjacent neighborhood.

A survey was conducted in three neighborhoods on household waste handling and disposal. Geographic Information Systems (GIS)[1] analysis was undertaken to identify land availability for landfill siting and to reveal waste management alternatives in Beira. According to Bailey (1994), the benefits of using GIS analysis fall under three general headings:

1. flexible ability to geographically visualize both raw and derived data;
2. provision of flexible spatial functions to edit, transform, aggregate and select raw and derived data; and
3. reveal insights to the spatial relationships between entities in the study area.

The objectives of the present research are primarily to:

---

[1] A **geographic information system** (GIS) is an integrated computer-based system designed to capture, store, edit, analyze and display geographic information (Chrisman, 1997).

1. Characterize and describe the solid waste collection system in Beira;
2. Suggest potential areas in the city for future landfill site location using GIS analysis, and
3. Provide recommendations on solid waste management system and landfill facility in Beira, to protect citizens' health in particular and the environment in general.

1.2 Study area

Beira, capital of Sofala Province, is located in East Central Mozambique (Figure 1). As a seaport on the Mozambique Channel (an arm of the Indian Ocean), at the mouths of the Púngoè and Búzi rivers, Beira contributes to the economic vitality of the city. The city grew (beginning in 1891) as the terminus of a railroad into the interior by which it handles the foreign trade of Congo (Kinshasa), Zimbabwe, Zambia, and Malawi as well as of Mozambique (Dos Muchangos, 1989; Muhate, 1989).

Leaders in the original settlement did not consider environmental issues that might influence public health and the overall environment. The city is built in a floodplain, with some areas below sea level. In addition, this floodplain is comprised of clay soils that influence ground drainage. During heavy storms, some areas of the city are temporary inundated. Precipitation occurs from January to March with an annual total reaching 1,500 mm. The minimum precipitation occurs during September (19.1 mm) (Dos Muchangos, 1989). The warm Mozambique current flows from south near the equator and influences the climate of the City of Beira. The city experiences higher temperature and humidity compared to the inland areas in the country. The high precipitation contributes to environmental problems or contaminants from solid waste are transported by runoff and leached into groundwater. Some of this pollution reaches the estuary adjacent to the Beira landfill and probably affects the fisheries.

A survey conducted in Macuti, Matacuane and Macurungo (Figure 2) on household waste shows how citizens manage and perceive solid waste issues. The neighborhoods, located in urban district number one, include a significant concentration of buildings. The neighborhoods contrast in terms of house construction, the household waste collection, and social and economic stratification. In each one of the three neighborhoods one finds a range in housing styles, from temporary to single houses and apartments. Macuti is the mostly wealthy residential neighborhood, but still contains some poor residential areas. A private waste collector, operating twice a week, serves the neighborhood. Matacuane is a middle-income residential area, served by a municipal waste collection crew. Although large portions of the neighborhood provide easy access for the waste collection vehicles, not the entire neighborhood is covered. In some areas waste accumulates for long periods of time with all the consequences and health risk. In Macurungo, part of one portion is served by a well-defined road network, but the other portion has restricted accessibility, impeding accessibility of waste collection vehicles. This neighborhood does not benefit from regular waste collection service.

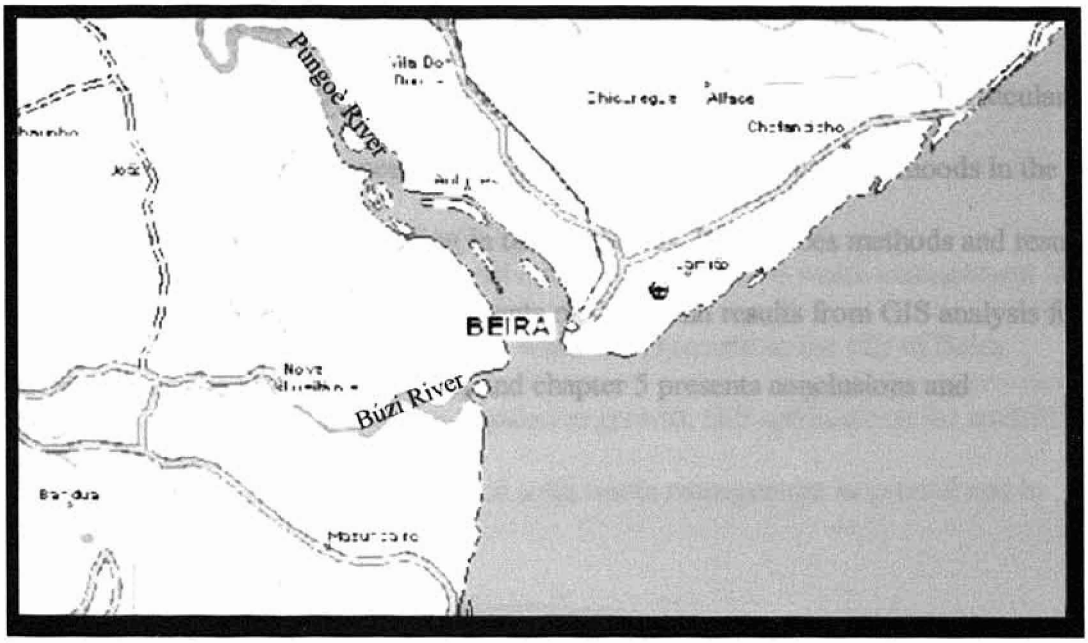

Figure 1. Central area of Mozambique, showing the city of Beira
Source: Multimap. United Kingdom.http://www.multimap.com/index/MZ1.htm

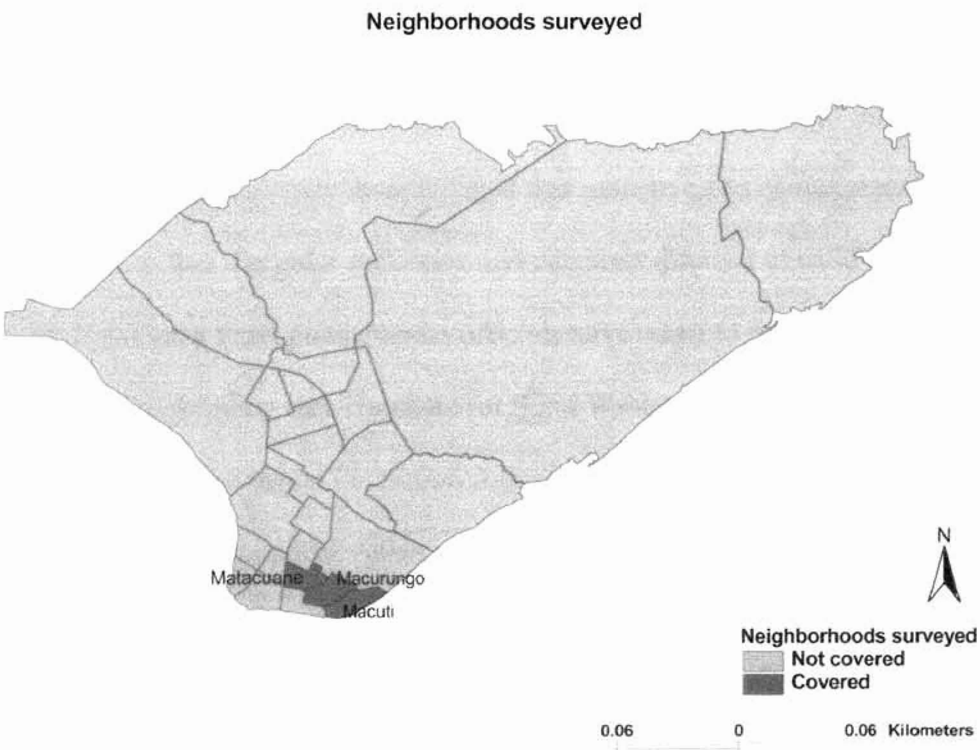

Figure 2: Areas where survey on household waste was conducted

This thesis composes of five chapters. Following this introduction, chapter 2 gives background information on solid waste management in general and in particular in the city of Beira; chapter 3 concerns surveys conducted in three neighborhoods in the city of Beira on household waste handling in the residences. It describes methods and results obtained from the survey; chapter 4 presents methods and results from GIS analysis for landfill site selection in the study area; and chapter 5 presents conclusions and recommendations from the study.

CHAPTER II

BACKGROUND

This chapter reviews some critical issues related to solid waste management in general, and in particular, municipal solid waste management in the city of Beira. Background material is presented on population growth; GIS applications for landfill siting, and other dimensions of integrated solid waste management in general and in Beira municipality in particular.

2.1 Overview of historical and actual contexts of Solid waste management systems

Solid waste management is no longer a new issue in cities of less developed countries. Growing concerns over preserving a livable environment, skyrocketing costs reflected in taxes or services charges, and several incidents of suspended service resulting from labor disputes have already demonstrated that modern cities cannot remain healthy, desirable places to live if regular collection and adequate disposal of solid wastes is absent. At the present time, public works officials have come to recognize the vital role of this public-housekeeping task (Institute for Solid Wastes of the American Public Works and U.S. Environmental Protection Agency, 1975).

In the recent past, concentration of population, intensive use of land, and consequent impact of environmental deficiencies on residents made self-disposal for household and businesses completely impossible. More recently, in many cities and municipalities of developed countries where technology is adequate, solid waste management had shifted form traditional models involving collection, transportation and disposal to a new and more environmentally safe solid waste management strategy involving reduction, reuse and recycling of waste.

Figure 3 shows a diagram of solid waste management, illustrating the Environmental Protection Agency (EPA) view of municipal solid waste management in the United States. The three stages needed for a successful integrated waste management strategy are revealed:

1. Source reduction
2. Recycling of organic and inorganic materials
3. Waste combustion (with preference to energy recovery) and landfilling.

In other words, the new perspective of solid waste management involves consideration of what wastes are covered, what wastes are not covered, and what constitute recycling and composting.

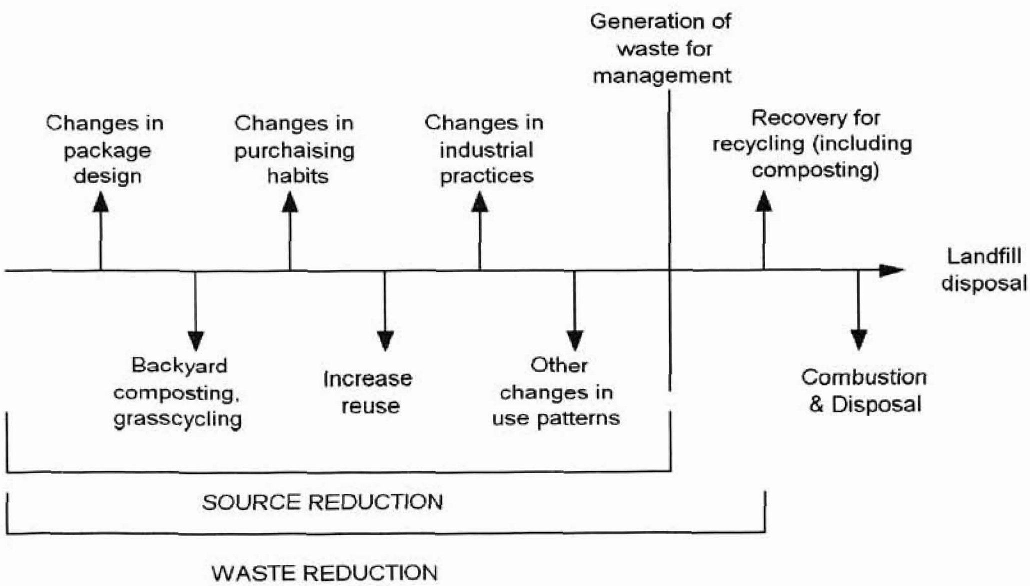

Figure 3: Diagram of Solid Waste Management.
Source: Franklin Associates, Ltd., (1998) based on EPA hierarchy

Stages of solid waste planning also require clear articulation policy goals for the overall waste management strategy. One must identify the full range of possible options and the methodical evaluation of environmental risks and costs associated with each option. Moreover, one must examine the tradeoffs between available options so that an option or package of options is available. In addition, one must examine risk tradeoffs and cost comparisons and careful consideration of implementation issues such as financing, waste volumes, enforcement, permit time frames, siting issues, and likely future behavior changes (Weimer and Vining, 1998). Many solid waste practices and management techniques are standardized. However, because the combination of physical, political, social, and economic conditions are not the same in any two communities, the optimum solution of management problems is still an art heavily dependent on the experience and skill of the administrator (Kreith, 1994; Institute for Solid Wastes of the American Public Works and U.S. Environmental Protection Agency, 1975). These planning efforts have been proven to be suitable for strategic municipal solid waste management in some cities while older practices remain in place in many developing countries.

Recycling is perhaps the most positively perceived and feasible of all waste management practices, but according to the survey conducted on the three neighborhoods, it still far from realization in the municipality of Beira. The lack of knowledge about waste type to be recovered, the absence of re-processing facilities of recovered waste and motivation on this practice are some of the constraints affecting this practice. The primary benefits of recycling are conservation of natural resources, separation of reusable products from the rest of the municipal waste stream and landfill spaces. The benefits of recycling are many. It saves precious renewable resources, lessens the need for mining of virgin materials, which consequently lowers the environmental impact for mining and processing, and reduces the amount of energy consumed. Moreover, recycling can help stretch landfill capacity (Kreith, 1994; Tchobanoglous et al., 1993).

Figure 4 illustrates how municipal wastes are typically collected in Beira. Unspecialized collection trucks make the task difficult to accomplish. For example, the type of truck used for waste collection influences a number of factors, including the amount of waste delivered per trip (and hence operating and maintenance costs), the degree to which wastes are compacted once they enter the landfill. At the time that field survey was conducted, in June-July 2001, municipal authorities operated seven tractors to collect municipal wastes, one self-loading container truck equipped with internal compacter, and one truck to handle large open-top containers, equipped with unloading mechanism. Both specialized trucks experienced mechanical problems because of financial constraints to import spare parts.

Municipal authorities rely on formal and informal market taxes to fund most of the activities in the city. Solid waste collection taxes are not sufficient to maintain the activity (each residence provided with electricity pays 10,000.00 Meticais monthly, equivalent to about 50 U.S. cents).

According to Institute for Solid Wastes of the American Public Works and U.S. Environmental Protection Agency, 1975, labor productivity can be enhanced by the efficient use of equipment. The improper application of equipment to a specific job and poor maintenance escalates costs to the municipality.

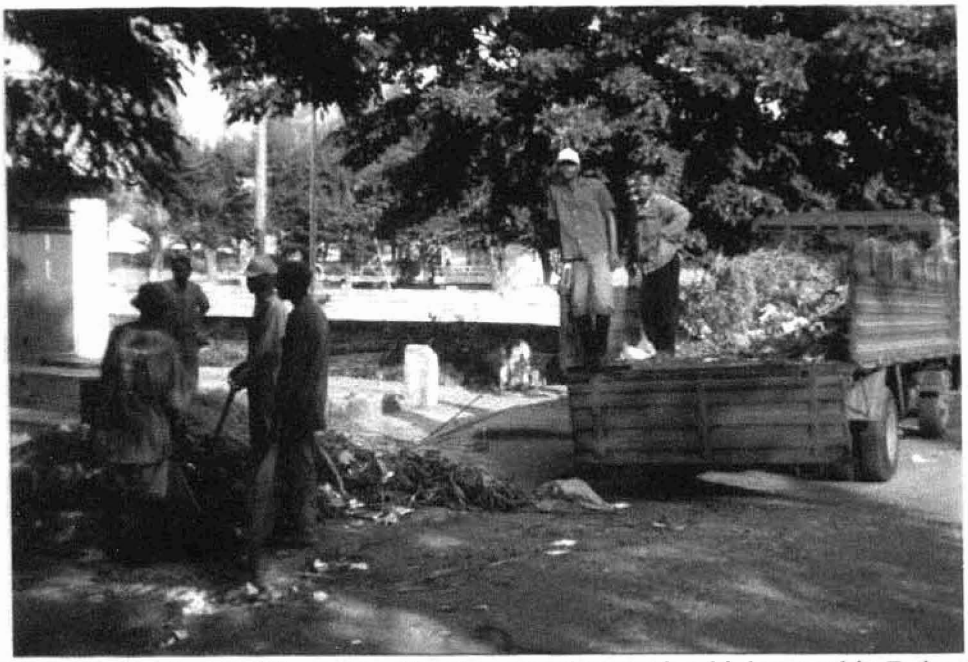

Figure 4: Typical solid waste collection practices and vehicles used in Beira

Not all areas in the city are covered by municipal solid waste collection (Figure 5). Even those that benefit from the service are not provided with containers. Some residents discard household wastes by the curbside, as illustrated in Figure 6. A great numbers of waste containers found in many areas are damaged, rendering the handling of waste even more difficult (Figure 7).

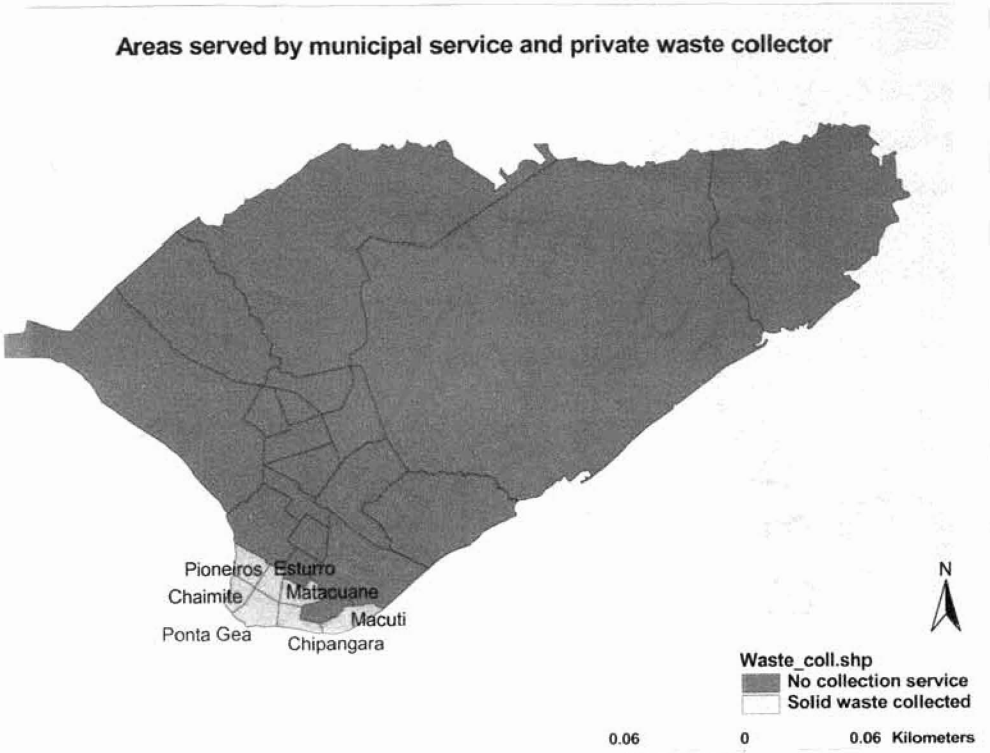

Figure 5: Neighborhoods in the city where household waste is collected

Figure 6: Solid waste deposited by the curbside in one of the residential areas Macuti

Figure 7: View of solid waste containers conservation in the city

2.2 Solid waste definition and classification

Solid waste includes refuse from human and animal activities that are normally solid and that is discarded as useless or unwanted (Tchobanoglous et al., 1993). The definition does not specifically refer about the heterogeneity of the solid waste stream in municipalities.

Municipal solid waste (MSW) includes durable goods, non-durable goods, containers and packaging, food waste and yard trimming, and miscellaneous inorganic wastes (Franklin Associates, 1998; Schwartz et al., 1998). More detailed definitions consider solid waste as consisting of putrescible and non-putrescible materials, including garbage, rubbish, ashes, incinerator residues, street cleanings and industrial and agricultural wastes (Sata, 1970).

Traditionally, three general classifications are used for municipal wastes, respectively residential, commercial and industrial. Residential, also known as "domestic" or "household" solid waste, consists of a variety of wastes produced by residents in houses and/or apartments (Appendix A.1). The fraction produced from the preparation and consumption of food is sometimes known as the putrescible (or food or compostable) component. The other major constituents of residential wastes, in addition to the putrescible component are glass, metal, plastics, waste paper and paper products, rubber, textiles, ash, soil, and similar debris, including broken pottery and china, bones, leather and hide remnants (Rushbrook and Pugh, 1999).

2.3 Trends in solid waste generation

The composition of urban solid waste has changed over time along with the amount produced per capita. According to Schwartz et al. (1998), the "per capita solid waste" is calculated as the average of municipal solid waste in tons collected by county or city in a certain period (year), divided by the county or city population.

In United States, prior to 1980, urban areas averaged 2.4 pounds of solid waste produced by each resident per day. By 1986, per capita waste generation had jumped to 1.6 kg/person/day, increasing to 1.9 kg/person/day in 1996 and to 2.1 kg generated per day in 1999 (Williams, 1994; Tchobanoglous et al., 1993). Other sources refer that increase of waste produced per capita had grown from 0.9 kg/person/day to 2.7 – 3.6 kg/person/day (McFarland et al., 1972). In the City of Beira, it is estimated that household waste generation averages 0.9 kg/person/day (Caetano, 2000). However, these amounts may differ from one community or neighborhood to another, since poor ones tend to be lower waste generators than richer ones. Another reason may lie on data sources. Few data sources do not provide true per capita waste generation quantities.

Most reports indicate data obtained by measuring collected weights or volumes. Since most installations do not have scales, most community "weight" figures are actually a translation of estimated truck volumes based on densities, which can vary from 136.1 kg to 317.5 kg/cubic yard (Tchobanoglous et al., 1993; Institute for Solid Wastes of the American Public Works and U.S. Environmental Protection Agency, 1975).

It is difficult to develop sound integrated municipal solid waste (MSW) management strategies without good data. Furthermore, it will be difficult to engage the public in a dialogue about the choice of an optimal strategy for waste management without data (Williams, 1994). Because data are often costly and difficult to obtain, decision makers should plan for an active data collection stage before making critical strategy choices.

2.4 Population growth, solid waste dilemma and human health in Beira

Since 1975, Beira has experienced a rapid population increase. Just prior to national independence in 1975, the city had less than 120,000 people. The first national census of Mozambique independent, in late 1980, indicated that Beira population had increased up to 214,613 inhabitants (Dos Muchangos, 1989). During the second census, in 1997, the city's population had grown to 409,260 (Figure 8). Appendix B.1 shows population distribution by neighborhood in 1997, representing a 5.3% annual increase (Palmer Associates et al., 1999).

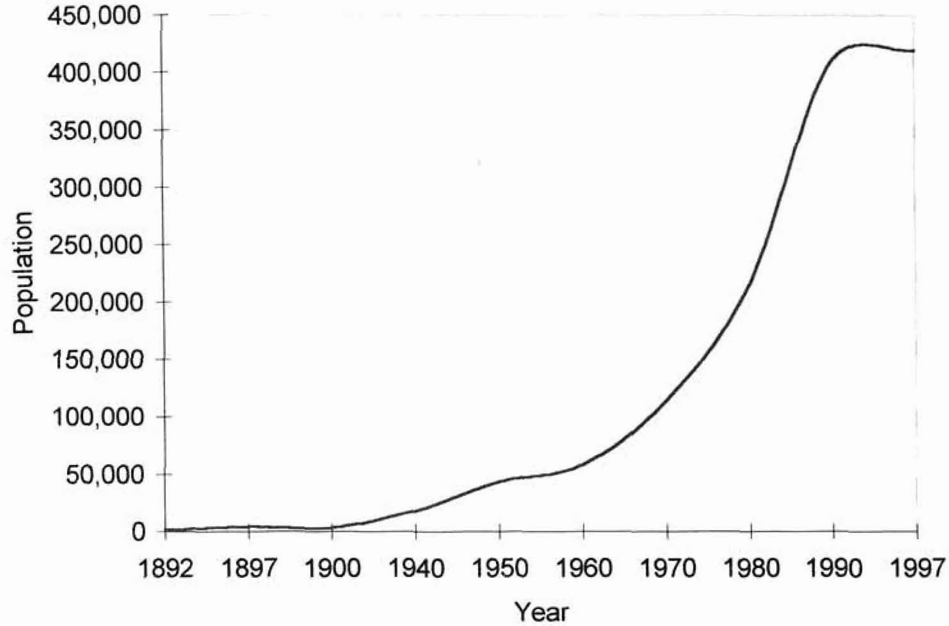

Figure 8: Population growth in Beira from 1892 to 1997
Source: Sheldon, K., 1989; Dos Muchangos, 1989; Gabinete de Planificação, 2001

Urban population growth is accompanied by an increase of municipal solid waste generation, impacting both waste collection capacity of the municipal services and landfill disposal. Figure 9 illustrates municipal waste collection in Beira from 1992 to 2000. From 1992 to 1997 some oscillations were observed and one of the factors that may clearly explain the variation is the reduction of waste collection trucks. After 1997, collection activities improved dramatically because the municipality purchased new waste collection vehicles, comprising of 7 trailer tractors. In the year 2000 two reasons explain the reduction of municipal waste collection: some of waste collection vehicles and tractors had broken down because of lack of maintenance; and some residential neighborhoods (Macurungo, Macuti, Ponta-Gea I and II, and Palmeiras I and II – Figure 10) had been assigned to a private municipal waste collector contracted by the municipal authorities, and the private collector does not share statistical data of waste collection with the municipality (Figure 11). Landfill practices have had direct health effects on the population living nearby. The landfill in Beira is located about 5 km from downtown (Chaimite neighborhood – Figure 5), within one of the most populated neighborhoods, characterized by poor living conditions and unplanned and exposure to malaria, diarrhea, cholera and other diseases. During 1997, for example about 11,000 people in the city were threatened because of malaria and diarrhea. During 1998, about 600 deaths were reported to have occurred in the city due to the same diseases (Palmer associates et al., 1998). According to the City Health Directorate, occurrence of malaria, diarrhea, cholera in the city (Table 1), may have been correlated with municipal solid waste handling and sanitation issues from one neighborhood to another and at the landfill location, respectively.

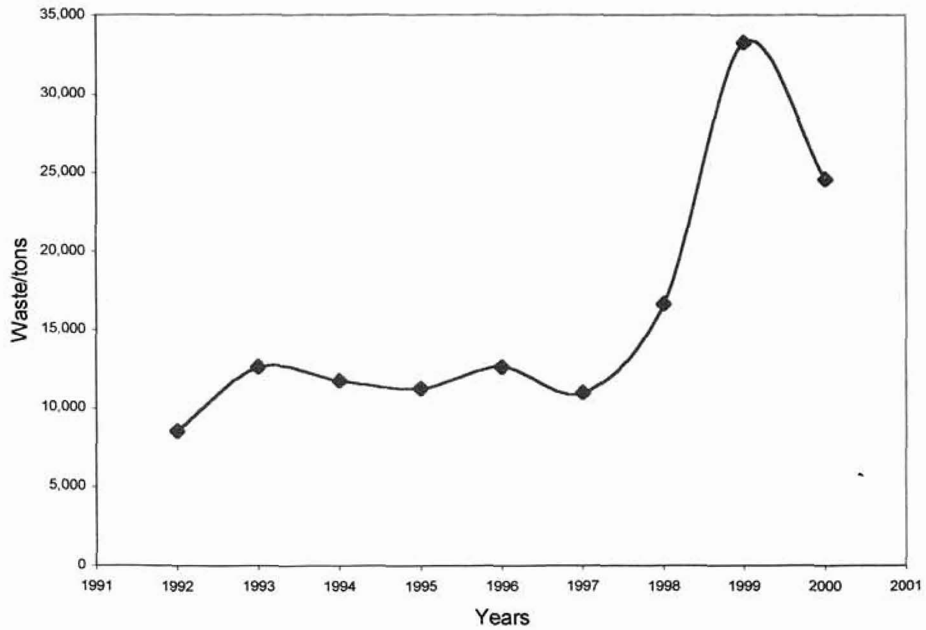

Figure 9: Municipal solid waste collection from 1992 to 2000
Source: Gabinete de Planificação, 2001

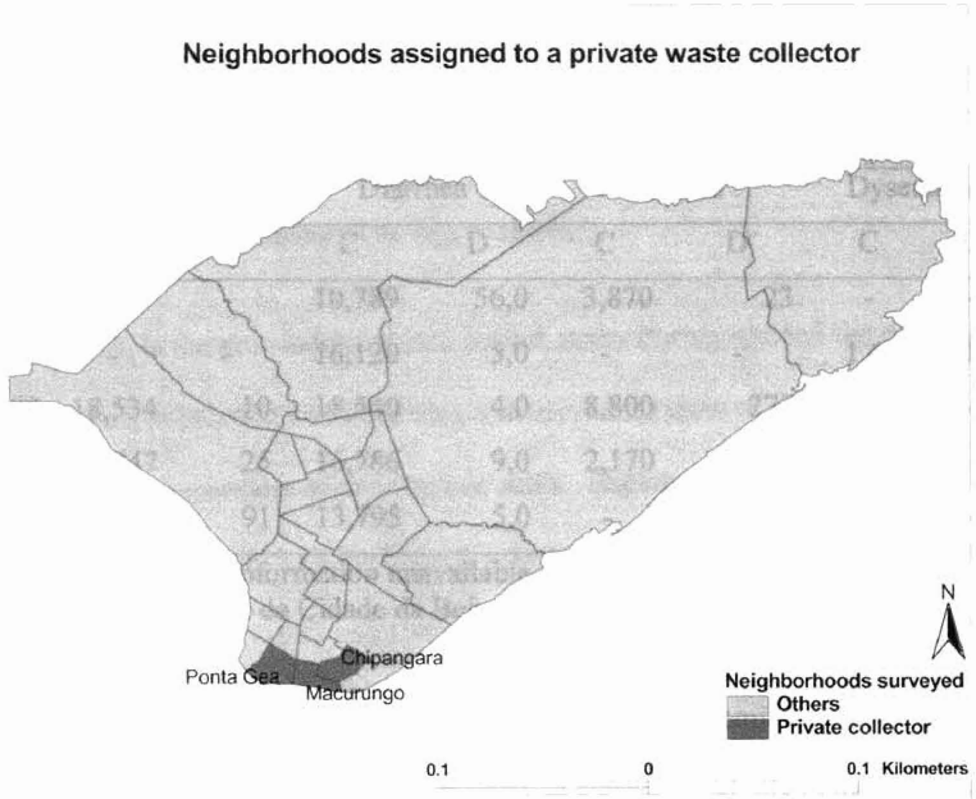

Figure 10: Neighborhoods assigned to a private household waste collector

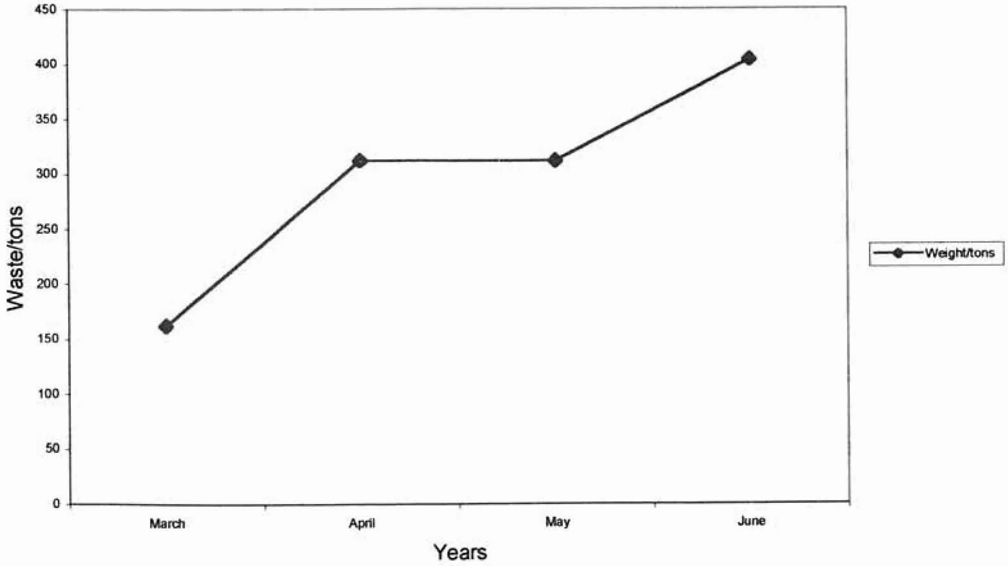

Figure 11: Household waste collected by a private waste contractor from March to June 2001

Source: Personal communication, AQUIMILAR, Ldª (2001)

TABLE 1
Diseases occurrence in the city from 1996 to 2000

Year	Malaria		Diarrhea		Cholera		Dysentery	
	C	D	C	D	C	D	C	D
1996	-	-	10,789	56,0	3,870	23	-	-
1997	-	-	16,120	5,0	-	-	1,675	1,0
1998	18,534	10	18,540	4,0	8,800	277	1,503	-
1999	10,747	25	16,786	9,0	2,170	10	2,244	-
2000	31,361	91	13,795	5,0	-	-	-	-

C = case; D = Death; - = Information unavailable
Source: Direcção de Saude da Cidade da Beira, 2001 and Caetano, 2000

Solid waste management studies should address the epidemiology of disease in relation to wastes as well as address such matters as nuisance and other environmental constraints by which solid wastes may make human life less pleasant, convenient, or healthy (McFarland et al., 1972).

Prior to independence, Beira had grown from a small military command to the size of a city in 1907 (De Lemos, 1989). During this period, 90% of the total population was rural. From these rates and during late 1960s and early 1970s, the urban population was separated into three different strata based on occupation and *Europeanization* status[2] (Kaplan, 1985). The first group of urban citizens, a small and heterogeneous upper stratum, consisted of civil servants, nurses, few prosperous merchants, and others with jobs that required literacy and some special training. The middle urban stratums consisted of manual workers and artisans, many self-employed whose jobs did not

[2] Assimilation into European culture

necessarily require literacy. The last and the largest group compose of illiterate and unskilled workers (stevedores, construction workers, canners and others). Because of the small number of population living in the city and mostly, their economic and social status, solid waste was not considered to be a problem.

After 1975, in the post-independence period, many Portuguese left the country, depleting the urban population and triggering a massive migration of rural population to the cities most males regardless of their lack of skills. Explanations for this migration to the cities included the search for a livelihood; long-lasting droughts in the countryside that lasted through the 1981-1982 and 1982-1983 growing seasons (in some places by destructive floods); and activities of Mozambican National Resistance (Kaplan, 1985). These factors contributed to a redistribution of population that resulted in rapid urbanization in Mozambique in general, and in Beira in particular.

The development of the local integrated solid waste management plan should follow a clearly defined, rational process as shown in Figure 12. This process should evolve through a sequence of analysis from the definition of goals and objectives to decision making on how the goals and objectives will be achieved. The steps in this process need to allow for continuous information flow, feedback, and adjustments to the planning process. Also, to plan the development of waste facilities, the waste manager needs information about the quantities and types of wastes that are generated within and around the municipality that may be included in the waste management system under the municipality's control (Rushbrook and Pugh, 1999). Municipal operations may be arranged differently in various organizational structures. Considerations include: size of agency, population density, form of government, other compatible public services, and traditional methods of organization (Denison, et al., 1994; Institute for Solid Wastes of the American Public Works and U.S. Environmental Protection Agency, 1975).

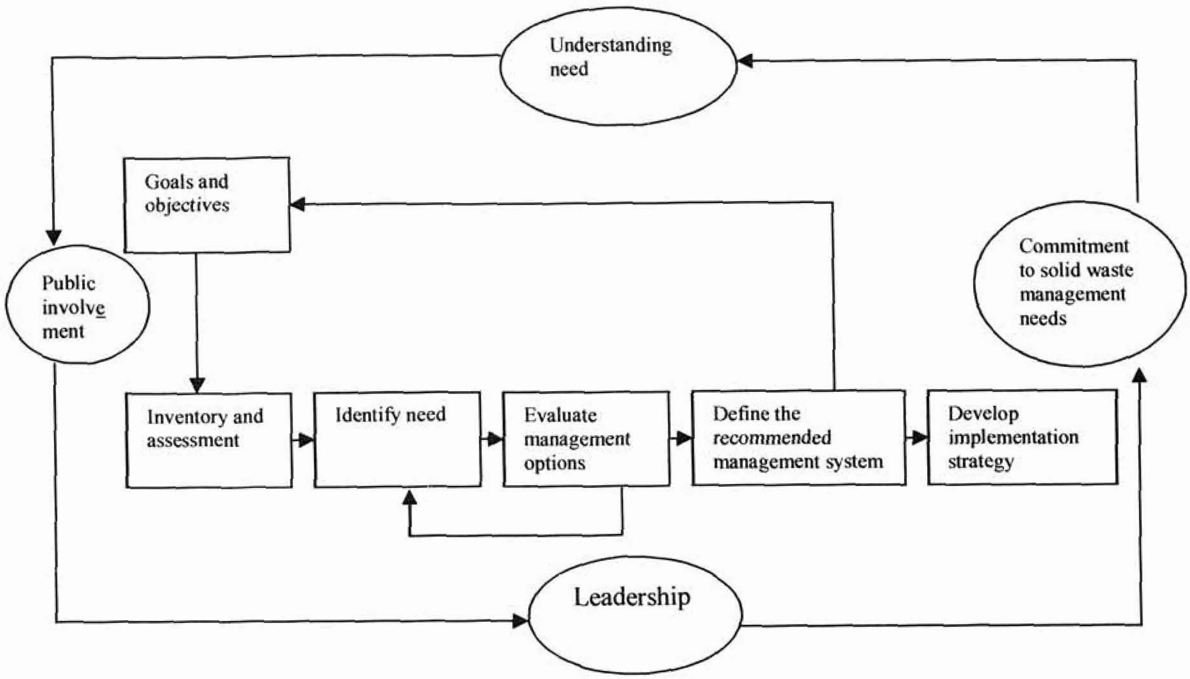

Figure 12. Local government planning process.
Source: Modified from Kundell and Ruffer (1994)

2.5 Landfill

Beira municipality does not possess consistent plans and strategies to deal with solid waste management. Rushbrook and Pugh (1999) discussed different aspects about solid waste landfills in middle and lower-income countries. They characterized a variety of ways that municipal solid waste is handled and suggested some improvements needed in these countries. The improvements to consider are grouped into the following three stages:

First stage: from open dump to "controlled dumping"

1. reduce the working area of the site to a more manageable size;

2. cover the waste with soil, sand or other type of covering material;
3. stop fires and
4. agree about rules of on-site work with scavengers if they cannot be removed completely.

Second stage: from controlled dumping to "engineered landfills"

1. gradually adopt engineering techniques to control and avoid surface water entering the waste;
2. extract and spread soils to cover wastes
3. remove leachate into lagoons;
4. spread and compact waste in to smaller layers;
5. prepare new parts of the landfill with excavation equipment, and
6. improve the isolation of wastes from the surrounding geology.

Third stage: from engineered landfill to "sanitary landfill"

1. landfill gas control;
2. extensive environmental monitoring;
3. highly organized and trained work force;
4. detailed record-keeping, and
5. on-site leachate treatment.

Neal and Schubel (1987) outlined disposal options to isolate solid waste from communities. Dumps are thrown to affect specific areas in their immediate vicinity, but other environmental factors such as wind, reveal that impacts are significant over large areas. Historical assessment of disposal options shows that there is an improvement on waste treatment over time. Schneider (1970) provided some guide on solid waste disposal and its hydrologic implications based on different kinds of soils and geology. He states that:

> "pollution potential is highest in permeable areas with shallow water table where the wastes are in direct contact with the ground water. In a relatively impermeable area, the pollution is generally confined locally to the vicinity of the waste-disposal site".

In their study about hydrogeology and water quality near a solid and hazardous waste landfill, Roche and Breen (1989) presented relevant information on impacts to groundwater. From leachate samples, they found out that leachates are highly mineralized and present high concentration of total dissolved solids.

Various safe options for disposing solid waste are available, including sanitary landfill, refuse filling, and controlled dumping (Sata, 1970). In the city of Beira, once solid waste is collected, it is deposited in an open dump, with no additional treatment. Occasional fires occur at the landfill site, destroying large amounts of solid waste. However negative impacts such as air pollution and odor have been reported and criticized by the citizens and other stakeholders in the city.

Sata (1970) discussed pathways for introduction of unwanted substances from landfills, affecting surface and groundwater pollution. The amount of water that enters a refuse from the surface will be governed by the rate of water application, the nature of the refuse and the climatic conditions. In Beira, the landfill is adjacent to a residential area where residents use groundwater for daily activities. Since the landfill is an open dump (Figure 13), runoff to the bay may be evident, making the matter worse because of its location few meters from the ocean.

Wilson (1981) stated that locating a landfill in impermeable strata such as soft clays and marls or fine-grained compact rocks of low permeability such as slates, shale, and mudstones may reduce leachate and other environmental problems, including public health risk. In contrast, the presence of lenses of sand, gravel, or similar permeable deposits may provide preferential routes for migration of leachate, although their existence may not be apparent from a surface inspection of the site.

Figure 13. Municipal landfill site in the city of Beira

Location of waste management systems is a factor affecting groundwater quality. Typical leakage from landfills and lagoons usually contain significant amounts of contaminants such as ammonia, nitrate, chloride and metals. These contaminants may reach aquifers and degrade the water resource such that it becomes hazardous to human health (Starrett et al., 2001).

2.6 GIS analysis

The use of ArcView ™ software will help to determine acceptable areas for solid waste landfill based on spatial patterns of present and future land use, vegetation, and population distribution. In siting a landfill area for solid waste management considerations must be given to the geology, topography, access, and surrounding land use. Land use considerations should include the issues of environmental justice for the poor and minority. This reflects a concern that some may be asked to accept a disproportionate share of undesired land uses.

In summary, a check-list for landfill siting consideration must take into account factors mentioned above, and others such as:

1) Hauling distance, representing the distance required to reach the location where the contents of the containers will be emptied;
2) Location restrictions: locations restricted for landfill siting; they include natural (certain type of soils, rivers, wetlands, protected forest and so on) and social (residential areas, and other social infrastructures) environments, but also political restrictions;
3) Availability of land area: considers how much land exists after applying all the restriction criteria;
4) Site accessibility: considers road network allowing easy access to the landfill site disposal;
5) Soil condition: landfills should not be sited in permeable and productive soils to avoid groundwater contamination and reduction of cultivated soils;

6) Climatic conditions: represents the atmospheric conditions for a long period of time, and generally refers to the normal or mean course of the weather. Dry or wet conditions influence differently on how the landfill should be build and maintained;
7) Surface water hydrology: good surface drainage to prevent water from seeping in or out of the landfill. Landfills must also control run-on and runoff. Run-on must be diverted to prevent erosion to the landfill;
8) Existing land use patterns: considers the heterogeneity and differentiation among areas and neighborhoods in urban settlement, infrastructures such as road network, and so on;
9) Local environmental conditions: determine if the landfill activities could cause or contribute to the likelihood or survival and recovery of endangered and threatened species. Also see if the landfill is located in a seismic impact zone or unstable areas;
10) Potential ultimate uses for the completed site: After landfill closure, it is important to consider the use of former landfill sites. This includes transforming the landfill sites in playgrounds and other entertainment activities.

Final disposal site selection usually is based on results of a detailed site survey, engineering design and cost studies, environmental impact assessment, and the outcome of public hearings.

Various analytical approaches differing in complexity, computational intensity, and ease of interpretation have been employed in locating potential sites for future landfill location. For example, Tao and Shyr (1998) (http://scs.ucdavis.edu/Services/ClassSupport/PROJECTS/) have used a geographic information system (GIS) model to identify the best suitable placements of landfill sites in Yolo County, California. That project was based on factors such as road access, restricted areas (like urban areas) and soil data. In Laminar County, Colorado, a project conducted using ArcView ™ was to "develop data and tools necessary to aid decision makers and special interest groups begin to understand the alternatives and tradeoffs in the landfill siting process"(Herzog, undated, http://www.esri.com/library/userconf/proc99/proceed/abstracts/a464.htm). A number of criteria for the project included landfill volume required (calculated from user input or readily available information), proximity to lakes and rivers, proximity to habitat and endangered species, distance to population centers, soil suitability for landfill placement and cover, zoning, area available, slope, elevation, and cost. Another project, developed by the Center for Advanced Technologies, for the four-county Northwest Arkansas Regional Solid Waste Management District used criteria such as distance from water intake, streams, and existing landfill sites (undated, http://www.cast.uark.edu/local/gis). A case study in Western Cape, South Africa, used primarily exclusionary criteria representing proximity to residential areas, airfields, mountains areas, nature reserves, indigenous forests, geological faults, cost, dams and rivers (Conrad, undated, http://www.globesa.org/conrad.htm).

Other examples involving GIS application on siting issues exist. Brainard et al. (1996) in their study "Assessing hazardous waste transport risk using a GIS" predicted the most likely routes for waste movement and assessment of the possible consequences in the event of a tanker accident. Bosagaolu et al. (1997), used geographical information analysis in the city of Ankara, Turkey, to identify candidate sites for a solid waste disposal facility. The site identification was developed through an overlay analysis using Arc/Info 7.1™. Digital thematic layers used for their study include groundwater, wetlands and swamp areas, surface water, roads, topography, ecological features, settlements, erosion susceptibility zones, and soil types. Candidate sites were narrowed down, leading to one or more sites for detailed investigation. Other studies by U.S. Department of Energy (1986) and Cruz (1993), as referred by Basagaoglu et al.(1997) indicate that GIS have been used to select sites suitable for land application for solid waste facilities in the United States and in Manila, Philippines.

Atkinson, et al. (1995) used GIS analysis to conduct landfill siting in Denton County, Texas. Environmental and other land use variables were mapped, digitized and analyzed. Baban, and Flannagan (1998) state that:

> "improper siting of landfill sites can affect air and water quality, land use and public health. Pressures placed on decision-makers have increased, as they now have to make decisions taking into consideration public satisfaction, environmental safety and economic practicality. GIS have the capability to handle and simulate the necessary economic, environmental and political constraints. They can play an important role as a decision support tool regarding optimum waste site location."

Allen et al. (1997) point out that a program for site selection and evaluation should ideally involve a two stage approach:

1) screening stage leading to the targeting of areas suitable for siting of landfills; and

2) evaluation stage, involving the detailed assessment of individual sites with the target areas, but with the ultimate goal to generate potential sites for landfill location.

Many other GIS applicability in siting issues can be mentioned; although they are not related to landfill siting, they use the same approach for siting purposes. To mention some, Lay and Zhiyong (1998) (http://scs.ucdavis.edu/Services/ClassSupport/PROJECTS/) in "locating potential sites for a stadium in Yolo County: an application of vector GIS, have come with a good example of applying GIS for siting purposes. Other project is that of Gamino and Contreras (1998) (http://scs.ucdavis.edu/Services/ClassSupport/PROJECTS/), who used GIS analysis to assess land availability for prisons in Yolo County. In all these examples, the authors used selection criteria and buffering techniques, operations that can be used for any other siting purposes. Watson (1997, http://log.on.ca/users/stewshow/sitessel.html) refers that one of the crucial operations to be taken into account while performing geographical analysis using GIS is "to conduct the screening analysis, an overlay mapping technique to identify areas with one or more constraints." The constraint areas will not be considered in optimal area identification, but the remaining lands. Depending on data availability, natural, political and social scenarios of the study area, a number of techniques can be applied to determine land availability and suitability for landfill location. Methods used for the City of Beira are outlined in section 4.2.

Capbell and Masser (1992) concluded that local government is one of the most important groups of users of geographical information systems (GIS). That range of potential applications in this field is considerable, extending from property registers and highways management to emergency and land-use planning (Department of the Environment, 1987). The results of the surveys conducted in USA and Europe indicate high level of commitment to GIS technology and the varied experiences of users in local government. These applications underscore the powerful capability of GIS in collection, management, retrieval, transformation, and display of spatial data.

CHAPTER III

SURVEY ON SOLID WASTE GENERATION: METHODS AND RESULTS

This chapter presents methods and results concerning the survey conducted on 3 neighborhoods (Macuti, Matacuane and Macurungo) on solid waste generation in the study area. The data obtained from the survey is outlined in graphs and tables and non-parametric Chi-square test was performed to assess the differences in responses in the neighborhoods.

3.1 Data collection and field work

The amount of solid waste collected in Beira is a small portion of the amount of solid waste generated as illustrated in Figure 9, primarily due to financial limitations. Solid waste management is generally seen as a low priority given the city's financial constraints (Coffey, 1999).

About 20% of the urban population receives regular solid waste collection services. However, this is confined to few areas in the city's neighborhoods (Figure 5) because some of the residential areas consist of temporary constructed houses that are unplanned (squatters), and difficult to gain access for collection vehicles.

As Mato (1998) noted in Tanzania, and with similarities in Beira, the large part of the waste that is not collected is buried or incinerated on-site haphazardly by roadsides, on open spaces, or in valleys and storm water drains (Figure 14 and 15). Uncollected waste found in many areas of the city, degrades in heaps on the ground, blocking drains and providing a breeding ground for rodents and insects. It comprises a transmission route for many diseases endemic in developing countries (Coffey, 1999).

Figure 14. Household waste buried

Figure 15. Household waste being burned

The only method of disposing municipal solid waste in the city is dumping in a local landfill located at about 5 km from downtown. Because of its location near of one of the most populated and unplanned residential area (Munhava-Matope) and the presence of scavengers (Figure 16) who extract “valuable” materials from the waste heaps, serious environmental related diseases threaten citizens in the city from direct exposure to the waste and environment. These grounds are suitable for mosquitos, flies, rodents reproduction. In summary, the city of Beira needs to upgrade its solid waste management system, from collection, handling and disposal of city’s refuse.

Figure 16. Scavengers at the landfill site

3.1.1 Procedures for the survey

The interviews carried out in the neighborhoods total 300 distributed 100 for each of the neighborhoods covered, however 298 where filled out. Although statistical measures were not undertaken to determine representative sample, I believe that the number of surveys in each neighborhood provided a reasonable sample size about how citizens in Beira regarded municipal solid waste management. To allow chances of any household in the neighborhoods to be covered in the survey, I have divided the number of houses in each neighborhood (Appendix B.1) covered by the number of surveys. The house to be interviewed was selected using random number between 1 and 10.

This ratio is expressed as:

$$S = \frac{Nh}{Ns}$$

Where:

S= Household survey sample;

Nh= number of houses by neighborhood and

Ns= number of surveys by neighborhood

The fraction number I obtained denotes the appropriate number of homes to be sampled in each neighborhood. For instance, Macuti contains 2,635 houses in total. The ratio would be 26.35, or approximately 26 houses. Homes to be surveyed were randomly selected within the neighborhood. Survey data were entered into a statistical package, SPSS (Statistical Package for the Social Sciences), to compile statistics.

3.1.2 <u>Results of the survey</u>

Responses from question 2 show that from the total of 298 surveys, 12.7% frequently discard paper, 11% food waste and, 39.9% discard respectively paper, food waste and yard waste; 9.3% combine food and yard waste; and 6.7% have on their waste stream food, yard and plastic waste. The remaining number of respondents generates waste composed of metals, glass, ceramic, wood. 13% did not respond to the question.

Figure 17 shows the distribution of type of solid waste produced in the neighborhood surveyed.

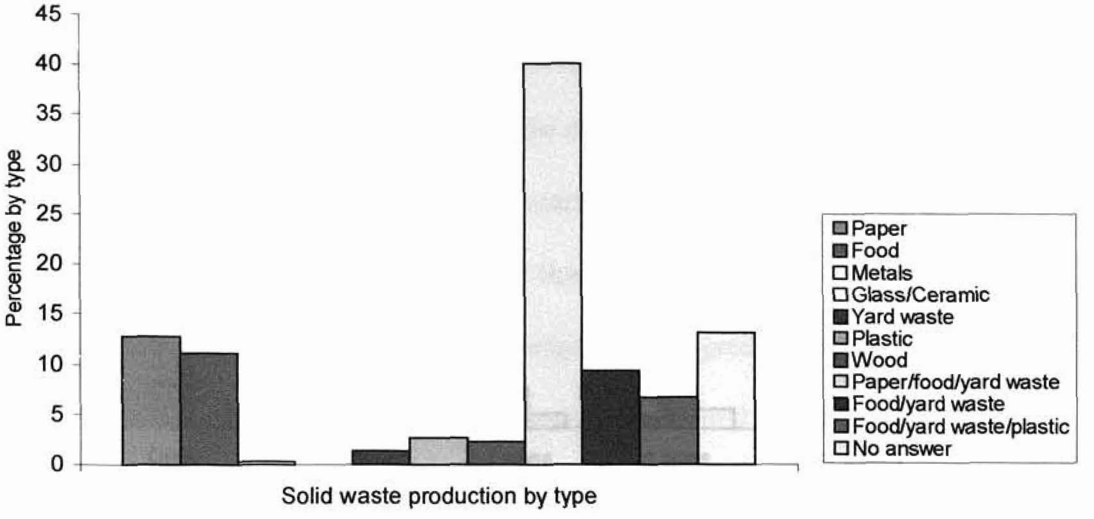

Figure 17. Percentage of household waste production by type in the neighborhoods surveyed (question 2)

Asked about the frequency of waste discard at the collection point, questions 11 through 13 reveal that 43.9% report daily disposal; 15.1% twice a day; 7.7% reported once a week, 6.4 and 3.4% report twice and three times respectively (Figure 18). Surprisingly, some respondents have monthly frequency and this may be explained by their economic status. The poorer the household, lesser frequency of waste discard will be observed.

The survey also revealed that wife/husband is responsible for discarding household waste (question 14), followed by housekeeper with respectively 31.2% and 24.6%. About 18.8% give the responsibilities to children and 13.4% involve other adults in the household (Figure 19).

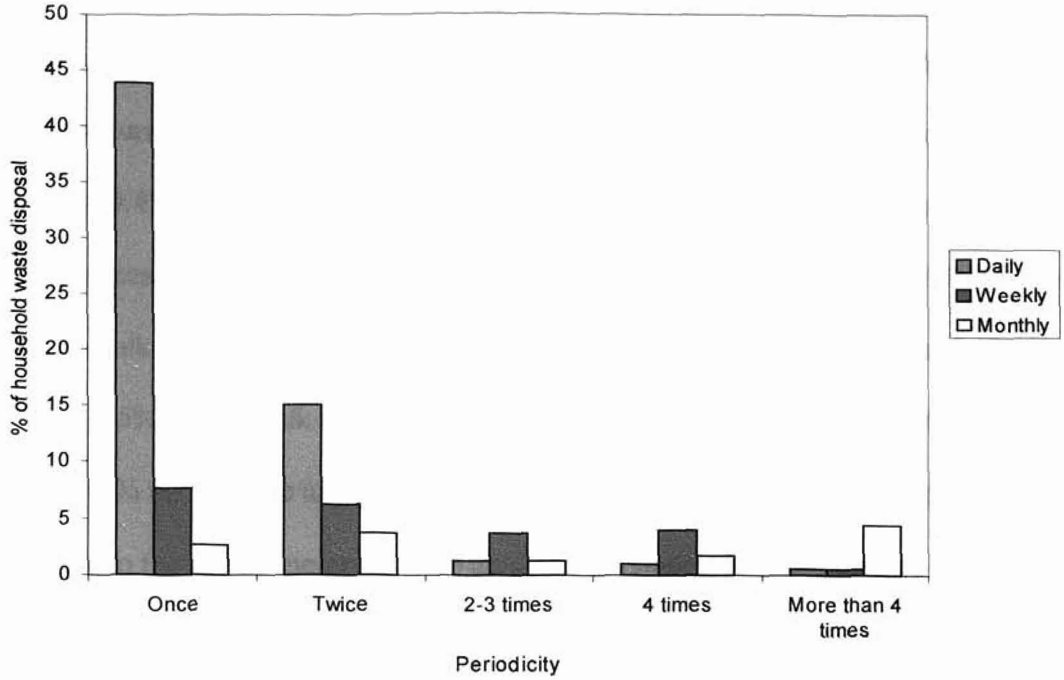

Figure 18. Frequency of household waste disposal in percentage (questions 11 through 13)

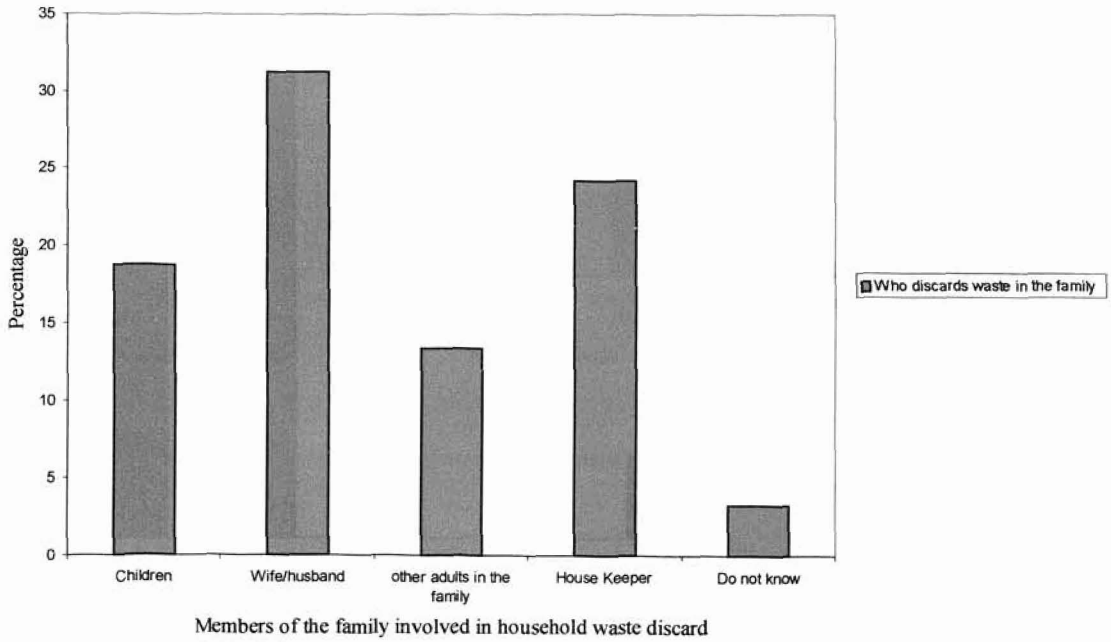

Figure 19. Members of the family involved in waste discard at the collection point (question 14)

The survey also addressed questions such as the distance traveled to discard household waste (question 7 and 9). On one hand, results from question 7 show that 39.9% are currently walking distances less than 10 meters; 23.2% walk between 10 and 49 meters; 9.4% respondents walk distances ranging from 50 to 99 meters; and only 4.3% walk distances greater that 100 meters. On the other hand, from question 9, 20.8% would accept to walk only distances less than 10 meters, while 35.6% between 10 and 49 meters. 18.5% would walk distances greater than 50 meters but less than 100 meters and finally 10.4% do not have any problem walking distances greater than 100 meters. Regarding to the family members to be involved in household waste discard at the collection points (question 10), 28.5% would rely on children to walk such distances, while 27.2% on wife and husband. 17.1% will rely on adults and housekeepers, respectively and 4.6% do not know (Figure 20).

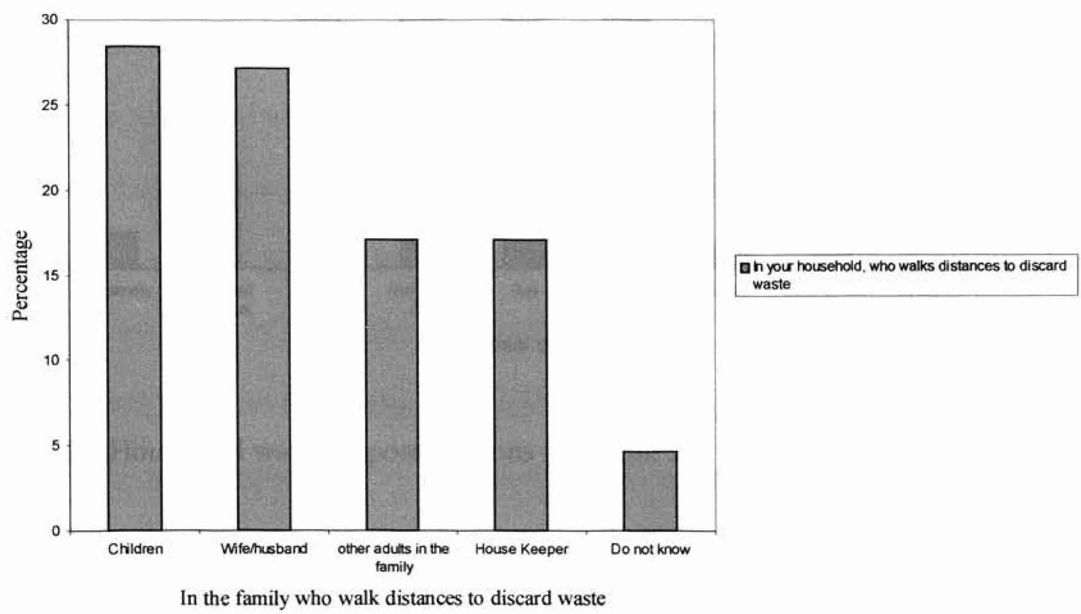

Figure 20. Members of the family walking distances for household waste disposal at the collection point (question 10)

If established collection points where containers are provided (question 8), 86.6% would agree to walk further to discard household solid waste. However, 10.1% would not accept to walk long-distances to disposal and collection points.

At the collection points, not all residents are provided with containers. Question 5 revealed that only 2% had access to containers while 6% were using their own household deposit containers. The majority use curbside disposal, representing 25.8% and 16.1% use abandoned lands to get read of their household waste. Other families bury or burn their waste and 0.7% said they use drainage trenches to dispose of waste (Figure 21).

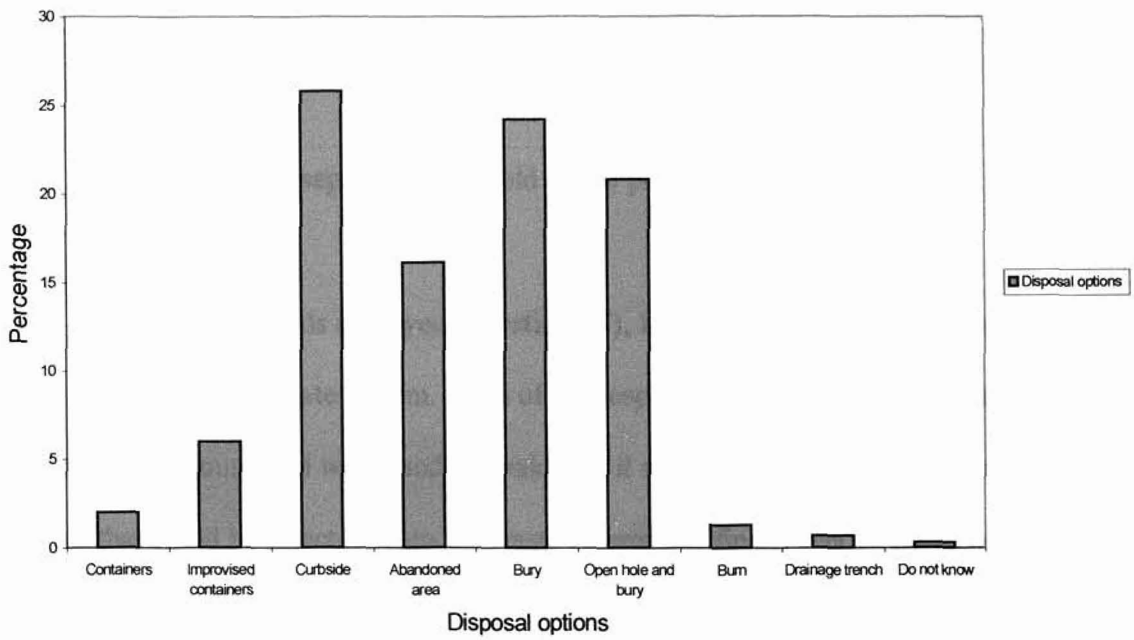

Figure 21. Household waste disposal options (question 5)

Regarding to household waste separation (question 19), 80.5% would adhere to the program if established. A small percentage, 5%, will not separate any item from household waste stream. 6.4% said that it would depend if it is worth and 4% do not know if they should separate and why they should be doing.

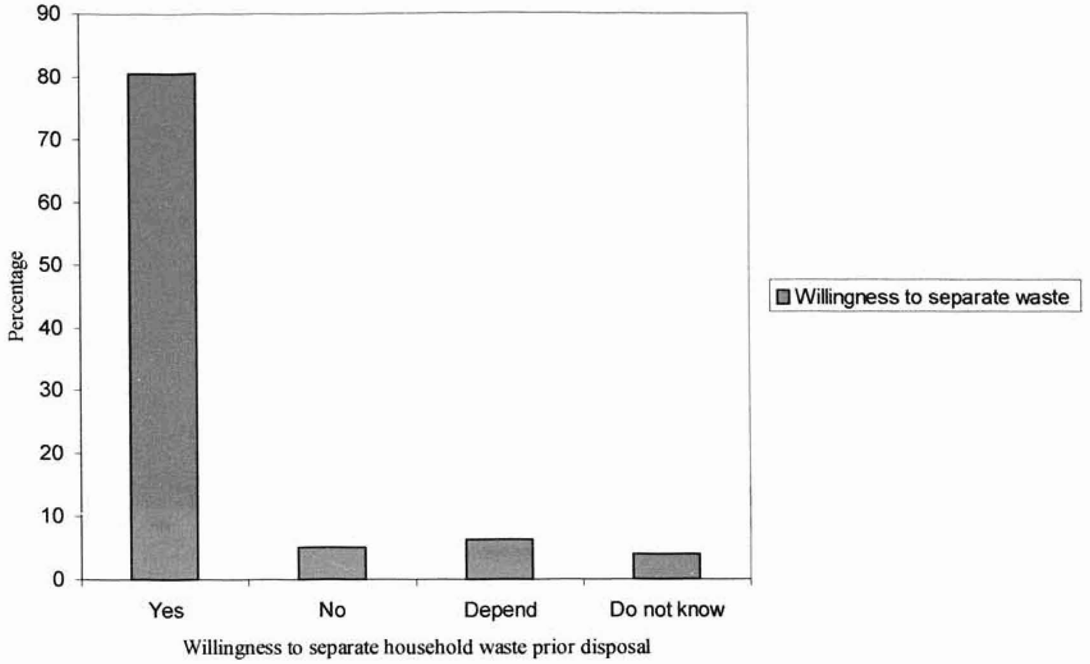

Figure 22. Willingness to separate household waste prior disposal (question 19)

In all neighborhoods surveyed (question 17), 81.9% are willing to reuse some items of the household waste stream. 7.7% of the respondents to the survey will not reuse any items of the household waste and 5% said that it will depend on the need of reuse of the items that could be selected from the waste stream and finally 3% do not know for sure if they are going to adhere the program (Figure 23).

Figure 24 shows the results of the willingness to pay to improve municipal waste collection in the city (question 15). The majority, 59.7% agree to pay for waste collection improvement. A significant percentage of the surveyed, 26.2%, will not accept to pay and one of the reasons behind this attitude is that municipal authorities has not yet proven to be capable of performing waste collection activity satisfactory. 12.4% of the respondents do not know if they are going to pay or not.

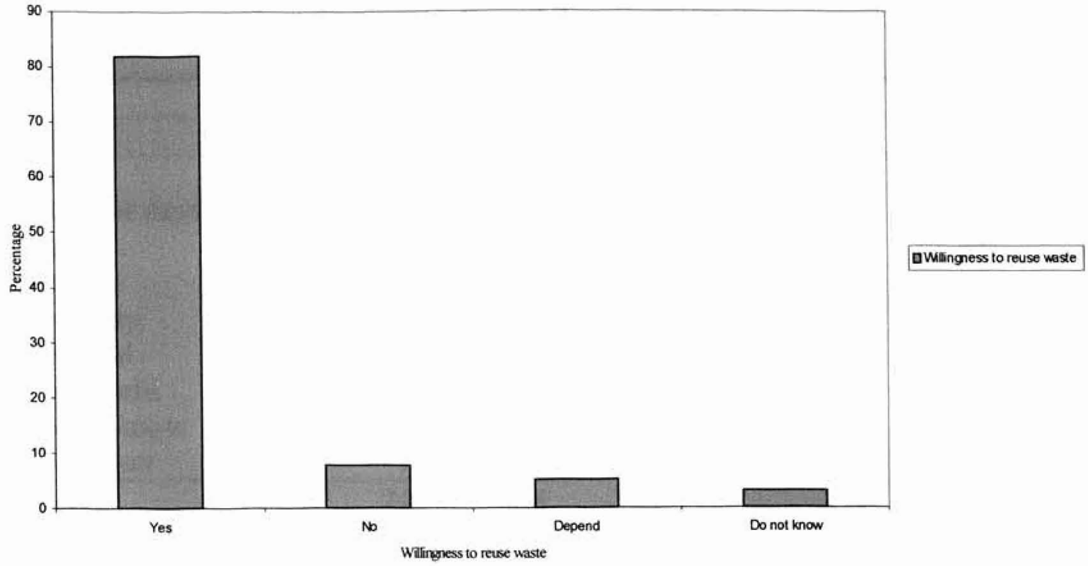

Figure 23. Willingness to reuse household waste (question 17)

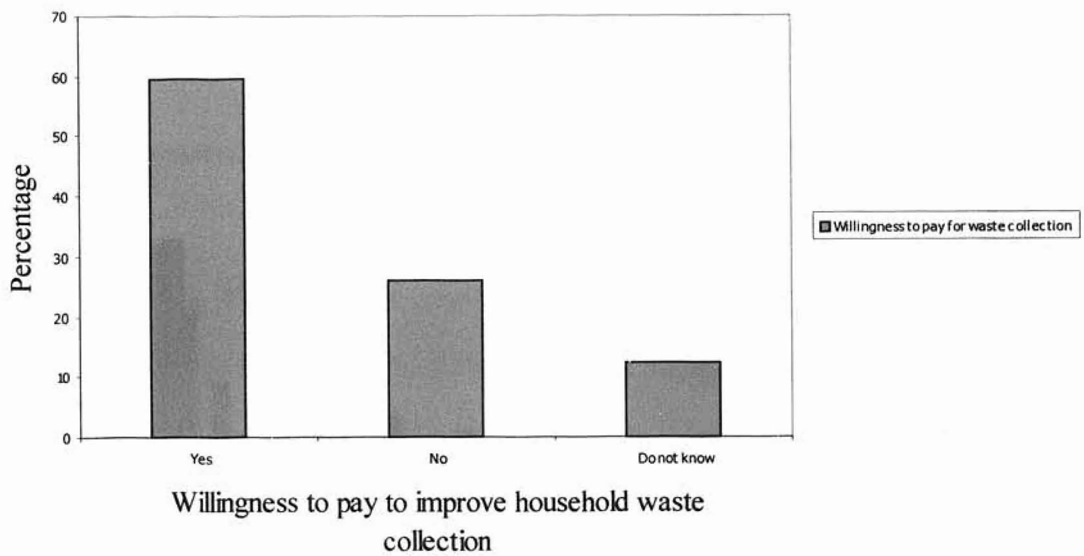

Figure 24. Willingness to pay to improve household waste collection (question 15)

During the survey, I also obtained data on how frequent each type of waste is discarded in the neighborhoods (questions 3.a through 3.g). The results are presented in Table 2 and Figure 25.

Table 2
Municipal waste discard frequencies by waste type

	Waste type						
Interval	Paper	Food	Metals	Glass	Yard waste	Plastic	Wood
Daily	164	210	17	18	97	98	69
Alternate days	39	16	13	6	20	47	12
Weekly	32	5	36	9	6	25	8
Monthly	10	3	19	11	3	3	6
Quarterly	3	0	4	5	2	1	1
Biannual	2	1	9	12	1	0	2
> 6 months	0	0	3	2	1	0	3
Do not know	6	0	43	0	0	1	0
No answer	8	13	0	52	42	43	41
TOTAL	264	248	144	115	172	218	142

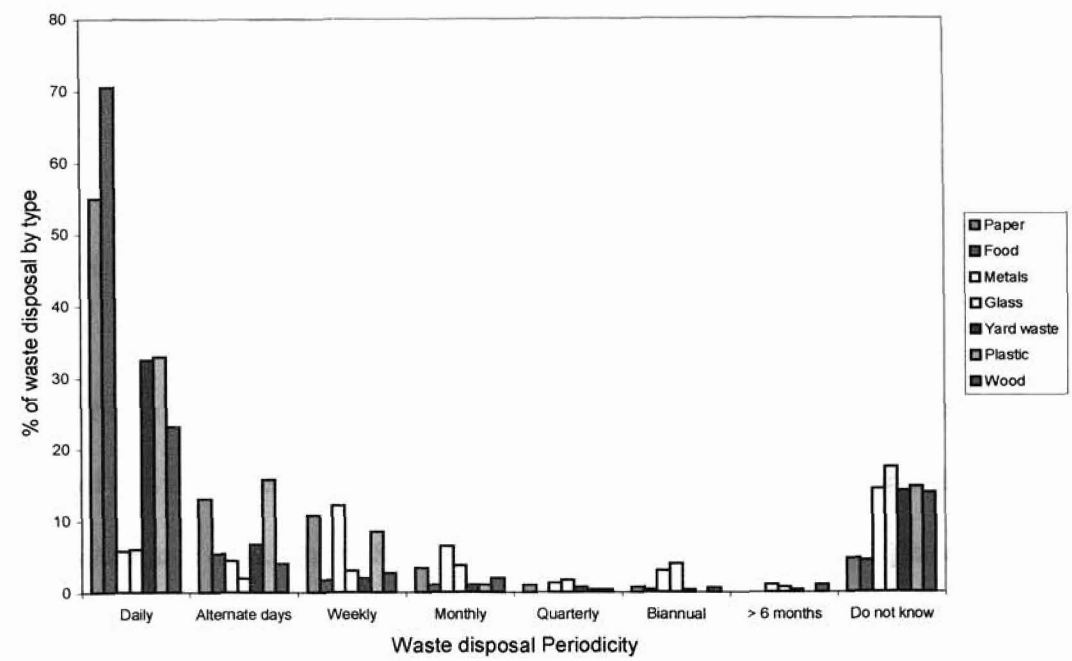

Figure 25. Interval discard by solid waste type - questions 3.a) through 3.g).

Asked about frequency of drops at the collection point (question 4), 50% discard their household waste as soon it is produced and 37.9% wait until it reaches certain volume. Only 2% have defined days to discard their waste and 2.7% discard depending on the type of solid waste – whether putrescible or not (Figure 26).

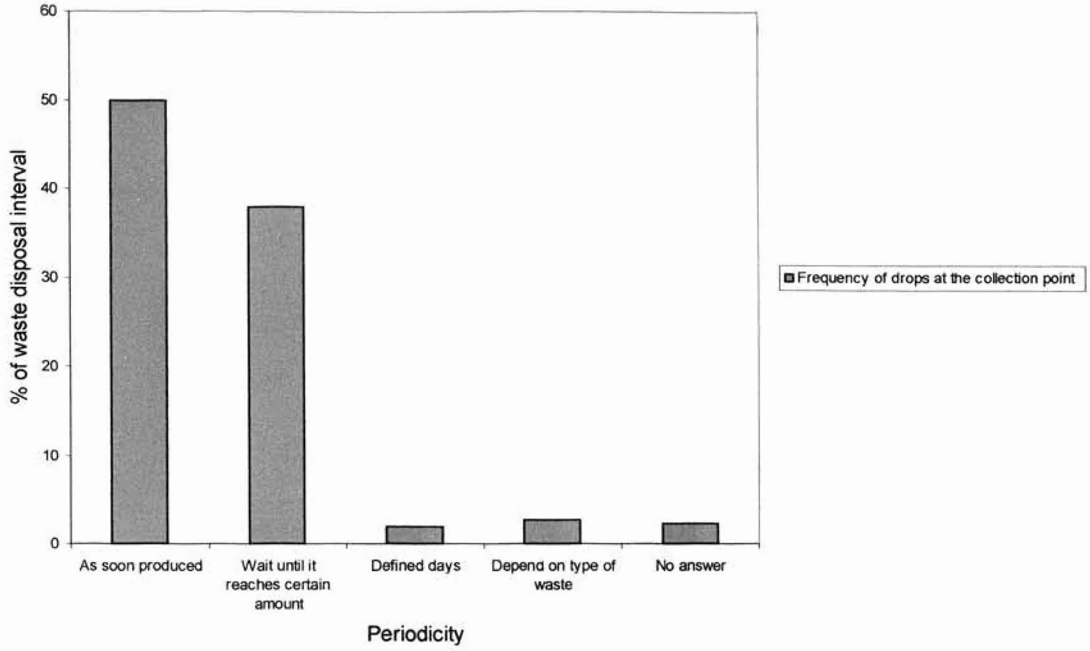

Figure 26. Frequency of drops at the collection point (question 4)

The three neighborhoods surveyed have different scenarios of waste collection by municipal services (question 21). According to the survey, only 4.4% have daily service, 6.7% on alternate days, while 18.1% rely on weekly service. The larger percentage, 41.9%, does not have any collection service provided by municipal services and 21.9% do not know the collection days used by municipal service (Figure 27).

Figure 28 reveals how satisfied the respondents are with municipal service (question 22). Only 0.3% out of 298 respondents to the survey feels that the city council is doing an excellent job, however 11.1% and 12.4% think that it is doing respectively good and mediocre job. 19.1% and 18.8% think respectively, that municipal authorities are doing a bad and very bad job, and 7.4% are indifferent about the job done by the city authorities. Comparing actual municipal performance with the year 2000 (question 23), 11.7% think that municipal solid waste collection is getting worse and for 16.4% it has remained the same. 32.2% think that municipal solid waste collection is getting better and 15.4% do not know if it has improved or not (Figure 29).

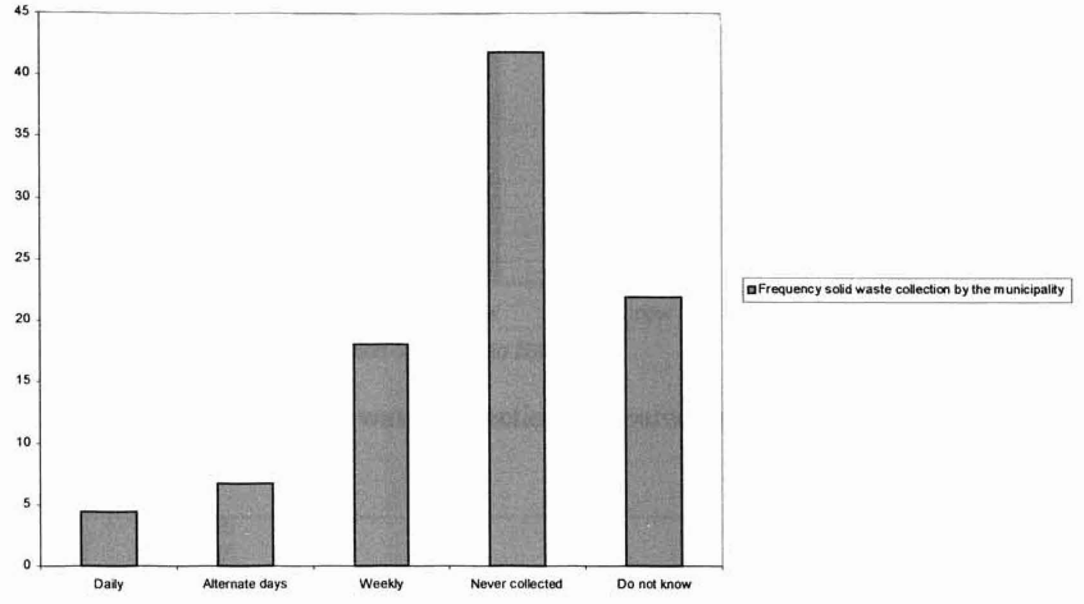

Figure 27. Frequency collection by the municipality (question 21)

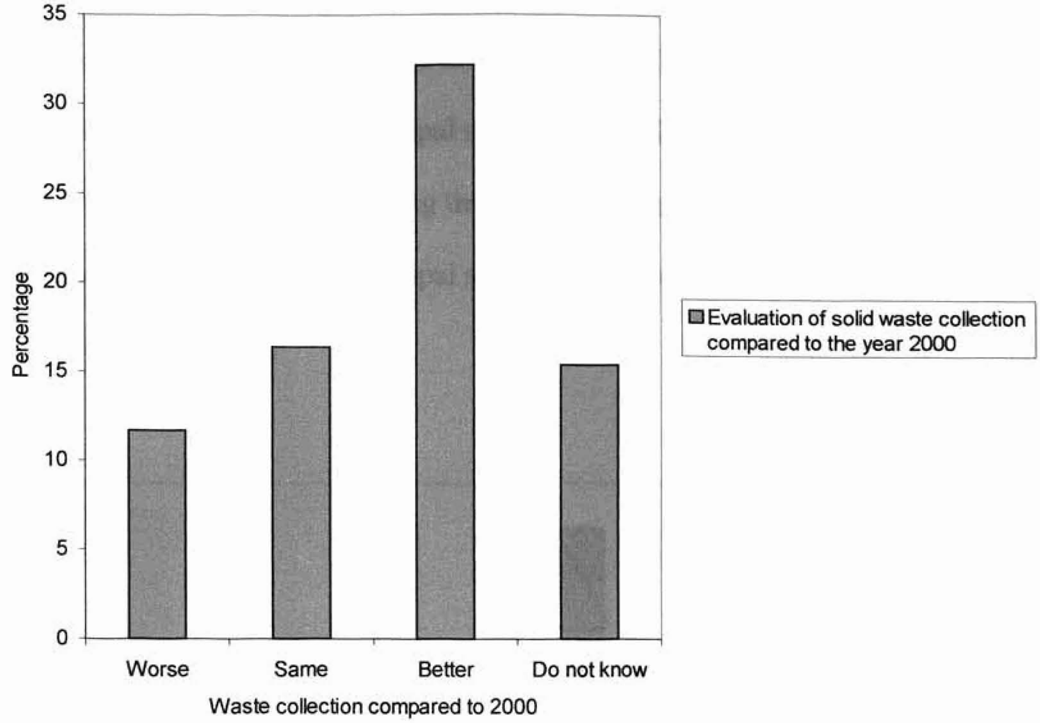

Figure 28. Evaluation of solid waste collection compared to the year 2000 (question 23)

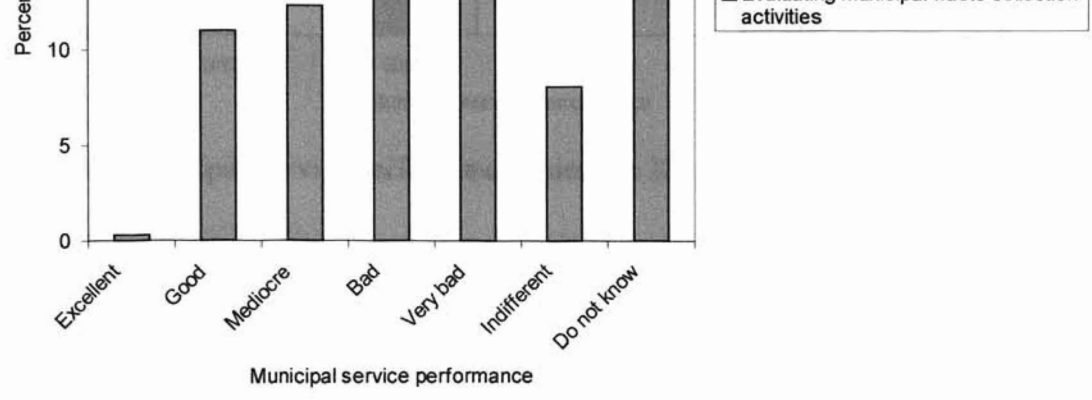

Figure 29. Evaluating solid waste collection by the municipal services (question 22)

Results by neighborhoods show that all three believe performance of the city authorities is declining by comparison to the year 2000 (Figure 28). However some interviewed still consider that municipal services are making an effort to improve solid waste collection, therefore considering that the job being done is good. The majority in the neighborhoods thinks that municipal solid waste collection is "bad" or "very bad" as depicted in Figure 29.

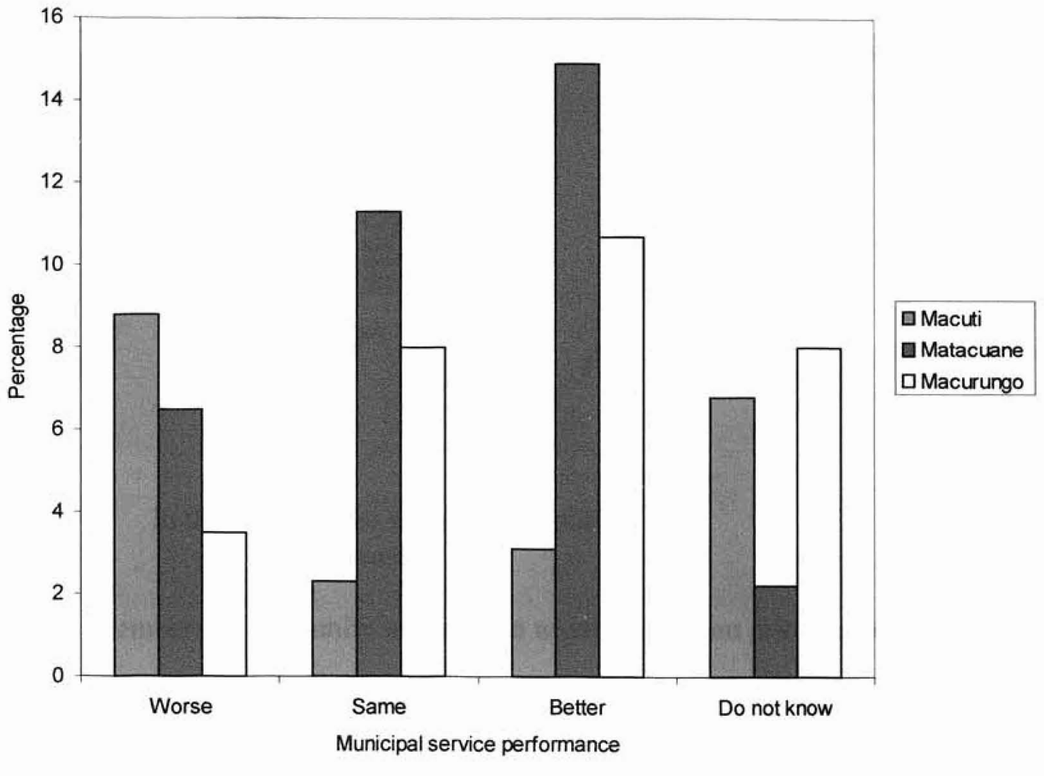

Figure 30. Municipal Service performance (question 22)

Assessing municipal waste collection performance, Figure 30 compares the three neighborhoods and as it shows, large percentage agree that it has improved its waste collection activities. Figure 31 also shows who, in the family, is going to separate household waste to turn the programs referred above more successful (question 19). The task is going to be performed by wife/husband (31.2%). Other members of the family more likely to participate in waste separation are children, representing 19.1%. Other adults in the family and housekeeper to be involved in waste separation represent respectively 18.5% and 14.4%.

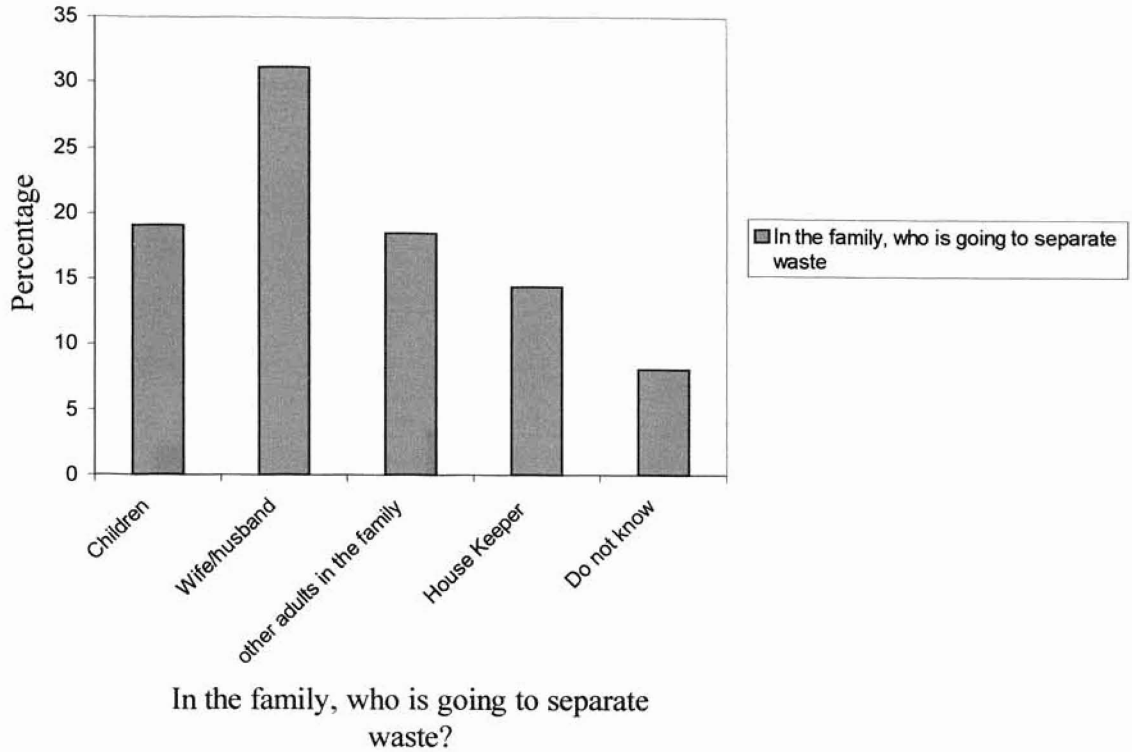

Figure 31. Members of the family involved in waste separation prior deposition at the collection point (question 19)

In all three neighborhoods, a high percentage of respondents is willing to walk further to discard household waste. Most residents would accept to walk distances greater than 10 meters, but less than 100 meters. Figure 32 compares the three neighborhoods in term of distances the surveyed are willing to walk to discard household waste. For distances less than 10 meters, all the three neighborhoods share almost the same percentage, respectively 6.8%, 7.1% and 6.4% for Macuti, Matacuane and

Macurungo. Notorious differences on willingness to walk distances to discard household waste are from 10 t0 49 meters (5.7%, 18.5% and 12.5% for Macuti, Matacuane and Macurung respectively). Macuti is the only neighborhood with the lowest percentage of children to walk those distances (Figure 33). This fact may be explained because of high percentage of housekeepers in the neighborhood.

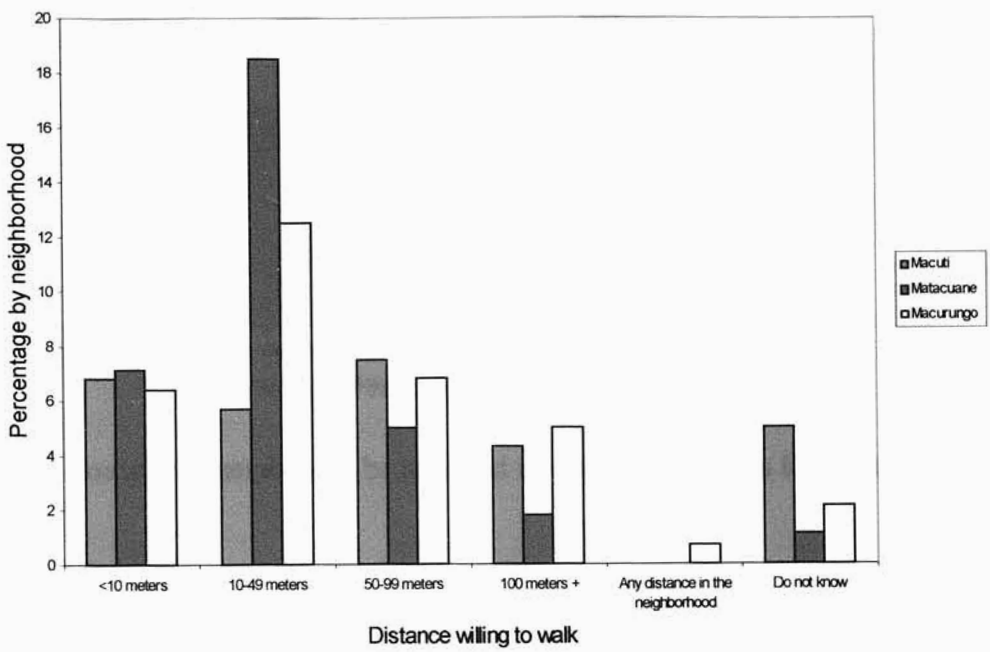

Figure 32. Distance willing to travel to discard household waste

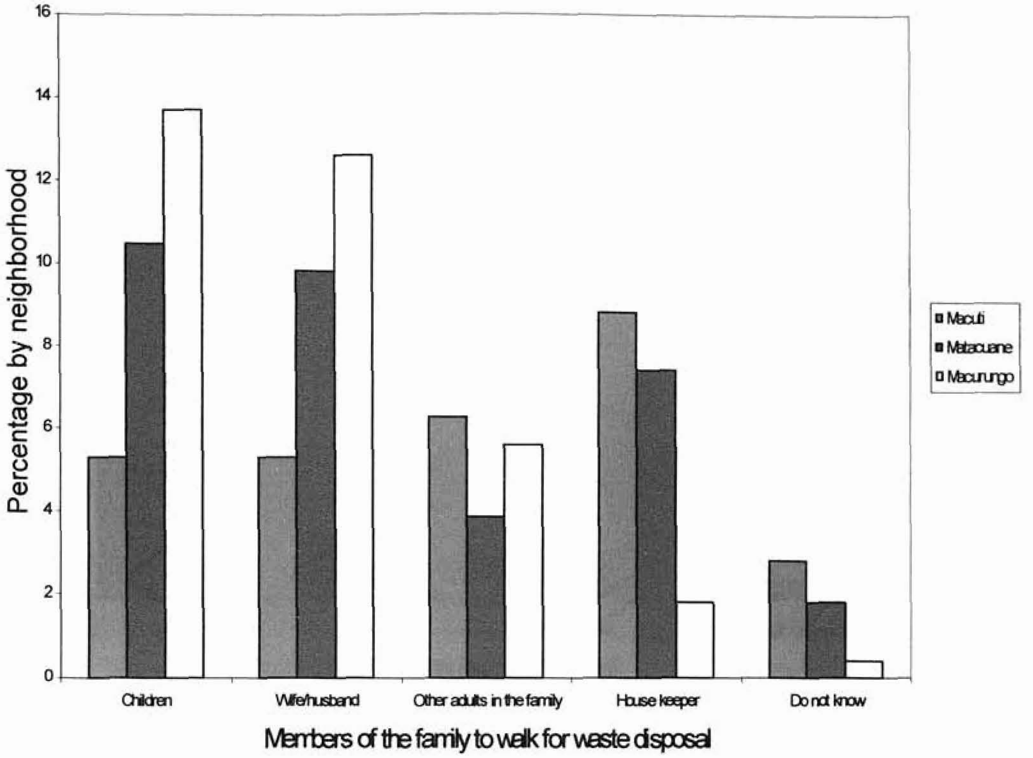

Figure 33. Household members to be involved in walking distances for waste disposal

Figures 34 and 35 show respectively the willingness to reuse and separate household waste. Respondents of the survey in all three neighborhoods think that the wife or husband and/or other adults of the household will mostly perform household waste separation (Figure 36). Even though I did not look for the explanation of involvement of those family members, adults are more likely to be careful on separating items that can be used for composting.

Higher percentages on willingness to pay more to improve municipal performance in solid waste collection were obtained in Matacuane and Macurungo (, 26.9% and 21.4%, respectively). In fact, the surveyed think that municipal service will perform well its task if provided with sufficient financial support (Figure 37).

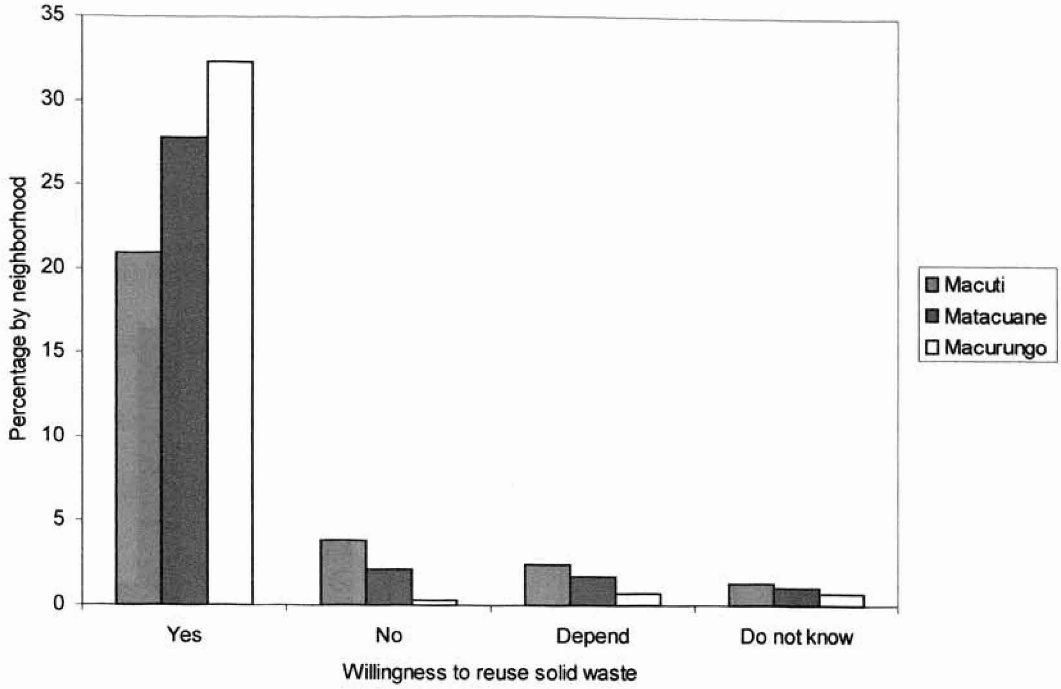

Figure 34. Willingness to reuse solid waste

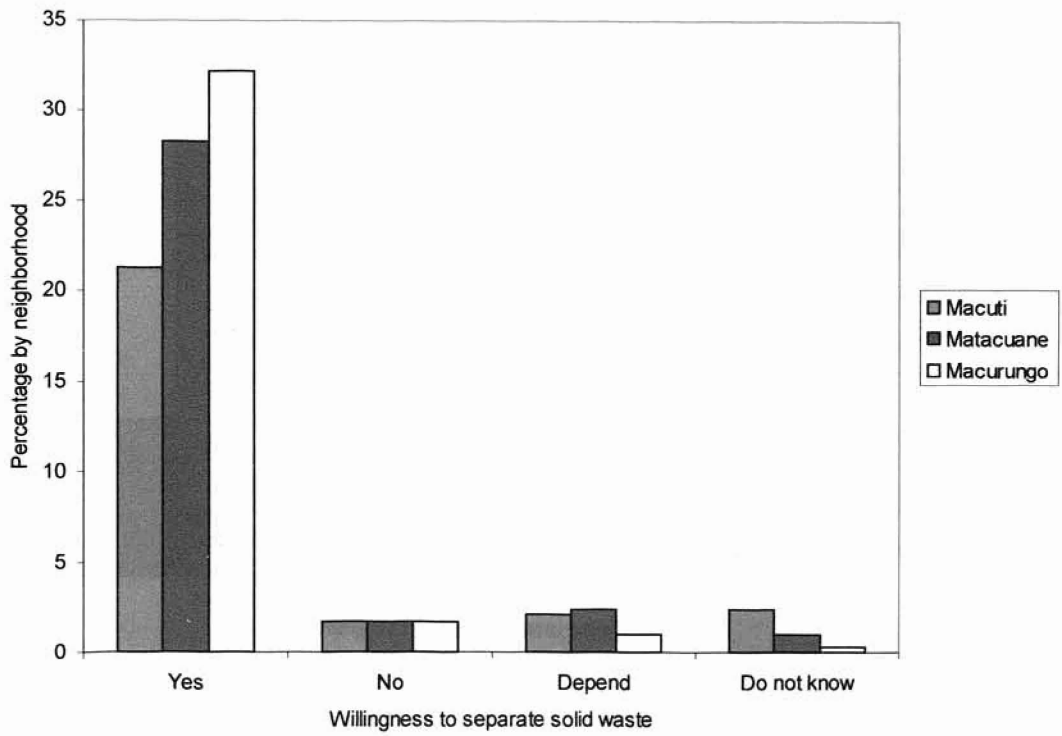

Figure 35. Willingness to separate solid waste

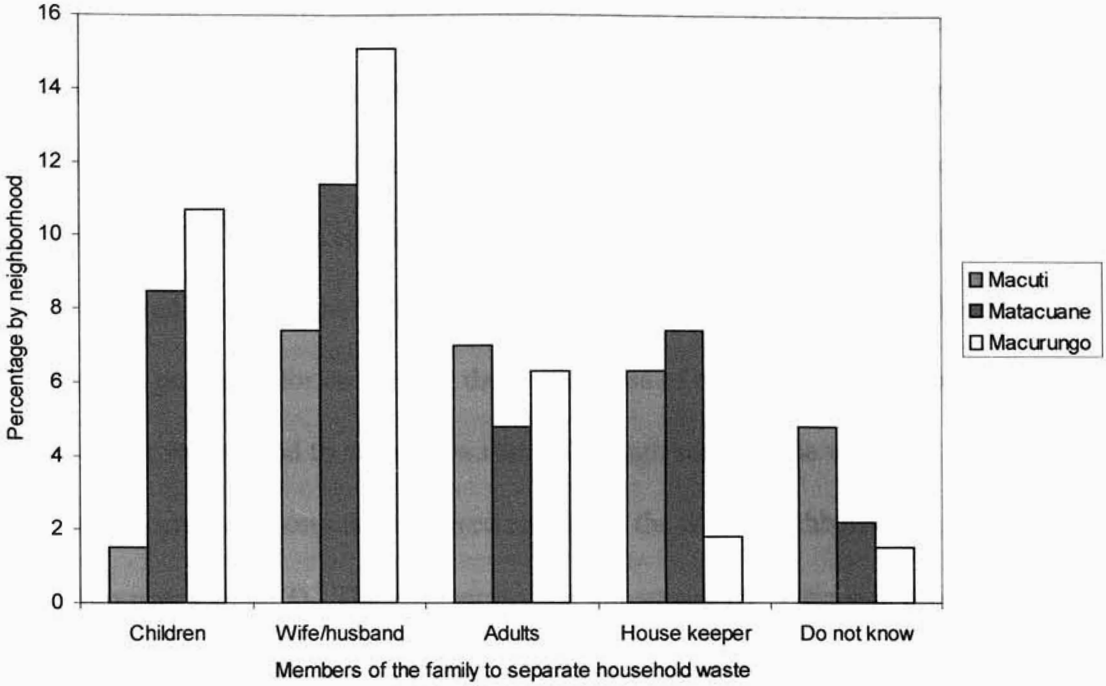

Figure 36. Members of the family to be responsible for waste separation

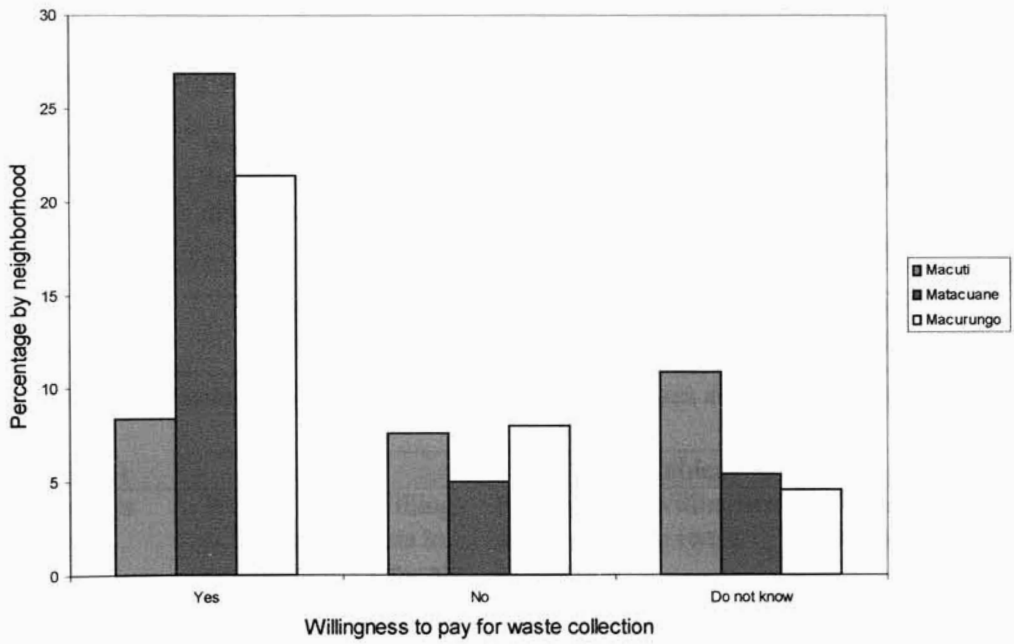

Figure 37. Willingness to pay for solid waste collection to improve the service

3.1.3 <u>Differences between neighborhoods</u>

The survey conducted in three neighborhoods in the City of Beira reveals that problems exist regarding municipal waste collection in the city. At the same time, it reveals that residents are willing to contribute to solve these problems. Some of the improvements to be considered are the willingness to walk distances longer than the currently walked to discard household waste if collection points were established; the willingness to pay taxes for collection; the willingness of residents to reuse some items from the waste stream and to separate waste. Although some of the variables described have high acceptance among the surveyed residents, the three neighborhoods present some differences (Table 3). The non-parametric chi-square (χ^2) test was used to discern whether differences between the neighborhoods are statistically significant.

Table 3
Chi-square test comparing the three neighborhoods (Macuti, Matacuane and Macurungo)

	Questions				
Statistics	Walking distance to discard waste	Family members to walk the distances	Collection days by the municipality	Evaluating municipal service compared to 2000	Willingness to walk farther for waste discard
χ^2	36.80*	32.57*	80.43*	42.01*	13.99*
P-Value	<0.0001	<0.0001	<0.0001	<0.0001	0.0073

Note: asterisk indicates significance at 1% level. All χ^2 values are significant at 10% level

(Cont.)	Variables					
Statistics test	Waste collection comparison to 2000	Willing ness to separate	Family members to separate waste	Willingness to reuse	Willingness to pay	Type of houses
χ^2	30.16*	10.54	34.97*	11.42	30.76*	31.37*
P-Value	<0.0001	0.1035	<0.0001	0.0763	<0.0001	<0.0001

Note: asterisk indicates significance at 1% level. All χ^2 values are significant at 10% level

Differences between the three neighborhoods were not significant (if $P>0.05$) in terms of:

1) Willingness to separate household waste prior disposal (0.1035);

2) Willingness to reuse household waste (0,0763).

Differences between the three neighborhoods were significant (if $P\leq0.05$) in terms of:

1) Walking distances to discard household waste (<0.0001);

2) Willingness to walk farther distances to discard household waste (0.0073);

3) Family members involved in walking the distances to discard waste (<0.0001);

4) Collection days by municipal services (<0.0001);

5) Waste collection compared to the year 2000 (<0.0001);

6) Evaluating municipal service performance in household waste collection, compared to the year 2000 (<0.0001);

7) Family members to separate household waste prior disposal (<0.0001);

8) Willingness to pay for household waste collection to improve collection activities (<0.0001), and;

9) Type of houses in the three neighborhoods (<0.0001).

Matacuane benefits from household waste collection service, but many areas of the neighborhood are not served, which explains those who were interviewed do not believe that their involvement will improve waste management in the city. Also, economic status of the residents does not encourage many residents to dedicate income to pay to improve municipal waste collection activities. The differences in house construction in the three neighborhoods is explained because of mix in housing construction in Macuti and Matacuane (from apartments to houses and poor constructions), and in Macurungo the predominant housing construction type are the single residential houses, with some areas composed of poor housing construction.

CHAPTER IV

SITING A NEW LANDFILL: METHODS AND RESULTS

4.1 Land availability for landfill siting in the city of Beira

This section presents methods adopted to determine land availability for future municipal landfill siting in the City of Beira. Digital and hardcopy data used for this analysis were obtained from DINAGECA (National Directorate of Geography and Cadastre), and Palmer associates, PROJECTA, and Scott Wilson. Hardcopy maps were digitized and georeferenced into geographic coordinates based on digital world data from ESRI (ESRI, 2000).

By applying Geographic Information System analysis, I intend to identify alternative sites that should be considered for a future landfill siting in the city. Presenting exact location for a safe landfill disposal site requires many operations and considerations, including of land availability, physical and environmental aspects, population data, historical and political aspects. This tool is currently in use in municipal waste management either to perform pre-feasibility land selection for future considerations or in final land selection for landfill siting area, however its use should be considered carefully, by designing methods to be used during analytical process. Figure 39 shows methods used through all process of site identification in the city of Beira.

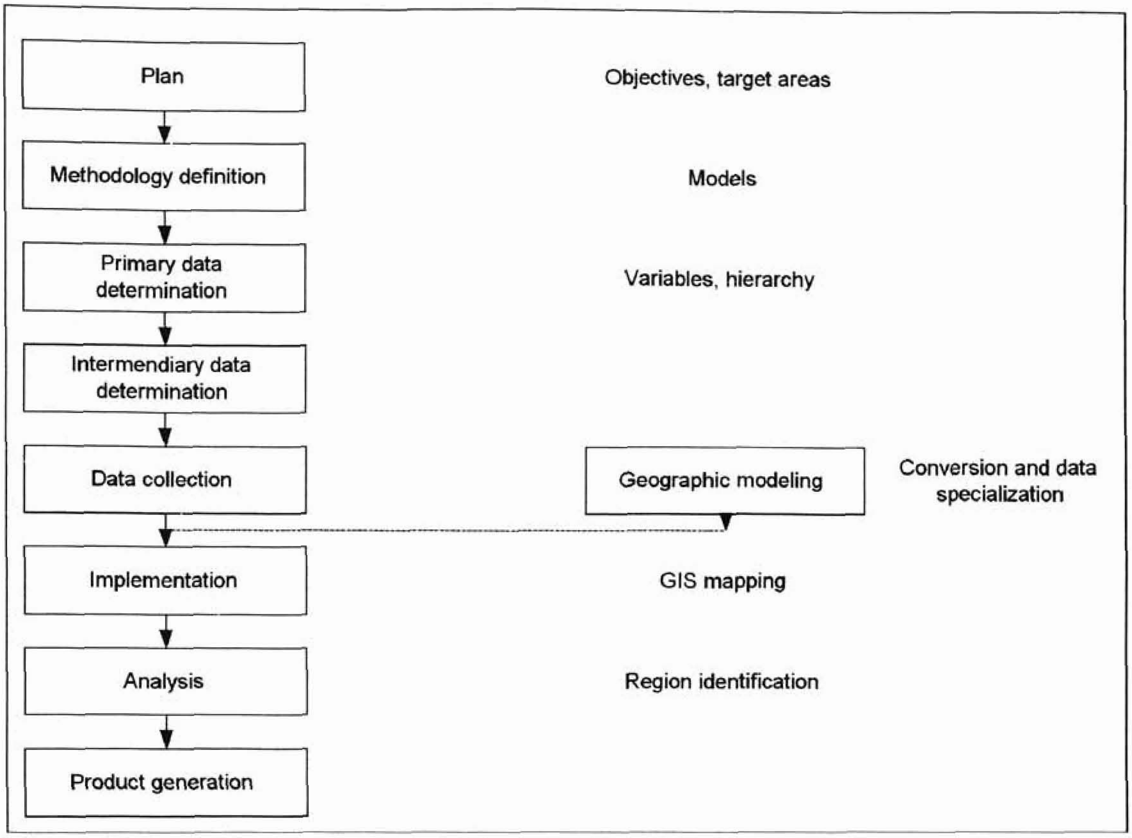

Figure 38: Basic phases of the methods used to perform GIS analysis
Source: adapted from Pires, F and Medeiros, C. B. (1996)

4.2 Methods

A layer presenting suitable areas for landfill siting in the City of Beira was generated from ArcView ™ and ArcTool box ™ software (ESRI, 2001). ArcTool box ™ was used to re-project digital data obtain from DINAGECA, and convert polylines into coverages in order to build topology (build and clean commands) for posterior use of the data set with digitized thematic maps. Digitized data was obtain from Palmer Associates et al. (1998) and consists of land cover and land use themes, infrastructure (houses, roads, airport) themes, social aspect themes (population distribution, densities). Digitized data was georeferenced using TAS Basic extension (downloaded from Urban Incorporation

System web page) to the world coordinate system. Attribute Tables were input from data obtained at city council and are respectively demographic aspects.

ArcView ™ operations performed for layers generation are:

1. Data geoprocessing wizard operations, which includes:
   a) clip one theme based on another
   b) intersect two themes
   c) union themes
   d) merge themes together and
   e) dissolve based on an attribute
2. Editing tool to assign attribute Table to the themes. Also, attribute Table imported from dBf files (dBase files) were added using join command
3. Create buffers
4. Create new labels
5. Convert shapefile to grid
6. Overlay themes

4.2.1 Landfill selection criteria

According to Rushbrook and Pugh (1999), landfill siting represents one of the most important decisions a municipality has to make in developing and implementing its waste management plan because of cost minimization on waste transportation, site development, operation and environmental protection. To minimize political tensions, the municipality generates a list of selection criteria to be considered according to local climate, political and cultural circumstances. It is important to develop a short list of candidate sites and aided by GIS analysis this operation may be easier and offer better results. These operations will allow exclusion. Table 7 shows the World Bank approach for exclusion criteria applicable worldwide and Table 8 shows exclusion criteria subject to local interpretation.

Table 4
Exclusion criteria applicable worldwide

Aspect	Criteria
Transport	T1. More than 2 km from a suiTable main road T2. More than an economic travel distance from points of waste collection vehicles
Natural conditions	N1. Flood plains or other areas liable to flooding N2. Extreme morphology (steep or over-steep slopes liable to landslips or Avalanches
Land Use	L1. Designated groundwater recharge, sole source aquifer or surface water catchment areas for water supply schemes L2. Incompatible future land use designations on or adjacent to the site, particularly hard (built) development or mineral extraction L3. Within a military exclusion zone
Public acceptability	P1. Within 200 m of existing residential development (this minimum distance may be larger in some places due political, geological or social requirements
Safety	S1. Within 5 Km of an airport runway in the direction of approach and take-off S2. Area of former military activity where buried ordnance may be present S3. Within a microwave transmitter exclusion zone S4. Within a safe buffer distance (say 100 m) from an existing or planned quarry, which will undertake blasting with explosives S5. Areas known to contain collapsing soils (such as loess)

Source: Rushbrook and Pugh, 1999

Table 5
Exclusion criteria subject to local interpretation

Aspect	Criteria
Natural conditions	N3. High or seasonal water Table N4. Karsic or geological faulted areas, or areas containing mine workings, where leachate may migrate rapidly from the site to a poTable aquifer N5. Wetlands (swamps or marshes) or other areas of ecological Significance
Land Use	L1. Designated groundwater recharge, sole source aquifer or surface water catchment areas for water supply schemes L2. Incompatible future land use designations on or adjacent to the site, particularly hard (built) development or mineral extraction L3. Within a military exclusion zone
Public safety	P2. Within an accepTable distance (desirable minimum distance 200 m) from historical, religious or other important cultural site or heritage)

Source: Rushbrook and Pugh, 1999

Many other approaches can be found in the literature. For example, Shyr (1999: http://scs.ucdavis.edu/Services/ClassSupport) has selected few criteria to perform land availability for Yolo County in California. Restrictions include:

1. 300 meter away from major roads and railroads
2. 100 meters away from major streams
3. 300 meters away from urban areas
4. 300 meters away from city boundaries
5. 300 meters away from the existing landfill
6. Soil drainage must be poor and very poor
7. Surface Area must be flat

Section 4.2.2 presents spatial analysis applied for the City of Beira. Results from the analysis will be presented in this section and comprises of layers of major spatial analysis operation performed.

4.2.2 Spatial analysis

The analysis performed in this study was based on Shyr, 1999 buffering criteria. Figure 39 describes spatial analysis undertaken to produce the results presented in Figure 43 (landfill suitability). Features included in digitized thematic map of land use and land cover (Figure 40), include vegetation (forest, grassland, mangrove, palm, and shrub), wetlands, mud, infrastructures, farms, agricultural areas (current and abandoned) and actual landfill site. Forest, mangrove, wetlands are some of the features considered in the buffering criteria (Figure 41). This exclusion criteria was created using buffer command from theme, create buffer, based on criteria discussed in section 4.2.1. A buffer zone layer was created using merge command from geoprocessing wizard and then dissolved (Figure 42). Potential areas for landfill site were determine from overlay of buffer zones and land use land cover themes (Figure 43). Figure 44 shows layer displaying potential sites for landfill in the City of Beira. The final layer results from isolating potential areas from overlaid layer (buffer zones and land use land cover) by applying the conditions on Figure 39. The operation undertaken was to the conversion of landfill suitability shapefile to a grid and query based on the three-landfill suitability criteria (least suitable, unsuitable and suitable areas). Finally, the theme selected is overlaid with the roads theme and display the most suitable areas for landfill sites in the City of Beira.

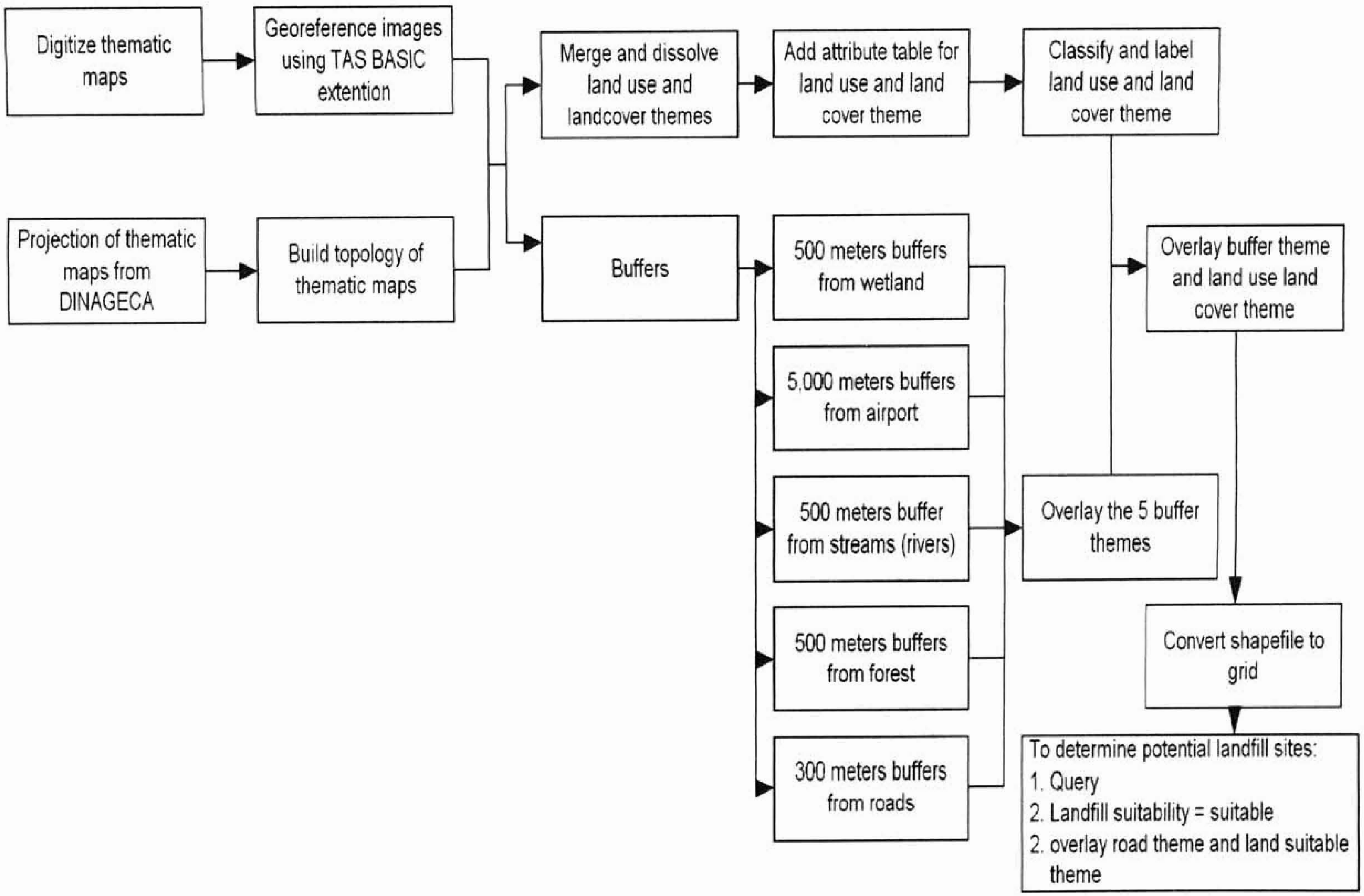

Figure 39: Operations performed to produce the final layer showing potential areas for future landfill siting

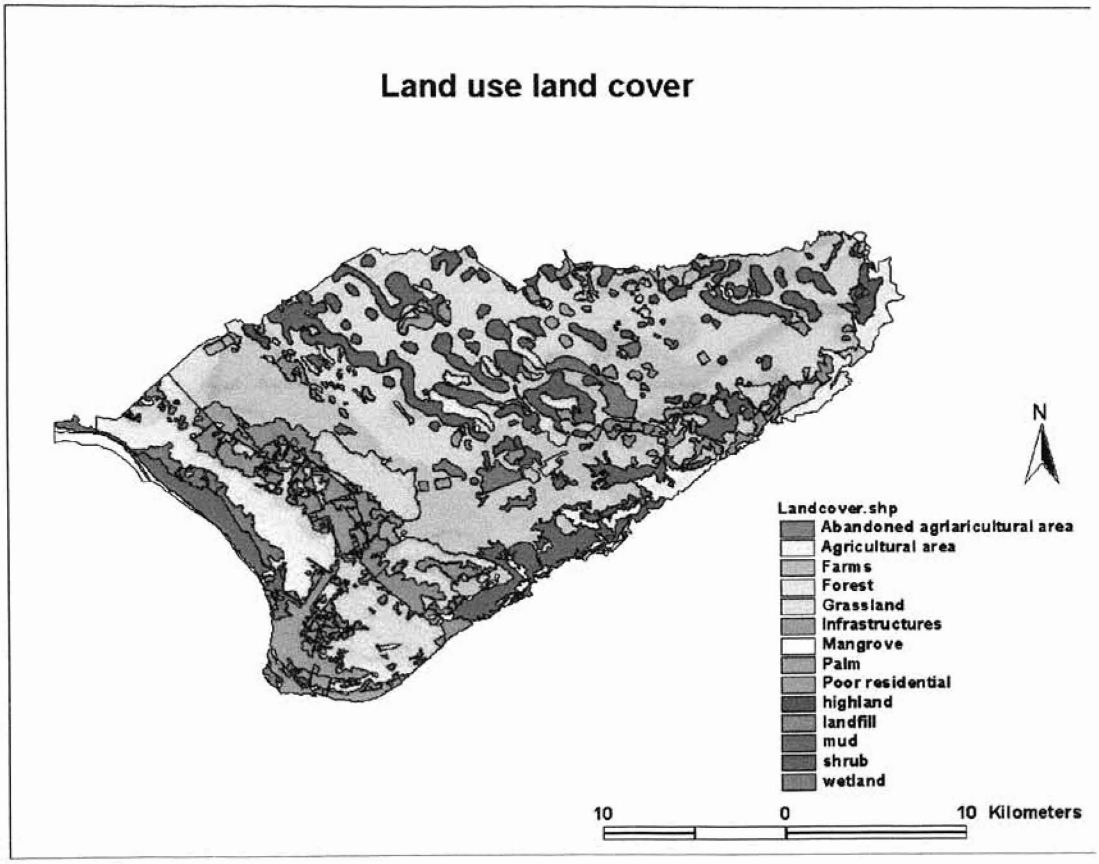

Figure 40: Land use and land cover

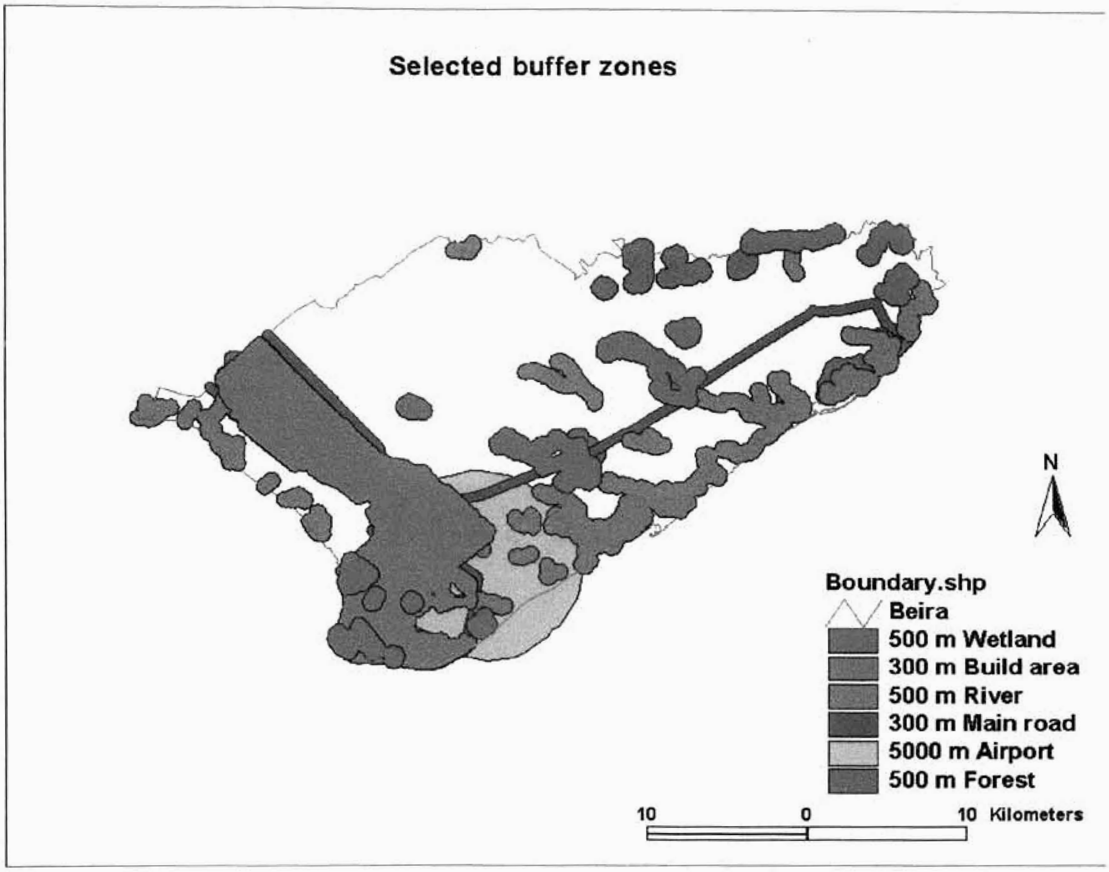

Figure 41: Selected buffer zones

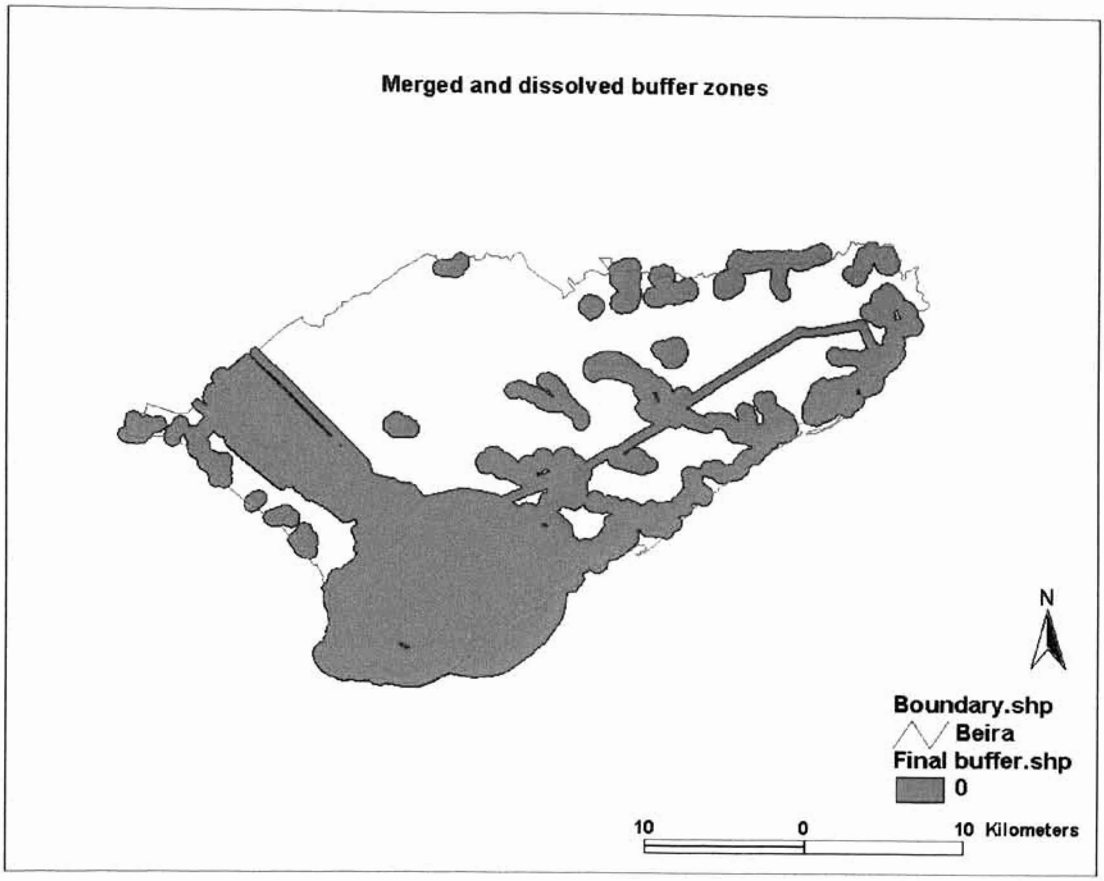

Figure 42: Merged and dissolved buffer zones

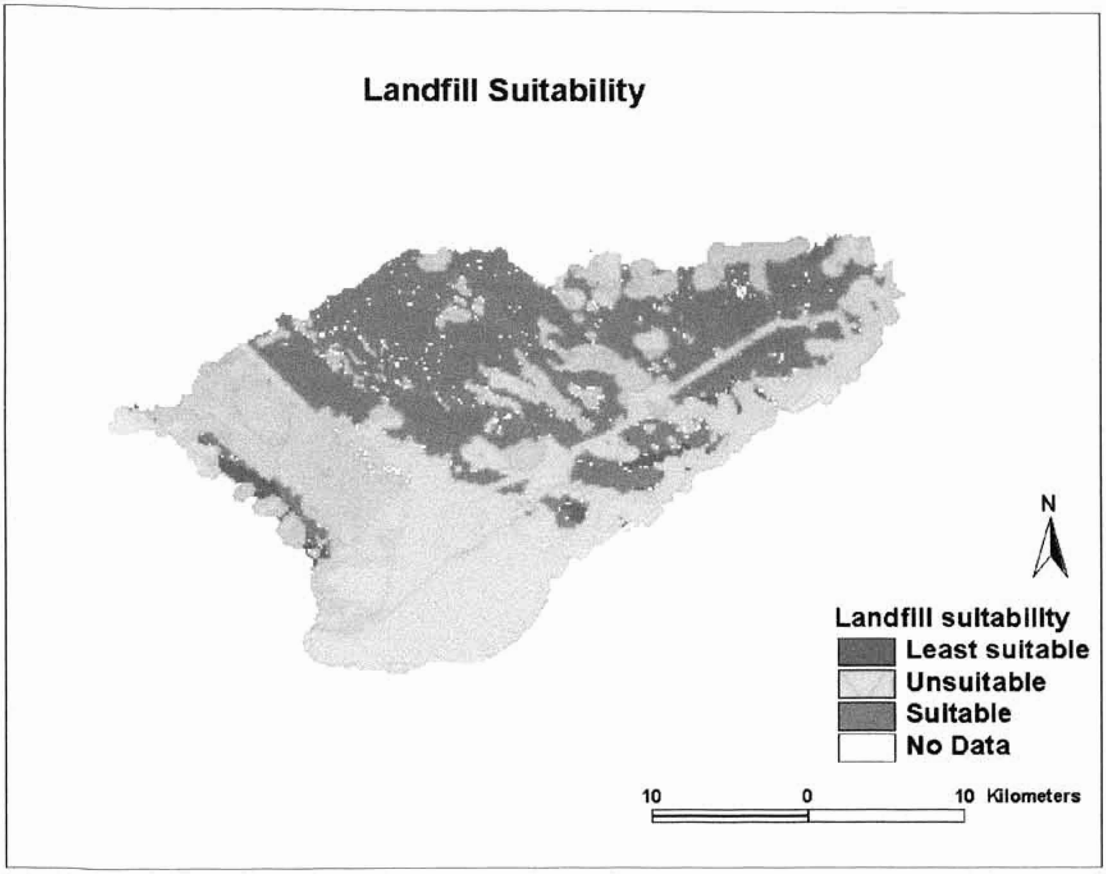

Figure 43: Landfill suitability

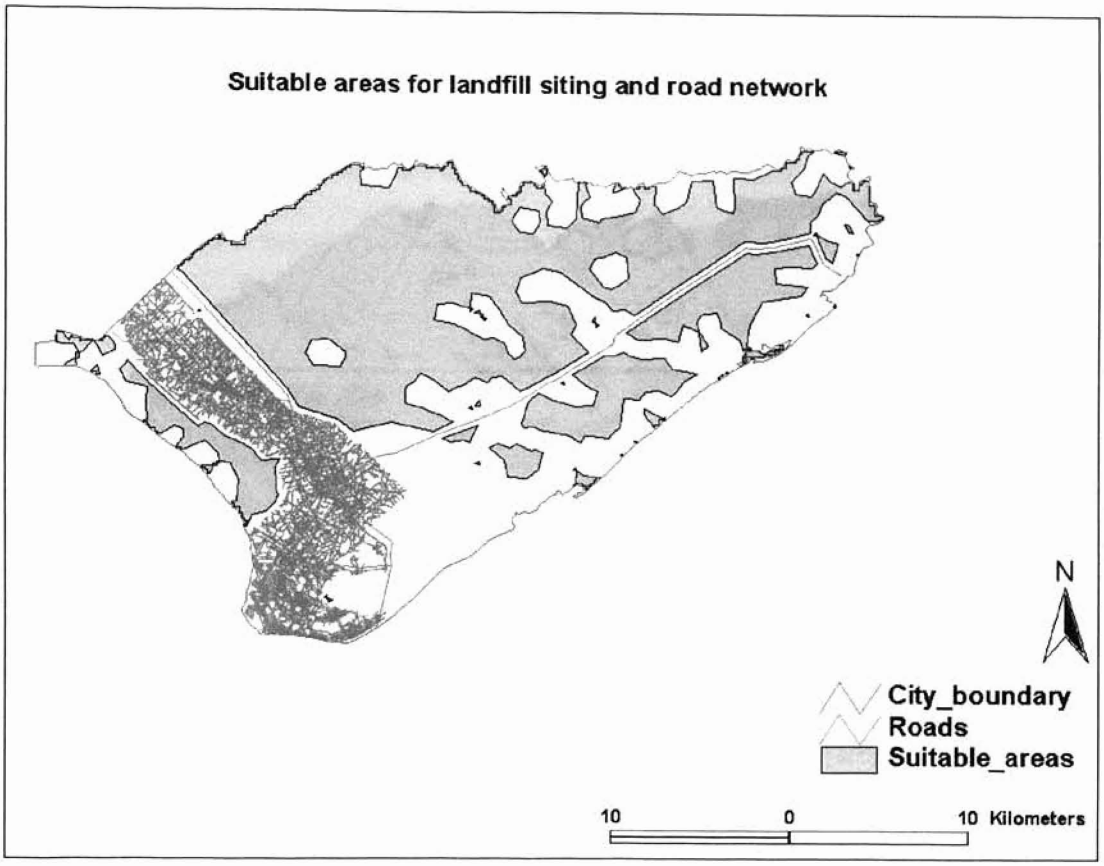

Figure 44: Suitable areas for landfill and road network

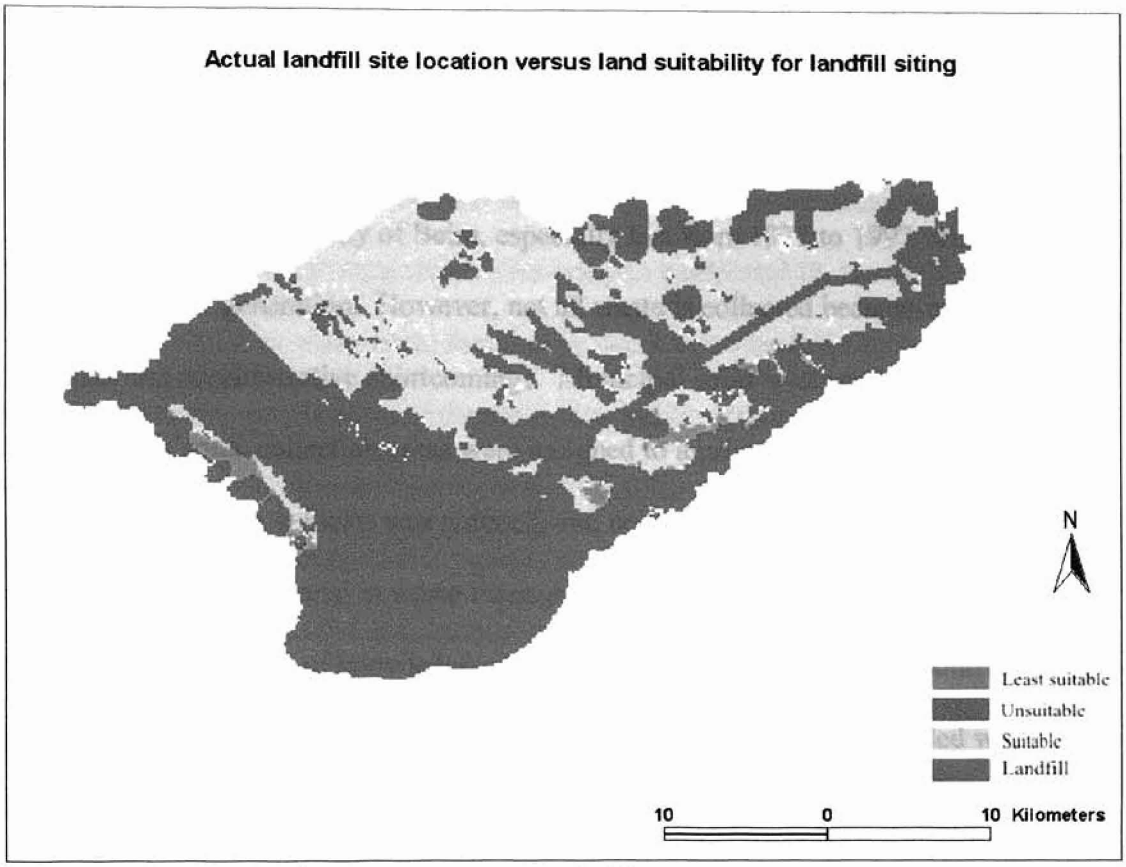

Figure 45: Actual landfill location in an unsuitable area

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Municipal solid waste in the City of Beira was characterized using data collected at the municipal administration and by field surveys. Also, variables that affect site suitability for landfill location were analyzed with GIS to identify potential new sites. Population growth in the city of Beira, especially fast from 1975 to 1997, stimulates household waste generation. However, not all waste is collected because of financial, technical and administrative shortcomings. Municipal solid waste collection dropped in 2000 because some collection areas were assigned to a private waste collector, the number of collection vehicles was reduced, and because of inadequate number of qualified technical personal in waste management, waste collection, and vehicle maintenance. The lack of knowledge on how to handle household waste contributes to waste proliferation in the neighborhoods. In many residential areas provided with containers, residents continue to deposit household waste on the ground surface, rendering it difficult for municipal authorities to collect the waste.

Waste is not collected in some areas in the city due to poor access by collection vehicles that need additional space for maneuvers. According to the survey results, residents in some of these neighborhoods, especially in poor ones, have adopted other ways to handle household waste. Burial and on-site incineration are some of the alternative ways of dealing with household waste. Residents also are willing to pay to improve household waste collection. A large number of the respondents of the survey in three neighborhoods is willing to separation and reuse household waste. In all surveyed neighborhoods family groups members are involved in household waste discard at the collection.

The existing landfill is an open dump, located in an unsuitable area and without fencing to prevent people from scavenging. Municipal waste does not receive any other treatment prior to disposal. Because of its proximity to a residential area, waste poses a health threat to the adjacent population.

Landfill siting depends on data availability, political will, social acceptability, environmental and engineering issues. GIS analysis performed for the city of Beira, illustrate that there are many areas found to be suitable for landfill site location. Spatial analysis included classification of thematic data, buffer zone creation and overlay. The actual landfill is located in unsuitable area. Exploring capabilities of GIS analysis, it is possible that the city can find suitable areas for landfill location in order to protect citizen's health in particular and the environment in general.

Municipal authorities and the private contractor collection service can use findings from this study to improve household waste collection in the three neighborhoods in Beira. The survey also provides information that can be used by municipal authorities to establish environmental educational programs on household waste.

The city needs to adopt new approaches for municipal solid waste management. The municipality does not have any material recovery program. The city authorities should encourage recycling, reuse and composting of household waste, especially in areas with difficult accessibility by collection vehicles.

Also, municipal authorities need to evaluate options for landfill re-location. In some extent, there is a need of upgrading the waste disposal facility to the second stage (controlled dumping) in order to prepare for the other stages of landfill development in the city.

It is important that municipal authorities start to consider adopting the use of safer landfill disposal methods. Finally, municipal authorities should find a way to conduct studies on environmental diseases (malaria, diarrhea, cholera and dysentery) in order to assess its relationship with solid waste mishandling.

REFERENCES

Allen, A.R., Dillon, A. and O'Brien, M., 1997. Approaches to landfill site selection in Ireland. Engineering Geology and the Environment. Proceedings Symposium. Athenas, Vol.2. pp.1569-1574

Atkinson, S.F.; Schoomaster, F.A.; Lyons D.I.; Coffey J.M., 1995. A geographic information systems approach to sanitary landfill siting procedures: a case study. Environmental professional, Vol. 17, N_o 1, pp.20-26

Baban, S.M.J.and Flannagan, J., 1998. Developing and implementing GIS-assisted constraints criteria for planning landfill sites in the UK. Planning Practice and Research, Vol. 13, N_o 2, pp. 139-151.

Bailey, T. C., 1994. A Review of Statistical Spatial Analysis in GIS. Fotheringham, S. and Rogerson, P. (Ed.). Spatial Analysis and GIS. Bristol, PA; pp. 13-44

Barlaz, M.A., Ranjithan, R., Weitz, K. A., and Nishtala, S. R., 1995. Life-Cycle study of municipal solid waste management: system description. EPA cooperative agreement 832052.

Basagaoglu, H., Celenk, E., Marino, M.A. and Usul, N., 1997. Selection of waste disposal sites using GIS. Journal of American Water Resources Association, Vol. 33, N_o 2, pp. 455-464.

Brainard, J., Lovett, A., Parfitt, J., 1996. Assessing hazardous wastes transport risks using GIS. International Journal of Geographical Information Systems. Vol.10, N_o 4, pp.831-849.

Caetano, J., 2000. Local governance and solid waste management in Beira municipality – Mozambique. Report in partial fulfillment of the requirement of Master in Management. University of the Witwatersrand. Faculty of Management. RSA.

Capbell, H. and Masser, I., 1992. GIS in Local Government: Some findings from Great Britain. International Journal of Geographical Information Science, 1992, vol. 6, N_o 6, pp. 529-546.

Coffey, M., 1999. Cost-effective systems for solid waste management: Journal Waterlines, V. 17 Nr.3, p.23-25.

Chrisman, N.R., 1997. Exploring Geographic Information Systems. 2nd Ed. New York : J. Wiley & Sons

De Lemos, M. J. C., 1989. Aruângua, Chiveve ou Bângoè? Breve considerações sobre a toponímia da Cidade da Beira. Coelho, J. P. B. and de Lemos, M. J. C. (Ed.). Arquivo: Boletim do Arquivo Historico de Moçambique - Cidade da Beira. Instituto Nacional do Livro e do Disco, Maputo, pp. 5-20.

Dennison, R. A., Ruston, J., Tryens, J. and Diedrich, R., 1994. Environmental perspectives. Kreith, F (Ed.), Handbook of solid waste management. McGraw-Hill, Inc. pp.7.1-7.27.

Direcção de Saude da Cidade da Beira, 2001. Relatorio de Actividades Realizadas no ano 2000, Beira

Dos Muchangos, A., 1989. Aspectos Geográficos da Cidade da Beira. Coelho, J. P. B. and de Lemos, M. J. C (Ed.). Arquivo: Boletim do Arquivo Historico de Moçambique - Cidade da Beira. Instituto Nacional do Livro e do Disco, Maputo, pp. 239-296.

ESRI, 2001. ArcGIS. Environmental Systems Research Institute. Redlands, California

Franklin Associates, Ltd, 1998. Characterization of Municipal Solid Waste in The United States: 1997 Update. Prepared for U.S. Environmental Protection Agency and Industrial Solid Waste Division Office of Solid Waste. Report No. EPA530-R-98-007

Gabinete de Planificação, 2001. Relatorio annual de 2000. Direcção dos Serviços Urbanos, Conselho Municipal da Beira

Institute for Solid Wastes of the American Public Works and U.S. Environmental Protection Agency, 1975. Solid Waste Collection Practice. 4th edition. Slavik Printing Company. Chicago, Illinois.

Kaplan, I., 1985. The society and its environment. In: Mozambique: a country study. Foreign Area Studies. The American University. pp.71-128

Kundell, J. E. and Ruffer, D. L., 1994. Introduction. Kreith, F (Ed.), Handbook of solid waste management. McGraw-Hill, Inc. pp. 6.1-6.15.

Kreith, F., 1994. Introduction. Kreith, F (Ed.), Handbook of solid waste management. McGraw-Hill, Inc. pp. 1.1-1.24.

Mato, R.R.A.M, 1999. Environmental implications involving the establishment of sanitary landfills in five municipalities in Tanzania: the case of Tanga municipality. ELSEVIER: Resources, Conservation and Recycling 25: 4, pp.1-16

McFarland, J. M., Glassey, C. R., McGauhey, P. H., Brink, D. L., Klein, S. A. and Golueke, C. G., 1972. Comprehensive studies of solid waste management, final report. Sanitary Engineering Research Laboratory: College of Engineering and School of Publich Health: University of California, Berkeley, 72-3.

Muhate, I., 1989. Alguns aspectos do retrato historico e perspectivo do Porto da Beira. Coelho, J. P. B. and de Lemos, M. J. C (Ed.). Arquivo: Boletim do Arquivo Historico de Moçambique - Cidade da Beira. Instituto Nacional do Livro e do Disco, Maputo, pp. 347-368.

Neal, H. A. and Schubel, J. R., 1987. Solid Waste Management and the Environment: The Mounting Garbage and Trash Crisis. Prince-Hall, New Jersey

Palmer Associates Projecta Scott Wilson Joint Venture, 1998. Plano de Estrutura da Beira-Dondo: Politicas e Propostas. Beira

Palmer Associates Projecta Scott Wilson Joint Venture, 1999. Plano de Estrutura da Beira-Dondo: Politicas e Propostas. Beira

Pires, F., and Medeiros, C. B., 1996. Um Ambiente Computacional de Modelagem de Aplicações Geográficas. Caderno de Informações Georreferenciadas. Volume 1:1 Artigo 4

Roche, J. T. de and Breen K. J., 1989. Hydrology and water quality near a solid- and Hazardous- waste landfill, Northwood, Ohio. U.S. Geological Survey: Water-Resources Investigations Report 88-4093

Rushbrook, P. and Pugh, M., 1999. Solid waste landfills in Middle-and-lower income countries: a technical guide to planning, design, and operation. World Bank technical paper No.426. WA, DC

Sata, K.M., 1970. Sanitary landfill leachates. Thesis submitted to the Facult of the Graduate College of the Oklahoma State University in partial fulfillment of the requirements for the degree of Master of Science.

Schneider, W. J., 1970. Hydrologic Implications of Solid-Waste Disposal. Water in the Urban Environment. Geological Survey Circular 601-F, Washington

Schwartz, G. G., Skinner, H. G. and Duncan, R., 1998. Solid waste pancreatic cancer: an ecologic study in Florida, USA. International Journal of Epidemiology. Great Britain; 27:781-787.

Sheldon, K., 1989. Mulheres trabalhadoras na Beira. Coelho, J. P. B. and de Lemos, M. J. C (Ed.). Arquivo: Boletim do Arquivo Historico de Moçambique - Cidade da Beira. Instituto Nacional do Livro e do Disco, Maputo, pp. 201-209.

Starrett, S., Itani, O, Davalos, H., Najjar, Y., and Reddi, L., 2001. Locating waste management system sites using GIS. Electronic Journal of Geotechnical Engineering.

Tchobanoglous, G, Theisen, H. and Vigil, S., 1993. Integrated solid waste management: Engineering principles and management issues. Irwin McGraw-Hill

Weimer, D. L. and Vining, A. R., 1998. Policy Analysis – concepts and practice. 3rd Edition. Prince Hall, NJ, pp.486.

Williams, M. C., 1994. Integrated municipal solid waste management. Kreith, F. Handbook of solid waste management. McGraw-Hill, Inc. pp. 2.1-2.16

Wilson 1981 Wilson, D. C., 1981. Waste Management: Planning, Evaluation, Technologies. Oxford University - Harwell Laboratory. Clarendon Press Oxford, NY

Appendix A

Table A.1
Components of MSW to be considered in the system

Residential waste	Multifamily dwelling waste	Commercial waste
Yard waste	**Yard waste**	1. office paper
1. grass [a]	1. grass [a]	2. old corrugated containers
2. leaves [a]	2. leaves [a]	3. phone books
3. branches [a]	3. branches [a]	4. third class mail
4. Food waste	4. Food waste	5. aluminum cans
Ferrous metal	**Ferrous metal**	6. clear glass
5. cans	5. cans	7. brown glass
6. other ferrous metal	6. other ferrous metal	8. green glass
7. non-recyclables	7. non-recyclables	9. PET beverage bottles
Aluminum	**Aluminum**	10. newspaper
8. cans	8. cans	11-12. other recyclables
9-10. other – aluminum	9-10. other – aluminum	13-15. other non-recyclables
11. non-recyclables	9. non-recyclables	
Glass	**Glass**	
12. clear	10. clear	
13. brown	11. brown	
14. green	12. green	
15. non-recyclable	13. non-recyclable	
Plastic	**Plastic**	
16. translucent – HDPE	14. translucent – HDPE	
17. pigment – HDPE bottles	15. pigment – HDPE bottles	
18. PET beverage bottles	16. PET beverage bottles	
19-24. other plastic	19-24. other plastic	
25. non-recyclable plastic	25. non-recyclable plastic	
Paper	**Paper**	
26. newspaper	26. newspaper	
27. office paper	27. office paper	
28. corrugated containers	28. corrugated containers	
29. phone books	29. phone books	
30. books	30. books	
31. magazines	31. magazines	
32. third class mail	32. third class mail	
33-37. other paper	33-37. other paper	
38. paper – non-recyclable	38. paper – non-recyclable	
39. miscellaneous	39. miscellaneous	

[a] Yearly average compositions are required.
Source: Barlaz et al., 1995

Appendix B

Table B.1

Preliminary census data of the City of Beira, by residential areas, during 1997

	Population of the City of Beira after 1997 census						
Neighborhood	Area	Hectares	Houses	Families	Men	Women	Total
Macuti	2,568,485,184	256,849	2635	2544	6364	5880	12244
Chipangara	1,889,703,217	188,970	5733	5596	12758	12180	24930
Ponta-Gea	3,034,963,509	303,496	4153	4739	13365	11674	25039
Matacuane	2,112,729,300	211,273	5111	6257	15547	13603	29150
Macurungo	2,412,229,195	241,223	2499	2719	7494	7149	14643
Muavi	23,241,218,981	2,324,122	1513	1554	3334	3254	6588
Vila Massane	3,582,476,102	358,248	3967	4884	10922	11335	22257
Inhamizua	56,091,585,339	5,609,159	3320	3183	7300	7572	14872
Matadouro	32,153,133,325	3,215,313	2361	2391	5779	5544	11323
Ndunda	7,808,893,420	780,889	1439	1614	3861	3561	7422
Mungassa	6,107,643,427	610,764	743	855	1973	1928	3901
Chingussura	2,275,527,779	227,553	3680	4597	11094	11029	22123
Nhangau	241,705,513,704	24,170,551	914	920	1625	1510	3135
Nhangoma	92,227,484,935	9,222,748	329	333	630	519	1149
Tchondja	70,239,772,355	7,023,977	795	799	1466	1387	2853
Mananga	2,273,354,951	227,335	3237	4323	9589	9776	19365
Esturro	1,565,967,092	156,597	4170	4624	12074	10822	22896
Pioneiros	2,763,069,654	236,307	1053	1364	3726	3507	7233
Chota	14,413,712,069	1,441,371	887	921	2231	2193	4424
Maraza	3,010,578,362	301,058	4857	5058	18620	19997	38617
Vaz	3,666,573,057	366,657	1210	1273	3047	3046	6087
Munhava	9,357,447,205	935,745	6248	7032	16540	25302	41842
Alto da Manga	5,258,675,986	525,868	2677	3213	8680	8404	17084
Manga Mascarenhas	12,260,347,755	1,226,035	4165	4453	10800	10374	21174
Nhaconjo	4,804,235,654	480,424	4282	4951	12424	12476	24700
Chaimite	1,576,854,946	157,685	3002	2929	7721	6480	14201

Source: Gabinete de Planificação do Conselho Municipal da Beira

Appendix C

Questions addressed in the survey about household waste handling

1. How do you describe your type?
   A. Temporary
   B. Apartment
   C. House
   D. Do not know

2. What kind of household waste do you generate at home?
   A. Paper
   B. Food
   C. Metals
   D. Glass/ceramic
   E. Yard waste
   F. Plastic/rubber
   G. Wood
   H. Paper/food/and yard waste
   I. Food/yard waste
   J. Food/yard waste/plastic
   K. Do not know

3.a) what is the interval deposition of paper?
   A. Daily
   B. Alternate days
   C. Weekly
   D. Monthly
   E. Quarterly
   F. Biannual
   G. Do not know

3.b) what is the interval discard of food waste?
   A. Daily
   B. Alternate days
   C. Weekly
   D. Monthly
   E. Quarterly
   F. Biannual
   G. Do not know

3.c) what is the interval discard of metals?
   A. Daily
   B. Alternate days
   C. Weekly

D. Monthly
E. Quarterly
F. Biannual
G. Do not know

3.d) what is the interval discard of glass/ceramic?
A. Daily
B. Alternate days
C. Weekly
D. Monthly
E. Quarterly
F. Biannual
G. Do not know

3.e) what is the interval discard of yard waste?
A. Daily
B. Alternate days
C. Weekly
D. Monthly
E. Quarterly
F. Biannual
G. Do not know

3.f) what is the interval discard of plastic/rubber?
A. Daily
B. Alternate days
C. Weekly
D. Monthly
E. Quarterly
F. Biannual
G. Do not know

3.g) what is the interval discard of wood waste?
A. Daily
B. Alternate days
C. Weekly
D. Monthly
E. Quarterly
F. Biannual
G. Do not know

4. How often do you discard household waste at the collection point?
A. As soon I produce
B. Wait until it reaches certain quantity
C. I have defined days
D. Depends on kind of waste

E. Do not know

5. Where do you discard your household waste?
   A. Container
   B. Improvised container
   C. Curbside
   D. Abandoned site
   E. Bury
   F. Dug a hole and deposit it
   G. Burn
   H. Drainage trench
   I. Do not know

6. Who is the container where you deposit household waste belongs?
   A. Personal
   B. Municipal authorities
   C. Community
   D. Do not know

7. How far do you walk to the household waste collection point?
   A. <10 meters
   B. 10-49 meters
   C. 50-99 meters
   D. >/= 100 meters
   E. Do not know

8. Will you walk farther than the distance you are walking now?
   A. Yes
   B. No
   C. It depends
   D. Do not know

9. How many meters would you be willing to walk?
   A. <10 meters
   B. 10-49 meters
   C. 50-99 meters
   D. >/= 100 meters
   E. Do not know

10. In your household family members who is going to walk such distances?
   A. Children
   B. Wife/husband
   C. Other adults in the household family
   D. House keeper
   E. Do not know

11. How many times do you discard household waste during a day?
    A. Once
    B. Twice
    C. 3 to 4 times
    D. More than 4 times
    E. Do not know

12. How many times do you discard household waste in a week?
    A. Once
    B. Twice
    C. 3 to 4 times
    D. More than 4 times
    E. Do not know

13. How many times do you discard household waste per week in a month?
    A. Once
    B. Twice
    C. Daily
    D. 3 to 4 times
    E. More than 4 times
    F. Do not know

14. Who discard household waste in your house?
    A. Children
    B. Wife/husband
    C. Other adults in the household family
    D. House keeper
    E. Do not know

15. Would you accept to pay to improve household waste collection?
    A. Yes
    B. No
    C. It depends
    D. Do not know

16. Would you accept to pay even more to improve household waste collection?
    A. Yes
    B. No
    C. It depends
    D. Do not know

17. Would you participate in a program to reuse household waste?
    A. Yes
    B. No
    C. It depends
    D. Do not know

18. Will you separate household waste prior disposal?
    A. Yes
    B. No
    C. It depends
    D. Do not know

19. Who is going to separate household waste in your house?
    A. Children
    B. Wife/husband
    C. Other adults in the household family
    D. House keeper
    E. Do not know

20. Who collects household waste in your neighborhood?
    A. City council
    B. Private waste collector
    C. Just bury it
    D. Do not know

21. What is the frequency of municipal household waste collection in your neighborhood?
    A. Daily
    B. Alternate days
    C. Once a week
    D. Never is collected
    F. Do not know

22. How do you evaluate municipal services on household waste collection?
    A. Excellent
    B. Good
    C. Mediocre
    D. Bad
    E. Very bad
    F. Do not know

23. How do you evaluate municipal services in household waste collection compared to the year 2000?
    A. Worse
    B. Same
    C. Better
    D. Do not know

VITA

Jaime Bessa Augusto Neto

Graduate for the Degree of

Master of Science

Thesis: MUNICIPAL SOLID WASTE MANAGEMENT AND DISPOSAL SAFETY IN THE CITY OF BEIRA, MOZAMBIQUE

Major field: Environmental Science

Biographical:

Personal Data: Born in Vilanculos, Inhambane, on May 23, 1971, the son of Jose Neto and Rosina Lai.

Education: Graduate from Samora Machel Secondary School in December 1990; Received Bachelor of Geography in Pedagogical University, Beira, in July 1996. Completed the requirement for the Master of Science degree with major in Environmental Science at Oklahoma State University in May 2002.

Experience: From 1994 to 1997, worked for the Envirnmental Education Pilot Project at the City Council in Beira; from 1997 to 1998, worked as a Public Realtions Officer at the City Council in Beira.