

SPATIAL ANALYSIS OF INFORMAL SETTLEMENT
SPRAWL AND ITS ENVIRONMENTAL IMPACT: A CASE
STUDY OF KIBERA

BY

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UNIVERSITY OF NAIROBI
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A Research project submitted in partial fulfillment for the requirements for the degree
of Master of Arts in Environmental Planning and Management

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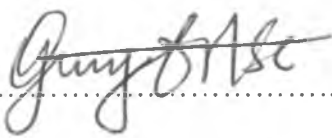
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DECLARATION


This research project is my original work and has not been presented for a degree in any other University.

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DEDICATION

To my parents Damaris and Japheth; brothers and sisters who always provided light for me in dark tunnels of life throughout my study. Thank you for your support and encouragement. May the Almighty God bless you!

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ABSTRACT

One of the United Nations Millennium Development Goals is to achieve significant improvement in lives of at least 100 million slum dwellers by the year 2020 (UN Habitat, 1990). This requires identification of slum settlements and study of their spatial expansion. Kibera the biggest slum in Nairobi has continued to expand spatially causing conflicts in land use and a host of environmental problems. This study was carried out to analyze the spatial sprawl of Kibera over time and space through the use of satellite imageries. Main research objective was to establish the pattern of spatial expansion of Kibera through the use of remotely sensed satellite imageries. Geographic Information System (GIS) was applied in manipulation of data and various analyses on the imageries. Factors which have influenced spatial expansion of Kibera were evaluated through interview data collected from selected respondents in Gatwekera village of Kibera. GIS and Remote Sensing techniques were used to study the spatial sprawl of Kibera and to identify the land use and land cover changes that had occurred, in addition to determining environmental impact of the slum growth.

The study established that Kibera has been expanding over time due to high immigration rate and this spatial expansion has been accompanied by changes in land cover and land use. The spatial sprawl has seemed to be of a definite pattern; majorly along the railway line and Mwitini River and its tributaries traversing the settlement. In 1976 more than half of Kibera was under forest cover, continued sprawl has slowly led to destruction of forest cover to create room for building houses which now occupy over 90% of Kibera land area. Other impacts include: overcrowding, lack of clean water, toilet facilities and poor sanitation. This study therefore recommended that adequate legislative measures be put in place to contain further spatial sprawl of Kibera into the forest reserve and neighbouring areas. High resolution QuickBird satellite imageries should also be used to constantly monitor the state of Kibera and the environmental hotspots for change. Low-cost high-rise buildings to be put up and essential services: water, sanitation, toilet facilities be provided.

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LIST OF ACRONYMS

SRS:	Satellite Remote Sensing
NCC:	Nairobi City Council
CZT:	Concentric Zone Theory
CBD:	Central Business District
ST:	Sector Theory
NASA:	National Aeronautical Space Administration
NOAA:	National Oceanic and Atmospheric Administration
LACIE:	Large Area Crop Inventory
USDA:	United States Department of Agriculture
MSS:	Multi-Spectral Sensor
KWS:	Kenya Wildlife Service
UNEP:	United Nation Environment Programme
DICE:	Durrel Institute for Conservation and Ecology of University of Kent
KFWG:	Kenya Forest Working Group
DRSRS:	Department of Resource Survey and Remote Sensing
MENR:	Ministry of Environment and Natural Resources
TM:	Thematic Mapper
GPS:	Global Positioning System
RCMRD:	Regional Centre for Mapping of Resources for Development
EPOI:	Environmental Points of Interests
RGB:	Red, Green and Blue Colours
GCPs:	Ground Control Points
AOI:	Area of Interest

OPERATIONAL DEFINITIONS

Satellite Remote Sensing: acquisition of information about objects (targets) located at the earth's surface by using sensors mounted on platforms located at a distance from the targets to make measurements of interaction between the object and the electromagnetic radiation.

Geographic Information System: computer based information system that provides capabilities for data input, management, manipulation, analysis and information output and dissemination.

Spatial: that which occupies space and can be assigned coordinate system in reference to the earth surface.

Sprawl: uncontrolled growth of settlement into the immediate neighbourhood

Land use: how land is used by humans, refers to the economic use to which land has been put

Land cover: refers to the vegetation, structures, or other features that cover the land such as grass, trees, water or large buildings.

Change hotspots: areas likely to undergo land use and land cover changes if the current change trends are not arrested or reversed.

Imageries: a record of spectral reflectance characteristic of specific object

Squatter settlement: indicate housing that is either the result of illegal occupation or has been developed in an unauthorized function.

Informal settlements: settlement which does not have the approval of the relevant planning authority concerned.

Slum: area of poor housing characterized by multi-occupancy, overcrowding and inadequate sanitation.

Flying toilet: factitious name for the use of plastic bags for defecation, which are then thrown into ditches, on the roadside, or simply as far away as possible

Atmospheric windows: parts of low absorptions in electromagnetic spectrum.

Discrimination: correct identification of land cover features represented by a spectral reflectance.

Ground truthing: actual verification on the ground of the data that has been captured on an image or map.

Classification: conversion of image data into spectral or thematic classes.

Resolution: the ability of an optical system to distinguish between signals that are spatially or nearly spectrally similar objects.

Pixel resolution: the ground area represented by a single pixel cell.

Spectral resolution: specific wavelength intervals in the electromagnetic spectrum to which a sensor is sensitive.

Spatial resolution: the smallest unit area measured, indicating the minimum size of objects that can be detected.

Geo-referencing: assigning of geographical locations to geographical objects.

Ground control points: well distinguished ground points of known coordinates identified on the map and image to be geo-referenced.

Vectorization: conversion of an image from raster to vector format.

Environment: a set of interlocking systems biophysical, natural, man-made or social within which all living things interact.

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

One of the most remarkable characteristics of human settlement in the 21st century has been the rapid urbanization as is reflected by the increasing population in urban areas relative to rural areas (UNDP, 2003). Kahinde (2002) noted that there were significant differences in the pace and patterns of urbanization globally with developing countries experiencing relatively more rapid rate of urbanization. Most people in rural areas, in the developing world, are forced to move out seeking new opportunities in the urban centers and this has resulted in rapid urbanization. This has been accompanied by various problems, which have created two distinct groups of urban dwellers: well housed population with all necessary services- the high and the middle income group; and the urban slum dwellers. Rapid urbanization in the developing world has resulted in increased growth and spatial sprawl of informal settlements popularly known as slums due to lack of cheap housing, unemployment, and poverty.

Slums are usually unplanned and therefore their uncontrolled spatial growth may result in many environmental challenges such as deforestation, poor sanitation, lack of clean water supply, poor health and diseases, water pollution, crime and waste disposal problems. The spatial sprawl of slums and consequent environmental challenges result in multiple problems requiring multi-disciplinary solutions. In multi-disciplinary solutions approach, there are needs for use of data from various sectors and disciplines so that the right decisions can be made. A technology that integrates data so that the right decisions can be made is therefore necessary. Geographic Information Systems (GIS) and Satellite Remote Sensing (SRS) provide the integration platform for spatial sprawl analysis and multiple solution approaches to the many environmental challenges posed by the slum growth.

This research was primarily concerned with the analysis of spatial sprawl of Kibera, the factors that have influenced its expansion and land use and land cover changes that have occurred in this slum. This was done using sets of satellite imageries dating back from 1976 to 2004 with a view that Kibera had spatially expanded over this period. Finally, this study considered the environmental impact of Kibera sprawl and the two-way interaction between Kibera dwellers and their environment. The poor in slums tend to be more exposed to diseases found in 'unclean' environment such as cholera, dysentery, typhoid and intestinal parasites (WRI *et al.*, 1996). Waste disposal is a common problem in the slums and this usually result in water pollution from both human waste and wastewater which end up untreated in rivers, canals, and open ditches due to high population density and lack of sewage system (Muthoni, 1999; UN Habitat, 2001).

The housing structures in slums are put up spontaneously without the approval of city planning authorities. This normally results into spatial sprawl of these settlements into forest reserves, hazard prone areas such as: along river banks, roads and railway buffer zones. UNDP (2003) and WRI *et al* (1996), cite the ripple effect of this uncontrolled growth as the cause of various household and neighbourhood environmental problems such as: overcrowding, indoor pollution, waste disposal, and inadequate infrastructure. Higher order effects of all these may be persistent health problems which in some cases could result into fatalities in the slums.

In an attempt to document the sprawl of Kibera over time and the resulting environmental problems, this study seek to analyze the spatial growth, establish the causes and pattern of expansion of the slum. This would assist in monitoring Kibera spatial sprawl which has and will continue to have impact on land cover and land use and the environment in totality. Tools that can provide instantaneous recording of conditions on the ground as well as integrate data from various sources in various formats are required for such studies.

In this study, Satellite Remote Sensing (SRS) and Geographic Information Systems (GIS) provided digital record of land cover and land use changes in Kibera environment in the period between 1976 and 2004 and were used to integrate various data types and formats. The research used SRS and GIS in time series analysis of Kibera spatial sprawl.

1.2 Problem Statement

The increasing rise and expansion of slums in urban centres and cities continue to remain a challenge many developing countries are trying to address (Kahinde, 2002). Factors contributing to increased growth of cities include: prospects of employment, better standards of living and amenity of urban life which tend to pull people to the cities. On the other hand, 'the push away' from rural areas is attributed to increasing poverty, landlessness and conflicts (Davidson & Myers, 1992). Consequently, urban basic facilities and infrastructure have continually shrunk against the ever-growing population exacerbated by high immigration rate (Brown, 1973; Aldrich & Sandhu, 1995).

The proliferation and spatial expansion of slums in cities, which Kibera is a case example is a problem most developing countries are facing. These countries lack the capacity to provide all urban dwellers with proper housing. According to WRI *et al*, (1996), due to scarcity of employment opportunities in urban centres, most people have resorted to settle in the slums where they build their own makeshift shelters out of cardboard, plywood or scraps of metal or pay low house rents. UN Habitat (1990) reported that 30% to 60% of the population in such cities live in substandard housing whilst WRI *et al* (1996), put the figure at approximately one billion people worldwide.

Nairobi, the capital city of Kenya, about 50% of the population is found in slums which on the contrary occupy less than 10% of its total land area (UN Habitat, 1990). Many slums are found in different parts of the city, Kibera being the largest both locally and among those in Africa (UN Habitat, 2000).

As demand for cheap housing increases, Kibera has continued to undergo spatial sprawl into its neighbourhood. Overtime, the room for external expansion has reduced leading to over-crowding, which may exacerbates rates of transmission of both communicable and infectious diseases in case of any outbreak. Indoor pollution caused by burning of wood fuel and charcoal, the primary sources of cooking energy in the slums are high (Achieng, 2004).

Kibera lack supply of clean water and the dwellers either share few available communal water taps or supplement by buying from the vendors. This greatly affects the level of hygiene hence the residents remain susceptible to illnesses caused by poor sanitary (UNDP, 2003). The ripple effect of uncontrolled growth of the slum on the physical environment include: deforestation, water pollution and improper waste disposal. Different studies have shown that spatial sprawl of slums have resulted into household and neighbourhood environmental problems combating the slum dwellers (Davidson & Myers, 1992).

Therefore, as a first step to tackling problems experienced in Kibera an analysis of its spatial sprawl was carried out. Spatial parameters considered were Kibera area of coverage and its increase overtime. In addition, environmental variables such as: housing quality, piped water availability, housing density, vegetation cover, sanitary facilities, and waste disposal systems were also considered. SRS and GIS that offer an avenue for study and analyses of spatial sprawl and these environmental challenges inherent in the slums were used. In this study, attempts were made to analyze the spatial sprawl of Kibera and to determine the pattern and factors that have influenced its expansion besides the resulting environmental impact of the growth. Questions addressed in this study included:

1. What is the pattern of spatial expansion of Kibera?
2. What are the factors that have influenced spatial expansion of Kibera?
3. What are the land-use and land-cover changes that have occurred in Kibera?
4. What are the environmental impacts of Kibera growth and expansion?

1.3 Objectives

The overall objective was to examine the spatial expansion of Kibera over time and space. The specific objectives of the study included the following:

1. Establish the pattern of spatial expansion of Kibera
2. Identify the factors responsible for the spatial expansion of Kibera
3. Identify and quantify land use and land cover changes in Kibera
4. Determine the environmental impact of Kibera growth and expansion

1.4 Working Hypotheses

The following working hypotheses were used to guide this research in attaining the above stated objectives:

1. There is a definite pattern of spatial expansion of Kibera
2. There are specific factors behind the rapid spatial expansion of Kibera
3. There are land use and land cover changes in Kibera
4. The growth and expansion of Kibera has had impact on the environment

1.5 Justification of the Study

With the rapid growth of Nairobi metropolis, there is increased pressure on housing, urban infrastructural facilities and services. The housing demand mostly for the poor residents and new jobless city immigrants has been largely unmet due to lack of cheap affordable or government subsidized housing facilities. Consequently, many slums such as Kibera, Mathare, Soweto and Mukuru kwa Njenga have come up in Nairobi City as areas of cheap housing for the poor. A number of people continue to move from their rural homes and other small towns to settle in Nairobi in search of job opportunities (Gichuki, 2005). This has put increased pressure on these slums with physical spatial expansion becoming inevitable to make room for building cheap houses for these new immigrants.

Kibera whose origin dates back to 1913 in the pre-colonial era as Nubian settlement, (Amis, 1980), has continued to grow to date as an area of cheap housing especially for new city immigrants (Muthoni, 1999). Henceforth the slum has experienced tremendous spatial sprawl putting increased pressure on land, destruction of forest cover and heavy pollution of Mwitini River and its tributaries traversing the settlement. Like in many other slums, houses in Kibera are put up on precarious areas such as banks of Mwitini River, railway and road buffer zones and areas no one would want to settle on. The spatial sprawl and internal densification of Kibera has led to overcrowding and unmet demand for basic services such as clean water, sanitation and efficient waste disposal (UN Habitat, 2001). Therefore, a study of spatial sprawl of Kibera; both internal and external is important in establishing its expansion trend and resulting environmental impact. This would provide essential data and information to the city planning authorities and help contain further sprawl of the slum and improve service provision to the inhabitants.

Like many other slums in Kenya, Kibera has been expanding in area and increasing in density due to several factors such as natural population increase, immigration and continued unauthorized settlements (UN Habitat, 1990). Monitoring these changes is an essential contribution to proper management of the urban environment. Data on slum areas can be acquired at great speed from SRS techniques that offer great potentials. High resolution satellite imageries from both Landsat Thematic Mapper (TM) and QuickBird imageries have provided invaluable information on issues of environmental monitoring in Kenya (Agastiva *et al*, 1981; cited by Situma *et al*, 2005). Information on these imageries is obtained through visual and digital interpretation while complementary data are obtained from aerial photographs and ground verification surveys.

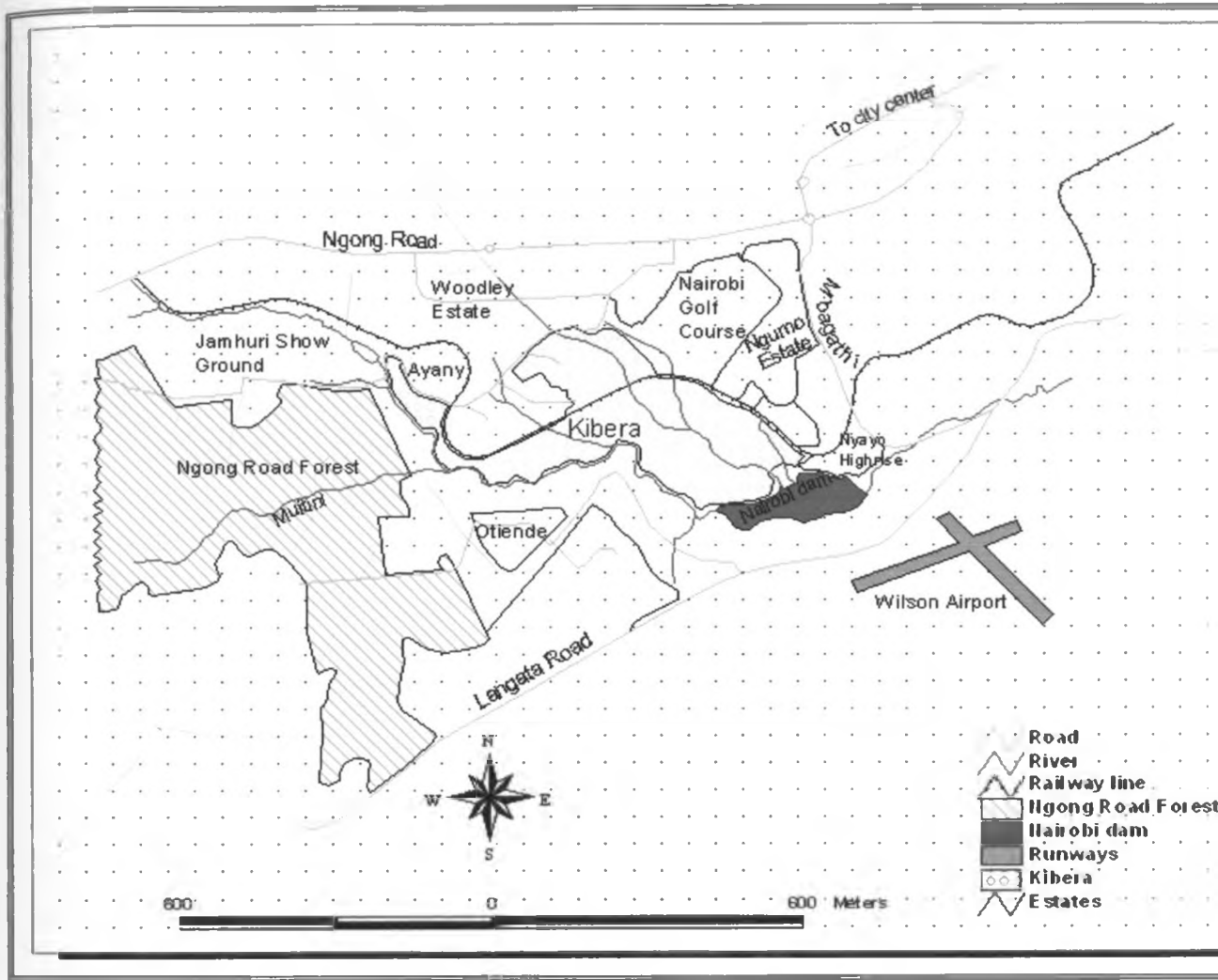
Most research works carried out in Kibera and other slums have concentrated on the socio-economic and environmental impacts of the slum. These include works of Muthoni (1999), *Community Participation in Solid Waste Management within Urban Informal Settlement*; Achieng (2004), *Community Participation in Housing Provision in Unplanned Settlement*; and Gichuki (2005), *Environmental Problems and Human Health in Urban Informal Settlement*. However, the analysis of spatial sprawl of Kibera in monitoring land use and land cover changes is important in providing necessary information on resource planning, management, decision making and policy formulation. Such data and information would facilitate sustainable, effective utilization, conservation and resolution of conflicts arising from various land uses and cover changes caused by the spatial sprawl. This research endeavoured to analyse the spatial sprawl of Kibera over time to establish the pattern and examined further the factors which may have contributed to expansion of the slum in the particular manner, besides reporting on the associated current environmental impact of the slum. This information could be utilized by the local authorities in the planning and provision of services as a mitigation measure against further spatial sprawl of Kibera.

1.6. The Study Area

This research was carried out in Kibera. Map 1.1 indicates the location of Kibera in Nairobi city and the neighbouring estates. Different aspects of the study area are discussed in the subsequent subsections:

1.6.1 Location and size

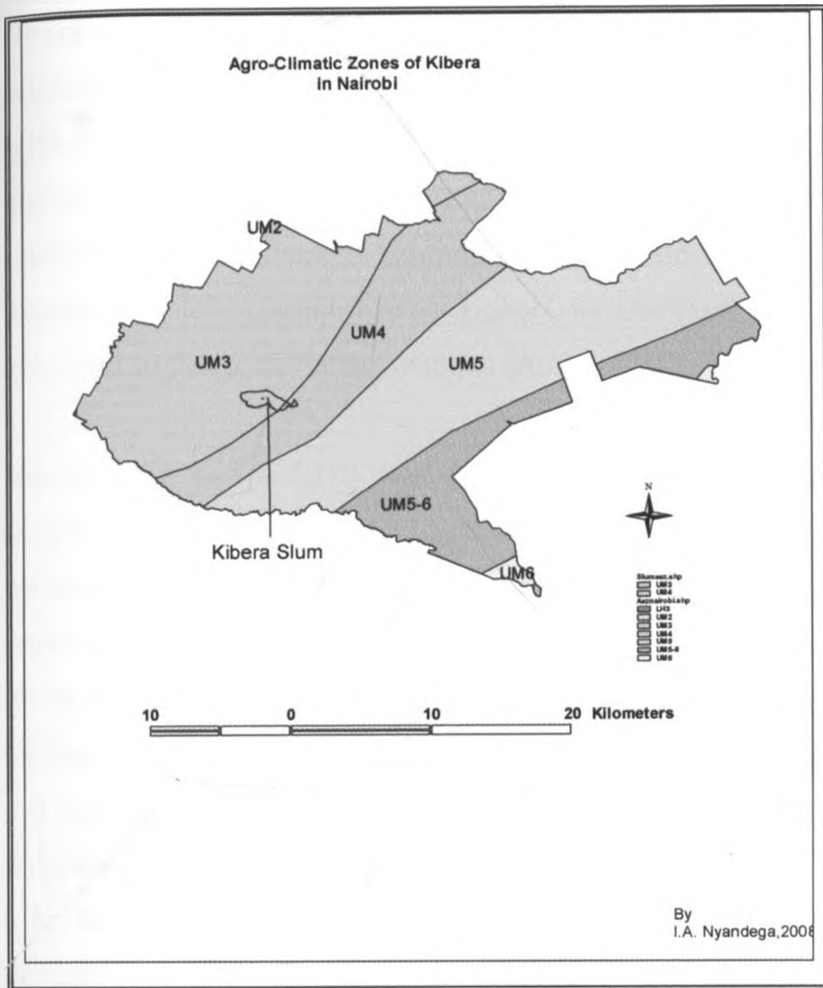
Kibera, a low class residential estate, is located on the southern part of Nairobi City, Kenya, approximately 7km south west of the city centre. It is bordered by Royal Golf course, Ngumo and Magiwa estates to north, Mwitini River to the south, Ayany and Fort Jesus estates to the west and Nairobi Dam estate to the east. The Kenya railway line passes through the area separating the slum and other settlements. Kibera occupies an area of about 262.5 hectares, enclosed within UTM coordinates (9855577.77, 252025.32; 9855577.77, 255879.03; 9854023.18, 255879.03 and 9854023.18, 252025.32).



Map 1.1: Location of Kibera in Nairobi.

1.6.2 Physiography

Kibera is at an altitude of about 1680m above mean sea level, therefore in the upper midland zone (agro-climatic zone classification based on temperature and moisture) with average rainfall of 855 mm annually. Before urban human settlement, Kibera was a forested land (the name borrowed from Nubian word *kibra* meaning forest) whose remnants can be seen in the nearby wooded land to the south eventually forming Ngong Road forest. Much of the original vegetation if not all, has disappeared due to long history of settlement and continued spatial sprawl of the slum.



Map 1.2: The Agro-Ecological Zones of Nairobi

1.6.3 Administrative units

Kibera is one of the administrative locations within Langata division. The location was initially organized into a total of nine villages namely: Kianda, Soweto, Gatwikera, Makina, Mashimoni, Kisumu Ndogo, Lindi, Laini saba and Siranga; each guarded by village elders. With continued spatial sprawl of the slum, the tenth village, Raila was emerged to the south west of Kibera and part of it across Mwitini River as the slum spatially expanded. The villages are characterized by dense population in the overcrowded makeshifts accessed by few motorable tracks and narrow pathways.

1.6.4 Historical origin

Kibera was part of Maasai grazing land in the pre-colonial period. It was taken by colonial government before World War II as a military reserve. The area was first settled by Nubians from Nubian mountains in Sudan, who owe their existence in Nairobi to the British imperialism in East Africa. The Nubians were used as soldiers in colonization of Uganda and they later followed the British to Nairobi. Original Nubian garrison was based in Dandora; however, in 1913 it was relocated to the present day Kibera (Amis, 1980).

Between the years 1913 and 1928, Kibera remained a military reserve under Kenya African Rifles (KAR). Soldiers who had served for over twelve years in the army were allocated plots, whose descendants and relatives form the Nubian community in Kibera today. The original site occupied in 1913 was wooded hence it was named Kibera, (borrowed from Nubian word *kibra*, meaning forest) (Muthoni, 1999). In 1928, the area was made Crown land by civil administration and new settlers were required to prove their relationship to the original Nubian servicemen. In 1933 Carter land commission recommended a gradual eviction from the settlement; however, this was not implemented. The demolition of Mathare Valley slum by colonial authorities in 1954 left Kibera as the only place with cheap African accommodation and self-built housing in Nairobi. Most Luos and Luhyas who migrated to Nairobi settled in Kibera, which up to date is exhibited by these two tribes dominating this settlement.

To take advantage of the influx of migrants in 1950s, Nubian communities extended their houses and built others for rental purposes, thus setting the emergence of landlordism in the informal settlement. Concentration of population was around Makina village, the first Nubian settlement. After Kenyan independence in 1963, the independent government ruling interpreted the agreement between the Nubians and the colonial government to have meant that the Nubians had no right to the land except their housing. The land hence forth was owned by Government of Kenya.

With influx of migrants into Nairobi, Kibera became and continued to grow as a low-cost housing area which supplemented the acute shortage in government housing. The settlement had both rental houses of the Nubian landlords and self-built squatter houses, constructed at the peripheral sites by those who could not afford to pay the rents. In 1963, boundary of Nairobi was extended to include Kibera. The Ministry of lands and settlements had to look into Nubian land rights in Kibera as pertains the latter's agreement with the colonial government. According to the Nubians Kibera was their ethnic reserve, on the other hand colonial government considered the Nubians as tenants at will.

1.6.5 Population

According to Amis, (1980) by 1972 the population of Kibera had grown to approximately 17000. Currently the population of Kibera ranges between 20,000 and 100,000 in each of the ten villages with Kisumu Ndogo, Laini Saba and Gatwikera villages having the highest population densities (Muthoni, 1999). The general population exhibits gender imbalance with 64% male due large number of single men who offer manual labour in Nairobi industrial area. The household sizes are generally large causing congestion and overcrowding due to limited space. Population of Kibera is primarily constituted by two groups of people: temporary residents who came to look for employment in the city and keep in touch with rural homes where they own land and are mostly tenants in Kibera; on the other hand, there are permanent residents that include the original Nubians and the rural landless (Achieng, 2004).

1.6.6 Infrastructure and environment

As is the case in most slums, building structures in Kibera are uncontrolled and houses occupy parts of unsuitable land such as valleys of river Mwitini. Kibera suffers from acute shortage of water services, drainage, garbage collection and general sanitation (Achieng, 2004). Nairobi City Council which is mandated to provide such services to the city dwellers considers Kibera as an illegal settlement and partly argues that extension of such services to the area would be formalizing the settlement (UNDP, 2003).

There are no proper garbage collection services by Nairobi City Council, and the residents have been forced in some places to organize means of handling their wastes through community participation (Muthoni, 1999).

Drainage

The soils of Kibera region are predominantly clayey types in the form of black cotton soil, and red soil with some rock outcrops. Much of Kibera is drained by river Mwitini and its tributaries in the form of rivulets and streams, some of which have turned into open sewerages due to rampant waste disposal problems. Proper drainage and sewer system are not provided in Kibera. Few open-earth drainage systems available between the housing, most of the time get clogged by solid waste materials which are dumped by the residents. Water pipes passing through the slum are often broken and water acquired illegally by some of the residents (UNDP, 2003). When pressure in such pipes gets low, the wastewater and even human waste may get sucked into the piped water system which may cause health problems to people tapping the water down stream.

Housing

Most houses in Kibera are in poor state and occupy precarious environment. The primary construction materials for the dwellings include mud, wattle and corrugated iron sheets. Majority of the housing units are limited to dimensions of five square meters and are contiguous with little or no spacing in between. The houses are overcrowded with average occupancy of up to 10 members per household, (Achieng, 2004).

Road network

The fact that Kibera is unplanned, the available open spaces continue to shrink against the ever-growing population, and only narrow paths are left to provide access to the dwellings. This inaccessibility may threaten the safety of inhabitants in case of incidences of fire outbreak and other emergencies since the movement of rescue vehicles would be impeded and may not gain access. Lack of open spaces and dumping sites has also left these narrow paths as the only available places where majority of residents dump all their waste.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter considered both theoretical and empirical literature related to growth of urban centres and in particular, spatial expansion of slums within the urban centres. Theoretical base of review focused on the following issues: urban growth and expansion; spatial sprawl of informal settlements (slums); environmental impact of slums and; general application of Satellite Remote Sensing (SRS) and Geographic Information Systems (GIS) especially in spatial change analysis. On the other hand empirical literature reported on the various case studies in which SRS and GIS have been applied in environmental monitoring and more specifically, urban growth monitoring.

2.2. Theoretical Base

Various theories have been put forward in trying to explain the process of urban growth structure and expansion. This section provides a review of some literature that relate to urban growth patterns and processes. It further considered the issue of informal settlement spatial sprawl and the associated environmental impact which were of primary concern to this study.

2.2.1 Urban growth models

Burgess (1925), Hoyt (1964), Harris and Ullman (1945) and Davie (1937) had advanced theories in trying to explain the process of urban growth, structure and expansion. The urban growth processes had tended to follow one or more of these ideas that have been advanced: the concentric zone theory, sector theory and multiple nuclei theory.

The concentric zone theory

Burgess (1925) developed the concentric zone theory (CZT), to try and explain the pattern of urban growth. According to Burgess (1925), in the absence of counteracting factors the cities should take the form of five concentric zones. Zone 1: the Central Business District (CBD) at the centre is a focus for the city's commercial, social and civic life. Zone 2: zone of transition, situated around the CBD. The zone is mixed up with light industries that have encroached the residential areas. The city's principle slums may be found within portions of this zone. Zone 3 is low class residential, zone 4 is middle class residential and finally the commuter zone beyond the cities limits constituted of fairly high quality residences along lines of rapid travel.

The sector theory

Hoyt (1964) in advancing the sector theory (ST) argued that residential land uses tended to be arranged in wedges or sectors radiating from center of the city along lines of transportation. This theory does not deal with other forms of land uses. Hoyt (1964) carried out empirical studies in United States of America and established that the patterns of rent could be relied upon as a guide to the structure of residential areas. He stated that rent areas in American cities tended to conform to a pattern of sectors rather than concentric circles. The rent areas were located in different sectors and the various areas changing with time. High quality residential areas tended to migrate outward in the sector and area of the older houses remaining behind became medium quality area, thus expansion of high grade neighbourhood was towards the periphery. On the other hand low rent residential areas tended to retain this low quality as it expanded outwards in a sector.

Multiple nuclei theory

Advanced by Harris and Ullman (1945), the multiple nuclei theory (MNT) suggested that frequently the land use pattern of a city was built around several discrete nuclei rather than around a single center such as is postulated in the CZT and ST. A nucleus refers to any attracting element around which growth of residential, business, industrial or other urban land use takes place. Many cities can be traced back from single initial nucleus such as the CBD, the port, rail facilities, a mine or some other localizing point; however, other nuclei have played roles as the cities continued to grow. Low class neighbourhood was often located near factories and rail road districts as opposed to the high class residential which were normally well drained and far away from rail roads and heavy industries.

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The CZT has been both challenged and supported by many scholars. According to Davie (1937) who mapped land uses and studied distribution of various social classes in America, cities generally exhibited the following patterns: the CBD were irregular in size and often more square or rectangular in shape than circular; areas of commercial land use extended out on the radial street from the CBD; industries were located near lines of water or rail transportation; low class housing near industrial and transportation area and; middle and high class housing almost everywhere. Low grade economy were concentrated near the center of the city, but in reality were found in every zone generally adjacent the industrial and rail property. Davie (1937) concluded that there was no universal pattern, not even ideal type of urban growth. In support of Burgess' CZT, Quinn (1940) observed that most cities conformed to the concentric zone theory: the CBD constituted the heart, followed by deteriorated area of development and in general poorer homes were located closer to the CBD and better homes farther out.

Firey (1974) after studying land use in central Boston challenged the validity of sector theory. He claimed that other factors apart from the rent: such as relief, location on waterfront, among others also affected the pattern of land use of some cities in addition to the cultural and social systems.

The growth of Nairobi which dates back to colonial era can be traced back to the construction of Kenya-Uganda railway line in 1898 as the initial growth nuclei. The presence of low class neighbourhood located in close proximity to the industries and railway line as confirmed by location of Kibera, which has the Kenya-Uganda railway line passing right through the settlement, make the structure of the city to partially conform to both MNT and Davies ideas, whereas the high class residential areas are located far away from the industries. There are other attracting elements that have influenced the growth of Nairobi in further support of MNT, for example apart from the main CBD, there are different growth centres as West-lands, Buruburu, Hurlingham, Yaya centre and Embakasi.

At the same time, the CBD of the city is found at the centre, and partially beyond the CBD there tend to be zone of transition which is characterized by light industries and few residential areas of different classes, this conforms to CZT advanced by Burgess. The pattern of residential settlement in Nairobi, however, does not conform fully to the CZT: whereas it is expected to have low class residential areas near the town center and high class residential areas further away, in Nairobi some high class residential areas tend to be in close proximity to the CBD such as Parklands, Milimani and Westlands.

In conclusion, the MNT in away was simpler than the other two theories (CZT and ST) and adjusted more easily to the present city growth conditions. The theory fits the highly flexible modern urban scene (Murphy, 1966).

However, in nearly all urban centres such as Nairobi, the structure and growth of the urban centres do not wholly fit in any of the single model. The origin, structure and the growth of many of urban centres tended to conform in part to CZT, ST and MNT. This is in agreement with Davie (1937) who after mapping various land uses in America concluded that there was no universal pattern, not even ideal type of urban growth.

2.2.2 Informal settlements (slums)

According to Kahinde (2002), inadequate housing in Africa cities ranges from minimum of 30% to a maximum of 90% in each city. As further noted, each country has its own unique complex mix of economic, social, political and demographic characteristics which affect the variation in housing inadequacy from country to country. Inadequacy in provision of proper housing by government is exhibited by presence of slum and squatter settlements. UN Habitat (2001) and Aldrich and Sandhu (1995) made the following distinction between slum and squatter settlement: slum generally refers to housing, regardless of tenure which has fallen into despair, on the other hand squatter settlement has to do with illegal (unauthorized) occupation and it could also double as a slum. The problems of both or either of these two indicate housing poverty.

The problem of inadequate housing and informal settlements afflicts regions nearly across the whole globe. According to Davidson and Myers (1992), Mexico City suffers from severe air pollution, lack of water, high unemployment and critical housing shortage. One third of the city's people live without sufficient water and electricity. Half of the city's rubbish is left to rot. Thus the environmental problems afflicting the slum dwellers are not just a confine of the developing world, though they are the most hard-hit. Kibera the study area is one of the slums within Kenyan capital city of Nairobi experiencing most rapid spatial growth accompanied with various environmental problems requiring urgent solutions.

2.2.3 Factors behind slum origin and growth in Nairobi

As the capital city of Kenya and centre of settlement, different factors could be cited for the origin and development of slums in Nairobi. The following subsection considers first, the origin and growth of Nairobi.

Origin and growth of Nairobi

Nairobi city, owes its birth and growth to the construction of Kenya-Uganda railway (Hutton, 1972; Obudho, 1992). The city takes the name from Maasai term *Ekare Nairobi*, meaning the place of cold water (Obudho, 1981). The railhead reached Nairobi in 1899 en-route for Kisumu. According to Obudho (1992), subsequent growth of Nairobi as a commercial and business hub for British East Africa Protectorate resulted from moving of railway headquarters from Mombasa to Nairobi. By 1890 it had become a large and flourishing settlement consisting mainly of railway buildings and separate areas for Europeans. A major contribution to the growth of Nairobi arose out of the fact that, until recently it served important economic function for Uganda and to a lesser degree Tanzania and provided the headquarters (Hutton, 1972).

Development and spatial sprawl of slums in Nairobi

According to Obudho (1981), unchecked urban growth in rapidly urbanizing parts of developing countries had created serious physical, social, economic and political pressures on majority of populations. The basic human need of this population is not being met. Almost 80% of Nairobi city's residential land has less than one quarter of the population, which is mainly the high income group in suburban planned residential areas (Obudho, 1981); thus less than 20% of the residential land accommodates remaining three quarters of the city's population. This has encouraged increased spatial sprawl of slums in the city with particular impact on majority of population which is poor and either have less access to land or public subsidized dwellings hence deteriorating the quality of life.

The spatial incidence of the process of rapid population expansion in Nairobi has also contributed to serious shortage of housing, particularly for low income persons. A number of slums and squatter settlement have developed and continue to sprawl within the city and along periphery of Nairobi built-up areas as a source of cheap housing (Obudho and Aduwo, 1989). According to Gichuki (2005), many people move from their rural homes and other towns to the capital city of Nairobi in search of better employment opportunities. The capacity of the government to provide proper housing and employment has dragged in pace in comparison to city's population growth, leaving majority to seek for housing in the sprawling slums despite numerous environmental impact.

Due to scarcity of better employment, majority of these immigrants worked at the city's industrial area as casual labourers and most of the time wages they obtained were never enough to cater for good housing (Wasike, 1996). Muthoni (1999) cited lack of cheap housing for this low income group of city dwellers as the main factor behind high incidences and spatial growth slums within Nairobi. Many slums such as Kibera, Mathare, Mukuru kwa Njenga and Soweto have come up within Nairobi and continue to expand spatially in aerial extent and in population density.

2.2.4 Environmental impact of slums

People who settle in slums exert various pressures on the environment and they are also affected by this environment. According to WRI *et al* (1996), majority of poor people live in shanties, some built on land that no one wants in the slums. Housing is a big problem to the city poor. According to Gichuki (2005), any available material ranging from wooden planks, poles, straw, cardboards, and in some cases iron beams constitute the primary construction materials for the shanties. Nairobi is nowhere near the level of services, housing or employment to cater for the residents housed in the slums (UN Habitat, 1990).

Muthoni (1999), after a study in Kibera reported that there was no adequate refuse collection services except in few cases where a community had organized their own means of wastes management. In study carried out within Mukuru Kwa Njenga slum in Nairobi, Gichuki (2005) further noted insufficient provision of clean water, sewerage, proper schooling and inadequate healthcare services in the slum. Spatial sprawl of slums and inadequacy or lack of essential services in slums impacts negatively both on the physical environment and slum dwellers. On the physical environment, spatial expansion of slums may lead to destruction of forest cover to give room for putting up of more housing structures. For example, the study area Kibera formerly was a forested area as earlier stated, however, continued settlement and spatial expansion of the slum has led to destruction of vegetation cover affecting the ecosystem balance.

According to UN Habitat (1997), all slums in Nairobi lack adequate sanitation facilities such as pit latrines, this has led to use of "flying toilets" by the slum dwellers especially in Kibera. "Flying toilet" is a facetious name for the use of plastic bags for defecation, which are then thrown into ditches, on the roadside, or simply as far away as possible. This manner of disposal of human excreta causes serious pollution. As in most slums everywhere, Skinner and Rodell (1983) observed that a lot of solid and liquid wastes were produced due to high human population. Since the slums lack waste collection services and sewage system, most of the waste are left on garbage dumps or any available space which causes serious pollution to watercourses through the slum as exhibited by heavily polluted Mwitini River and its tributaries in Kibera (UN habitat, 2001).

In analysis of spatial sprawl and monitoring of slum environment, both past and present datasets of Kibera were required to establish and monitor its spatial growth pattern, quantify land use and land cover changes besides identifying environmental change hotspots. SRS offers efficient means of acquiring data for spatial sprawl analysis and environmental monitoring.

Various archives of SRS data were used in conjunction with the latest field survey datasets in a GIS environment in analysis of Kibera spatial sprawl and location of environmental change hotspots within and adjacent to the study area.

2.2.5 Satellite remote sensing and Geographic information systems

Satellite Remote Sensing (SRS) developed from airborne SRS in the 1960s and 1970s. Various definitions exist for Satellite Remote Sensing, according to Litz and Simonett (1976); Satellite Remote Sensing is the acquisition of physical data of an object without touch or contact. Satellite Remote Sensing involves the determination of properties of objects without being in physical contact with them (Townshend, 1981). For purposes of earth resource surveying, the definition may be narrowed to the estimation of terrain characteristics and qualities by the use of data acquired from aircrafts or spacecrafts.

A better definition is provided by Short (1982) which states that Satellite Remote Sensing is the acquisition of information about objects or materials (targets) located on the earth's surface, or in the atmosphere by use of sensors mounted on platforms located at a distance from the targets to make measurements of interaction between the object and the electromagnetic radiation. This definition of Satellite Remote Sensing by Short (1982) was adopted for this study.

Remote Sensing satellites orbit the earth at altitudes ranging from low polar (200 km) to high equatorial (36000 km) and their sensors gather electromagnetic energy reflected, emitted or backscattered from part of the earth's atmosphere below the satellite (Cracknell & Hayes, 1991). Radiance data provided by satellite is processed into derivative products such as spatial sprawl analysis and land use maps, geology, water and atmospheric pollution in environmental application.

On the other hand, Fotheringha & Wegener (2000), defined Geographic Information Systems (GIS) as a computer based information system that provides capabilities for data input, management (storage updating and retrieval), manipulation, analysis and modeling and; data and information output and dissemination. GIS helps in effective planning and decision support. It is a technological tool that anyone can use with almost unlimited applications ranging from rural to urban to global (Aronoff, 2005). Some examples of GIS applications include: spatial sprawl analysis, land suitability analysis for growing certain crops, flood control planning, environmental impact assessment, desertification and urban expansion monitoring. Data in GIS consist of feature positions, attributes and relationships amongst features.

Electromagnetic energy

The unit of measurement in SRS is the *radiant energy* emitted or reflected by various objects on the earth's surface. Electromagnetic radiation is constituted of various wavelengths which collectively form the electromagnetic spectrum, (Aronoff, 2005). Drury (1998) defined Electromagnetic spectrum as energy of constant speed and a set of electromagnetic waves containing several spectral regions such as visible, near infrared and far infrared. Different spectral regions are utilized by various sensors to provide SRS information. This study utilized Landsat Thematic Mapper (TM) and the Digital Globe QuickBird imageries that operate in the visible and infra-red spectral regions of the electromagnetic spectrum to analyze the spatial sprawl of Kibera and study land use and land cover change.

Sources of electromagnetic radiation for passive remote sensing

The sun is the main source of electromagnetic radiation. The earth has no energy of its own, but objects on the earth react with energy from the sun, wavelength of the electromagnetic wave changes during this interaction from short to long depending on the object characteristics (Campbell, 1996).

The sun provides direct energy in the ultraviolet, visible and reflective infrared region with bulk of the energy in visible region of the electromagnetic spectrum. Thermal infrared is provided by the earth which converts short wave radiation from the sun into long wave radiation (Swain & Davis, 1978).

Different land surfaces reflect different proportions of solar radiation falling upon them in different spectral bands. Such difference in the reflectance of land led to the coining of the term 'spectral signature' defined as the amount of energy reflected by a particular material at specific wavelengths (Jensen, 2000). The amount of radiation emitted or reflected by any given material varies with wavelengths. These variations are used to establish 'signatures reflectance' for that material on assumption that similar objects or classes of objects interact in a similar way with electromagnetic radiation at any given wavelength (Rees, 1990). Consequently different objects should have different interactive properties with electromagnetic radiation. However, same objects may still have different spectral response, depending on unique object characteristics (Campbell, 1996).

Energy interaction and spectral reflectance in satellite imagery

Electromagnetic radiation through the atmosphere to and from matters on the earth's surface are either reflected, scattered, diffracted, refracted, absorbed, transmitted or dispersed depending on unique spectral characteristics of the matter (Drury, 1998; Jensen, 2000). The proportion of energy reflected, absorbed or transmitted would vary depending upon their material type and conditions. These differences permit distinction between different features on imagery. However, due to wavelength dependency, Cracknell and Hayes (1991) observed that two objects may be distinguishable in one spectral range and be very different on another wavelength band.

Configuration of spectral reflectance curve (a graph of spectral reflectance of an object as a function of wavelength) provides insight characteristics of an object and has a strong influence on the choice of wavelength regions in which SRS data are acquired for particular application (Jensen, 2000). In spatial analysis of Kibera sprawl, the surface cover was predominantly composed of iron sheet roofed houses, patches of bare ground and remnants of forest cover. Landsat Thematic Mapper (TM) imageries of band 1 (0.45-0.52 micrometer (um)) blue; band 2 (0.52-0.60um) green; band 3 (0.63-0.69um) red; and band 4 (0.75-0.90um) near infrared and QuickBird imageries were used in this study.

Landsat satellite imagery

Landsat satellites provide repetitive acquisition of high resolution multi-spectral data on global scale. This data has been utilized by variety of environmental scientists concerned with earths land surface and water bodies in their studies (Brandon 1999). Landsat Thematic Mapper (TM) data was used in this study because of its greater spatial, spectral and radiometric resolution than the Landsat Multi-spectral Scanner (MSS) data. Landsat TM has seven spectral bands with instantaneous field of view (IFOV) at a nadir of 30m, spatial resolution. The ranges of spectral and radiometric resolutions of the Landsat TM are shown in table 2.1.

Table 2.1: Spectral resolution of Landsat 4 and 5 Thematic Mapper (TM)

BAND	SPECTRAL RESOLUTION (UM)	RADIOMETRIC SENSITIVITY (NE Δ P)
1. Blue	0.45-0.52	0.8
2 Green	0.52-0.60	0.5
3. Red	0.63-0.69	0.5
4. Near infrared	0.76-0.90	0.5
5. Mid infrared	1.55-1.75	1.0
6 Thermal infrared	10.40-12.4	0.5(NE Δ P)
7. Mid infrared	2.00-2.35	2.4

(Source: Jensen, 2000)

Landsat TM sensor records surface reflectance of electromagnetic radiation from the sun in seven different bands. Imageries obtained were composited, independently classified, digitized and overlay operations performed to analyze the spatial expansion of Kibera.

QuickBird imagery

QuickBird satellite is a high resolution satellite owned and operated by Digital Globe. The pixel resolution for a QuickBird is 0.61 square metres for panchromatic and 2.44 square metres for multi-spectral imageries. This makes the satellite an excellent source of environmental data useful for analyses of spatial changes in land use, agriculture, forest and other environmental studies. QuickBird imagery data was used in this study to enable mapping of Kibera extent, discrimination of the housing units, rivers and roads based on their high resolutions.

Absorption of radiation by atmosphere

The earth's atmosphere absorbs radiation over a wide range of wavelength because of different kinds of gases found in the atmosphere. Radiation from sun is in short wavelength range of 0.1-5 μ m, with peak at 0.55 μ m; while the long wave radiation emitted from the earth is in the range of 5-50 μ m, with peak at 10 μ m (Ray, 1987). Main absorbing gases in the atmosphere include oxygen, ozone, carbon dioxide and water vapour, which affect energy of various wavelength bands. Remote sensing avoids these absorption areas and concentrate on wavelengths bands which have low absorption and high transmission. The Visible, near infrared and thermal infrared regions are windows of low absorptions (atmospheric windows) and therefore of high transmission in a spectrum, which in other parts show high absorption of radiation (Jensen, 1986). SRS exploits these atmospheric windows for data collection as have been utilized in various empirical studies outlined below.

2.3 Empirical Literature on Application of SRS and GIS

Many scientists have utilized Satellite Remote Sensing and GIS in their studies. This section of the report reviews actual work by other researchers in which SRS and GIS technique were applied and could compliment the current study. Some areas of environmental concerns in which SRS and GIS have been applied included: baseline resource inventories, change detection and spatial sprawl analysis.

2.3.1 Baseline resource inventory

In study of baseline resource inventories in agriculture, National Aeronautical Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA) and US Department of Agriculture (USDA) carried out one of the largest experiment in SRS of agriculture in Large Area Crop Inventory Experiment (LACIE) to estimate production of wheat on worldwide basis (Erickson, 1984).

Landsat Multi-Spectral Sensor (MSS) data was used to estimate the land area under wheat growing and was used together with meteorological data provided through World Meteorological Organization and NOAA satellite for the estimation of the likely yields of wheat. The training areas were identified as wheat or non-wheat and computer classification of large sample areas followed based on the training set statistics. Estimates of wheat yield were made using regression models which related past wheat yields to weather statistics in each region. It was clear that all the LACIE estimates were close to final figure and was much better than conventional estimation methods. Improvements in spatial resolution with Landsat Thematic Mapper (TM) and the SPOT sensors were suggested as solution to some problems encountered in discrimination, for a more reliable estimation in future.

2.3.2 Change detection and sprawl analysis

Another principle benefit of SRS and GIS is its monitoring capability. The National Oceanic and Atmospheric Administration (NOAA) satellites have been used by scientists to prepare maps and analyses of continental and global scale vegetation and vegetation change. Justice *et al* (1985), as cited by Ray (1987), used image datasets prepared by NOAA to compute global vegetation index to analyze the global area coverage. The data was further used in the period of 1983 to 1985. There were, however, some limitations experienced. As much as Normalized Vegetation Index was an indicator of vegetation phenology, it might have been a poor measure of both biomass and leaf area index.

Wilkie and Finn (1996), in detecting change using SRS, suggested differencing techniques which involved registration of imageries from two dates, subtraction of the pixel values, one from the other and then analysis and classification of the resultant differenced imageries. Alternatively, imageries from two dates can be expressed as a ratio and size of the deviation from unity used to classify the degree and type of change (Townshend, 1981). Secondly, two sets of multi-band imageries can be registered and then unsupervised classification carried out on the resultant single set imagery on the basis that areas which have changed would form distinctive clusters in the feature space. Kristof *et al* (1977) as cited in Townshend (1981) applied this in study of coastal change in southern Texas. It was, however, concluded that classifying each set of imageries separately and then differencing the classified maps was preferred (Townshend, 1981), as later was used in this research.

Kenya Wildlife Service (KWS) and United Nation Environment Programme (UNEP) carried out an aerial survey of Mount Kenya in 1999 to provide factual information on the type, extent and location of destructive activities in the forest.

To determine forest cover changes, an assessment was undertaken between the years 2000-2002 under cooperation of Durrel Institute for Conservation and Ecology of University of Kent (DICE), KWS, UNEP, and the Kenya Forest Working Group (KFWG). Time series analysis of 1987, 1995, 2000 and 2002 Landsat TM imageries of 30 metres spatial resolution were carried out. Interpretation of the imageries were based on "true colour" composition of bands 1 (blue), 2(green) and 3(red), and "aerial truthing" by low flying to validate results of the satellite imageries. Areas of various cover classes were compared to monitor the cover change, thus achieving its main objective. It finally recommended the use of GIS for effective monitoring of changes in ecosystem, using among others aerial survey and satellite imagery.

Tachizuku (2002) undertook a study to monitor long-term urban expansion using SRS imageries from different sensors to detect change. The method employed in the change detection utilized Landsat TM imageries and compared the land-cover category mixing ratio in each pixel derived from different sensors. This method was applied in the city of Bangkok with Landsat TM imageries for a period of 10 years to evaluate long term cover changes in the city.

Department of Resource Survey and Remote Sensing (DRSRS) of Ministry of Environment and Natural Resources (MENR) undertook a joint project to map land use and land cover changes in Kakamega forest between 1975 and 2005. This was necessitated by changes that had occurred in the forest due to several factors such as illegal excision, selective cutting of commercially viable trees, unauthorized settlement and uncontrolled grazing, like in many other forests in the country. Main objective was to provide information and generate database on status of Kakamega forest resources and its ecological changes to facilitate sustainable management geared towards conservation.

Landsat imageries of 1975, 1986 and 2000 were independently classified; the resulting individual cover type percentages were calculated and compared to show the land cover change analyses (Situma *et al*, 2005).

In the year 2003, forest cover mapping of Mau forest complex was undertaken by DRSSRS as a priority following the controversial illegal settlements. The forest was about 400,000 hectares and comprised of various blocks. Being a very important catchment area, and source of rivers such as Mara and Rongai, it became of paramount importance to map this forest. The method involved digitizing Landsat satellite imagery of 2003, which had prior been composited using spectral bands 3 2 1 for Red, Green and Blue respectively before performing unsupervised classification. The classification was aided by data from field sample points and aerial photography. The gazzeted forest land boundary was overlaid on classified image to clip the area under study. The whole of Molo forest was found to be under cultivation. However, the most intact of the 22 gazzeted forest blocks in this complex, was Chemogorok which had only lost 0.35% of its original coverage. Through the use of SRS data the objectives of mapping the forest complex, assessing the status and quantifying the area under different classes in each forest blocks were achieved.

In Change detection and spatial sprawl analysis, studies have been done in which SRS technique has been applied to examine changes in Kenya's five water catchments areas. Akotsi *et al* (2003) utilized image differencing and Normalized Difference Vegetation Index techniques with Landsat imageries to highlight areas within Cherengani, Aberdare, Mau, Mount Elgon and Mount Kenya where forest cover had been depleted. The study achieved its objective of mapping changes in the catchment areas and informing the stakeholders in forest management about extent of the depletion.

In India, Institute of Remote Sensing, in the year 2000, carried out a study to identify and map slums using IKONOS (1m by 1m and 4m by 4m) satellite imageries and assess environmental impact of the slum using GIS, supported by ground verification. The slums were identified on the basis of visual interpretation and were captured manually by on-screen digitization method. Detailed mapping of Dehradun slum area was carried out and database was prepared with the help of a structured questionnaire (for household and physical infrastructure). Parameters taken for the case study were individual condition of houses like: roof material, wall material, access to houses, drainage, water supply, electricity, sewerage, sanitation and street lighting. The study achieved its objective of locating the slums and identified the physical characteristics of slum areas that were interpreted through high-resolution Ikonos satellite imageries.

High-resolution satellite imagery (Ikonos satellite data acquired in April 2000) was used to identify and delineate slums in Dehradun to detect changes that had taken place in terms of slum spatial sprawl and development, and to map condition of such environment. GIS was used to identify slum areas that had fallen under flood vulnerability.

2.4 Limitation of Satellite Remote Sensing

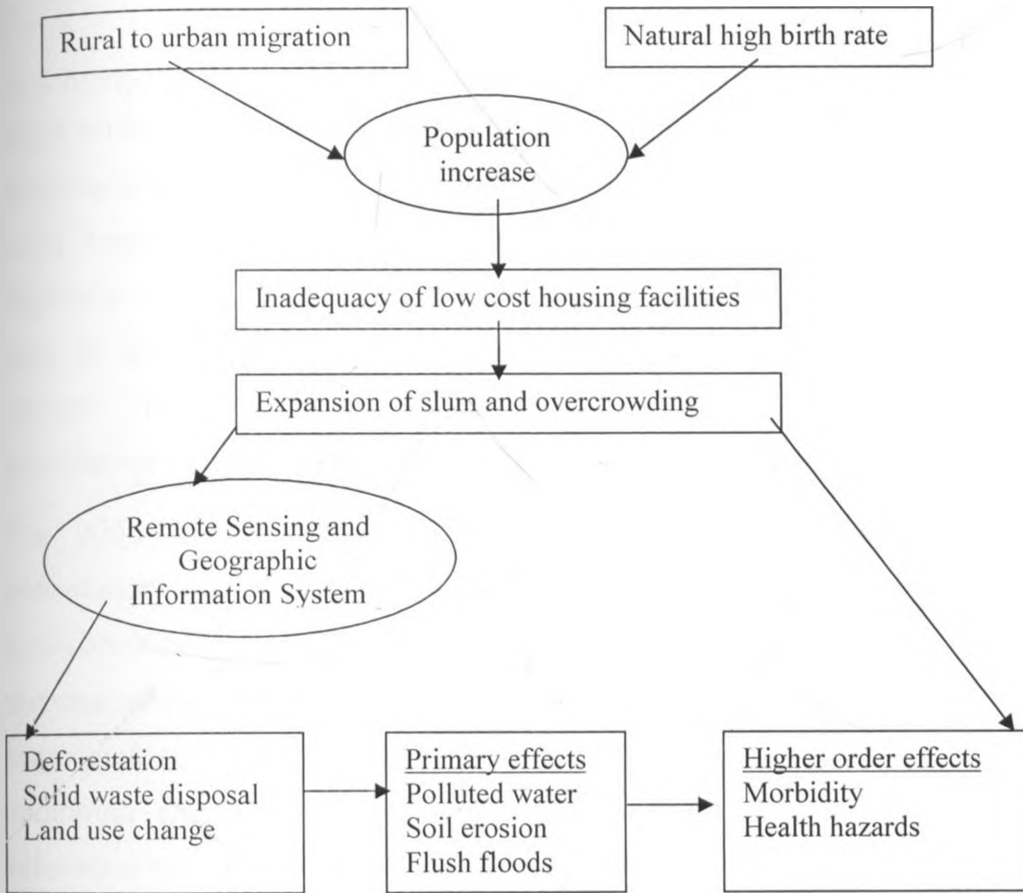
Considering the available literature in application of SRS and GIS, monitoring capability has had numerous applications. However, this potential has been hindered by the fact that there are frequently many differences between images other than those indicative of the terrain characteristics to be monitored (Lintz and Simonett, 1976; Jensen, 2000). For example, differences due to contrast in sun elevation and azimuth, and changes in atmospheric conditions, would need to be minimized. There are also other changes that occur concurrently with those being monitored causing difficulty and confusion. Such changes may operate over very different time scales from diurnal through seasonal, annual and much longer period. Aronoff (2005) suggested that imageries with similar calendar dates acquired at the same time of the day should be used to reduce effects of such changes and help overcome some of these problems.

2.5 Conceptual Model

The conceptual model figure 2.1, adopted by this study in analyzing spatial sprawl of Kibera identified population increase as the main cause of expansion. Both rural to urban migration and natural high birth rates result in demographic changes within urban centres. Employment opportunities might be overstretched by increased human population in these urban centres. This could lead to the populace inability to afford better housing facilities. Consequently demand for low cost housing facilities escalates and the landlords in slum tend to put up many shanties to tap the available and increasing demand for cheap housing. In addition, the urban immigrants who had access to land often put up their own structures with cheapest available materials.

Uncontrolled spatial expansion of the shanties may result in cutting down of adjacent forest cover to give room for makeshift structures. In some cases where there is no further room for such spatial expansion, extensions were erected on the old buildings resulting in overcrowded contiguous rows of small housing units with only narrow foot path access. Lack of drainage system and sanitation facilities may lead to improper solid and waste water disposal within the surrounding. Consequently pollution of water courses traversing such settlement become commonplace. Soil erosion and flash floods may be experienced more frequently due to lack of vegetation cover. Overcrowding in the settlement, presence of polluted water and poor sanitation precipitates into health hazards resulting into high morbidity.

Figure 2.1: Conceptual Model:



Key

→ Leads to

CHAPTER THREE

METHODOLOGY

3.1 Introduction

Data analysis was largely based on spatial analysis techniques including visual and digital image processing as well as GIS analysis function. Scenario creations were based on overlay, image differencing analysis together with systematic digitization. Collected field data were integrated with spatial remote sensing data sets to create GIS databases on which most of the spatial variables were derived. The results of spatial analysis generated both qualitative and quantitative spatial information on Kibera spatial sprawl.

The 2004 Quickbird imagery of Kibera, (image 3.1), constituted the main delimitation tool for study area. The imagery served to mark the boundary between Kibera and other neighbouring areas. Physical infrastructure, waste disposal sites, settlements, administrative units (villages), vegetation cover and water surfaces were identified and marked on the Quickbird imagery. Resulting photomap was used as a control unit of Kibera current status in order to determine the spatial sprawl and changes in land cover and land use. Landsat Thematic Mapper (TM) imageries dating back from February 1976, February 1987, January 1995 and February 2002 (image 3.2, 3.3a, 3.3b, 3.4a, 3.4b, 3.5a and 3.5b) were also used in the spatial sprawl analysis, identification and quantification of land cover and land use changes within Kibera based on 2004 Quickbird imagery delineation.

3.2 Sampling Design

Sampling units consisted of selected households in Gatwekera village of Kibera and research questionnaires were used to collect data from sample population through field interview. The interviewees were adult members of selected households within Gatwekera village and must have been residents in Kibera for at least six months to have had thorough knowledge of the study area.

Random probability sampling method was used to select respondents for this study. According to Kish (1965), 30-200 elements are considered sufficient for sample size when the distribution approaches normality; therefore, a sample size of 35 respondents was considered sufficient for this study. Due to time and financial limitations, Gatwekera village, the largest of the ten Kibera villages was used as a case study from which study sample was drawn for administering of questionnaires. In drawing the sample population ERDAS imagine 8.5 software was used to randomly generate 35 geospatial coordinates within Gatwekera village, which were later, located on ground with the help of GPS receiver and the housing unit closest to each one of these points located on ground.

3.3 Instruments of Data Collection and Processing

The instruments and equipment used in data collection and processing included the following:

- i. Personal computer with ERDAS imagine 8.5 and ArcView 3.3 processing software used in processing and analysis of digital datasets and other geo-spatial information.
- ii. Handheld Global Positioning System (GPS) receiver used in capturing geo-spatial coordinates of sample points during ground truthing.
- iii. Standard questionnaire for collection of the qualitative data.

3.4 Data Types and Sources

Both secondary and primary data were used in the spatial analysis of Kibera sprawl and the associated environmental impact. Various data types and sources used to solve the research problem and meet objectives of the study are discussed below.

3.4.1 Secondary data

Secondary data used were largely satellite imageries as indicated in table 3.1. These were collected from Regional Centre for Mapping of Resources for Development (RCMRD), at Kasarani, Nairobi, Kenya.

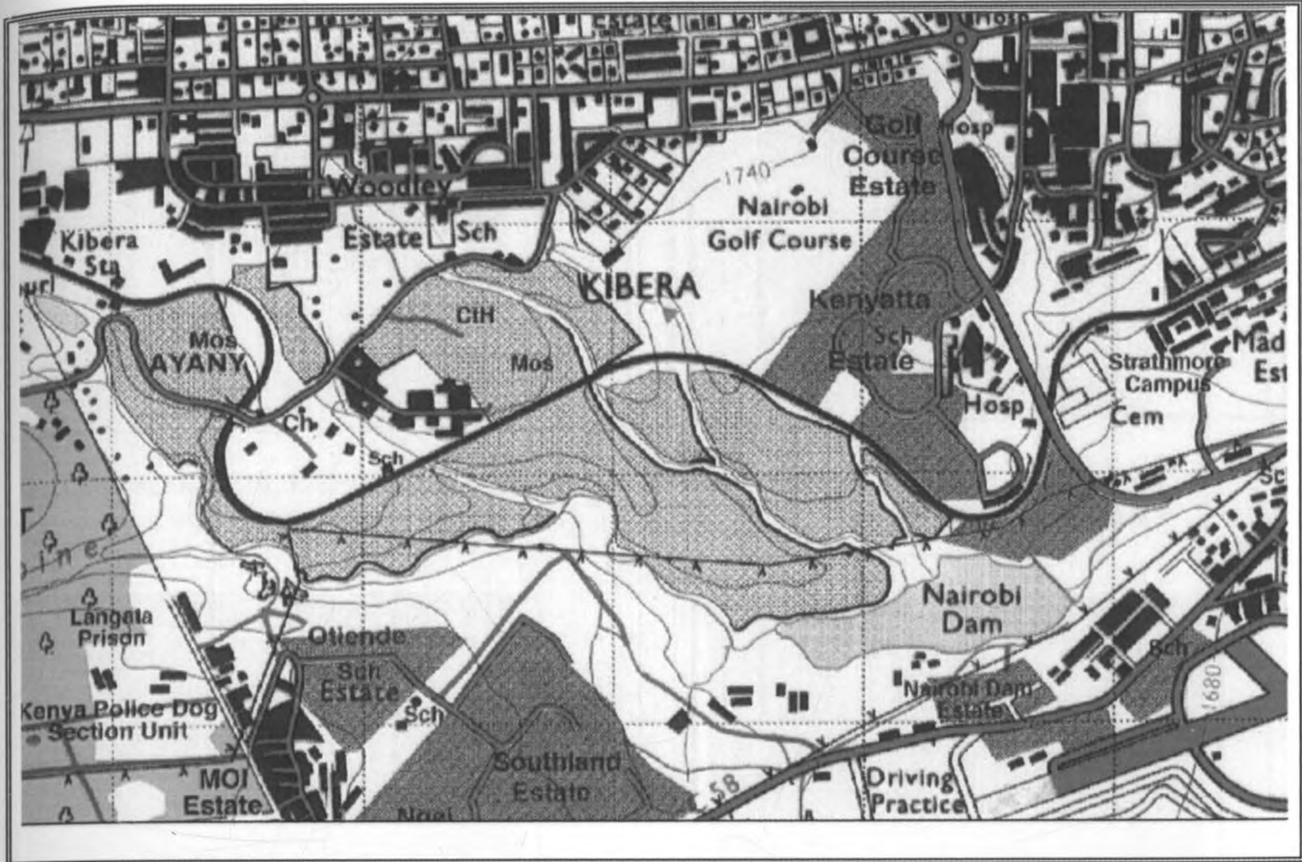
Landsat Thematic Mapper (TM) imageries were used mostly to map Kibera spatial sprawl and land cover and land use changes while QuickBird imagery was used to delimit actual Kibera sprawl boundary as at 2004, and to identify major geographical features within Kibera used in analysis of Landsat imageries. The land covers mapped included vegetation, bare surfaces and water bodies (river) while land use mapped included built up area (residential and commercial) and physical infrastructures.

Table: 3.1 Required spatial data from secondary sources

DATASETS	YEAR OF ACQUISITION	DATA SOURCE
<i>Landsat (TM) digital satellite imageries of Kibera and environs</i>	1976, 1987, 1995 and 2002 Resolution 30x30m metres	Regional Centre for Mapping of Resources for Development (RCMRD)
<i>Quickbird imagery of Kibera and environs</i>	2004, Resolution 0.61x0.61 metres	RCMRD
<i>Topographic Maps of Nairobi (Digital) Scale 1:50000</i>	1990	Survey of Kenya (SoK)

3.4.2 Spatial data capture

Spatial data were in the form of remotely sensed data based on QuickBird and Landsat Platforms. The QuickBird imagery (image 3.1) was for the year 2004 and its purpose was to assist in delimiting Kibera sprawl and in identification of various landmarks and spatial objects that could be used to represent change. Topographical map of Nairobi (map 3.1) was used in identification of some features within Kibera and in geo-rectifying of the satellite imageries. Landsat imageries of 1976, 1987, 1995, and 2002 (images, 3.2, 3.3a, 3.3b, 3.4a, 3.4b, 3.5a and 3.5b) were specifically used in spatial sprawl analysis, land use change detection and quantification.



Map 3.1: Topographical map of Nairobi



Image 3.1: Nairobi, 2004 QuickBird imagery



Image 3.2: Nairobi, 1976 Landsat false colour composite imagery

The white and black patches on the 1987 Landsat imagery (image 3.3a and 3.3b), indicate cloud cover and shadows respectively. This cloud and shadow effect, however, did not affect Kibera area significantly which was of interest to this study.

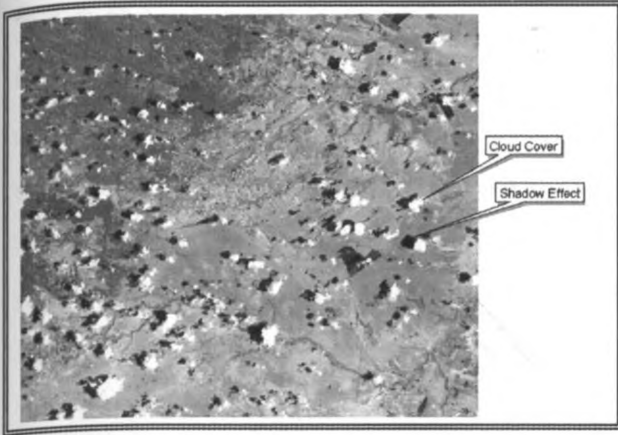


Image 3.3a: Nairobi, 1987 Landsat false colour composite imagery

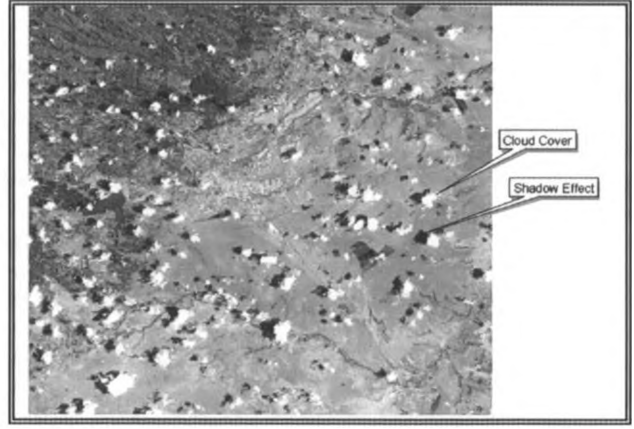


Image 3.3b: Nairobi, 1987 Landsat true colour composite imagery



Image 3.4a : Nairobi, 1995 Landsat false colour composite imagery



Image 3.4b: Nairobi, 1995 Landsat true colour composite imagery



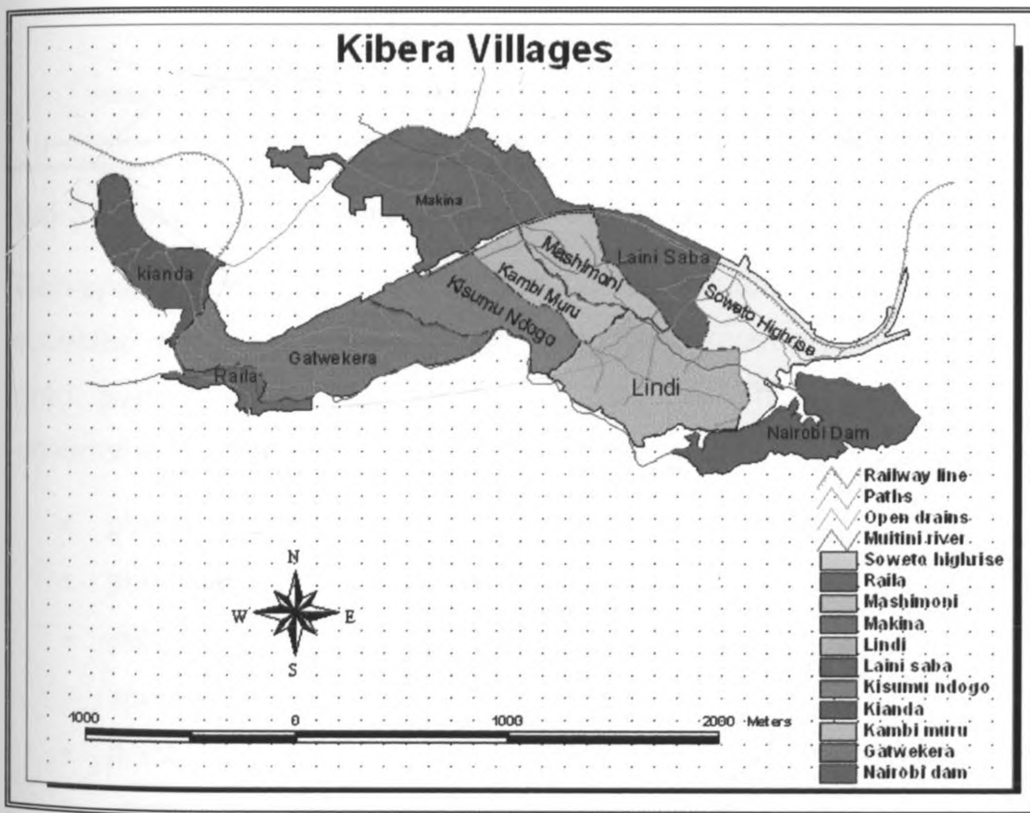
Image 3.5a: Nairobi, 2002 Landsat false colour composite imagery



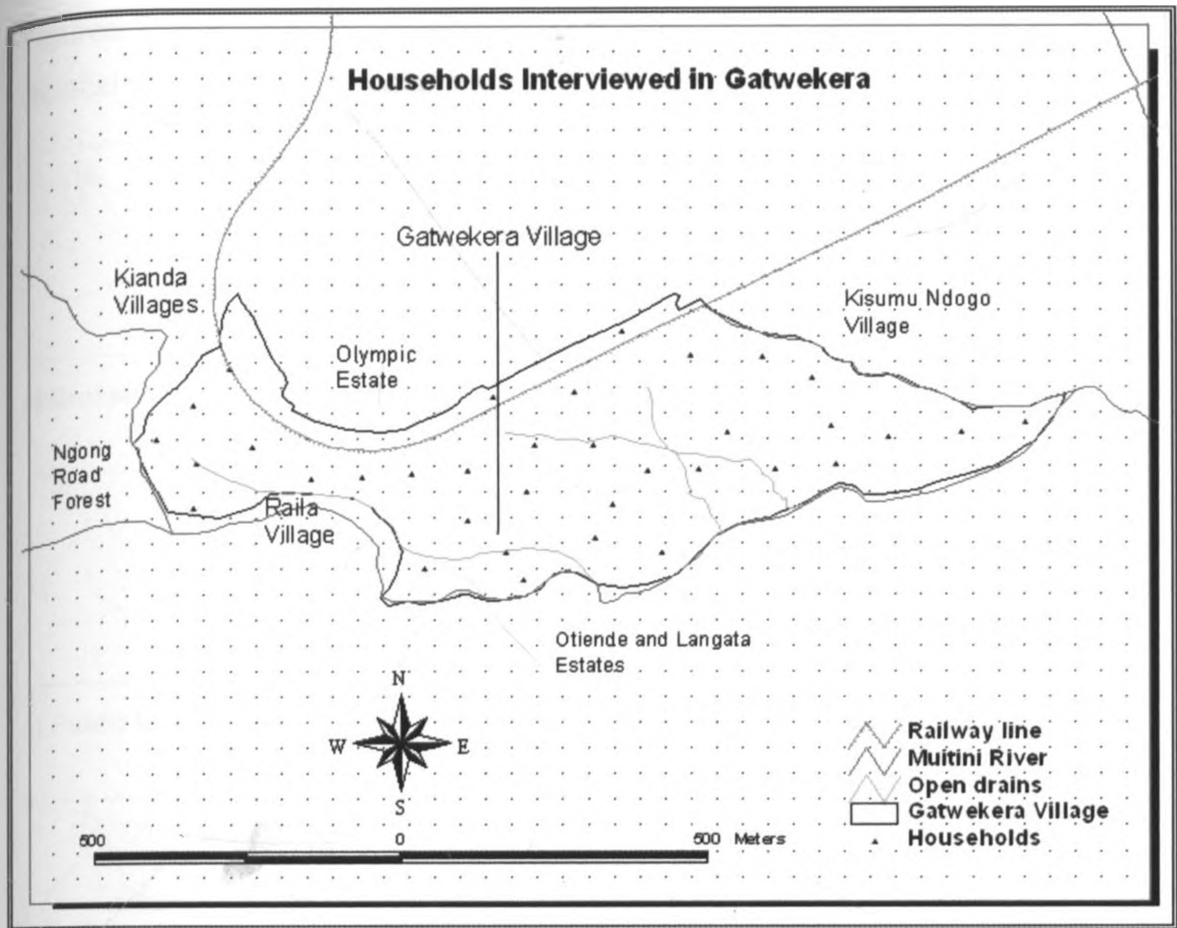
Image 3.5b: Nairobi, 2002 Landsat true colour composite imagery

3.4.3 Primary data

Primary data consisted of spatial and non-spatial variables. Field observations and interviews were carried out in a survey to capture information on non-spatial environmental parameters such as household characteristics, service provision, health, migration patterns and housing conditions within Gatwekera village in Kibera. Questionnaire including an observation table were the instruments of data collection. As earlier indicated, a total 35 adult respondents were interviewed to obtain information required for analysis. GPS receiver was used to locate on ground the points which had been randomly generated within Gatwekera village using ERDAS imagine software. For each of the 35 points located, the nearest household in each case was selected for interview. Map 3.2 and 3.3 show the ten villages in Kibera and the locations of housing units that formed the sample population within Gatwekera village respectively.



Map 3.2: The ten Kibera villages
(Source: Regional Centre for Mapping of Resources for Development)

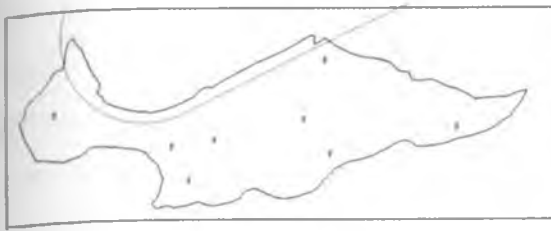


Map 3.3: Locations of households interviewed in Gatwekera (Source: Field work)

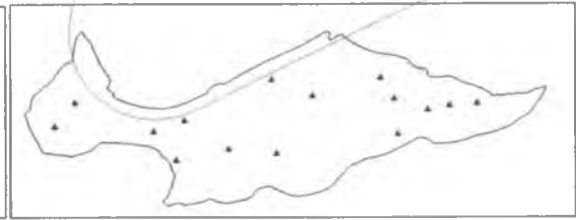
Geo-spatial coordinates of various spatial variables of interest were also collected within Gatwekera village using GPS receiver, and later downloaded onto personal computer for further studies. This included the following environmental points of interest (EPOI):

- public water points
- public ablution blocks
- public toilets
- spots of garbage dumps
- points of direct discharge of latrine effluent into open drains/river system
- street lights (flood lights in the whole of Kibera slum)
- points of broken water pipes

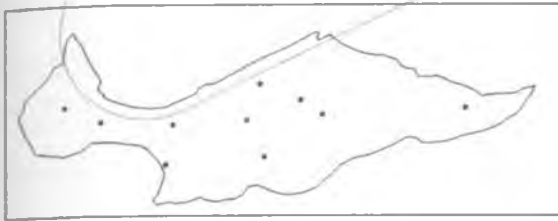
Figures 3.1a-g, indicate spatial locations of the environmental points of interest (spatial variables) captured in the field survey in Gatwekera village.



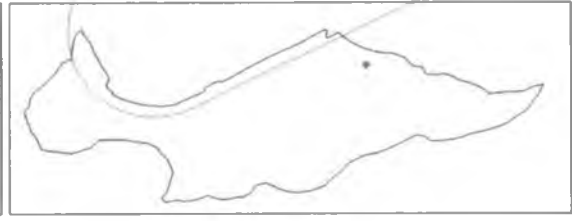
a) Broken water pipes



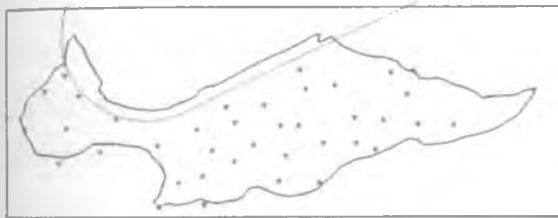
b) public water points



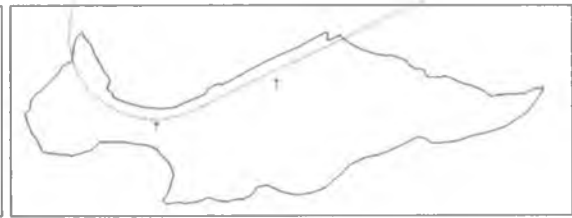
c) Public toilet/ablution blocks



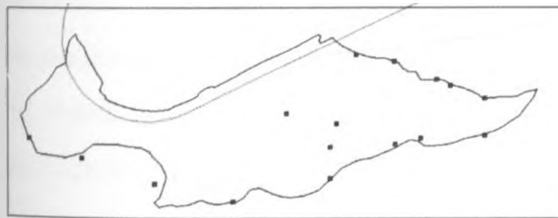
d) Health centres



e) Garbage dumps



f) Flood lights



g) Direct effluent discharge to river or drain

Figures 3.1a- g: Environmental Points of Interest, Gatwekera

3.5 Data Processing and Analysis

This involved preparation of image datasets for spatial analysis of Kibera sprawl, processing and analysis of questionnaires results.

3.5.1 Digital image processing

Satellite image data are transmitted to earth as digital values of response of each pixel in the wavelength employed in the sensor (Jensen, 1986). The digital values have to be processed into a more meaningful form. Processing of digital values involved image band compositing, standard deviation stretch and geometric registration (geo-referencing) of 1976, 1987, 1995 and 2002 Landsat TM imageries. Wavelength bands 4, 3 and 2 (infra-red, red and green) were used in every imagery to form false colour composite in which red, green and blue colour (RGB) channels were represented by wavelength bands 4, 3 and 2. Spectral resolutions for blue, green, red and infra-red bands were: 0.45-0.52, 0.52-0.60, 0.63-0.69 and 0.76-0.90 micrometers respectively; while the radiometric sensitivity were 0.8, 0.5, 0.5 and 0.5 for blue, green, red and near infra-red bands.

False colour composite of Landsat TM bands 4 (infra-red), 3 (red), 2 (green) and 1 (blue) were represented by red, green, blue and black colours respectively. The combinations of these bands were used in land cover and land use mapping, however, the accuracy of the results obtained tended to be low especially in areas of highly mixed cover classes (Jensen, 2000). In addition, true colour composite was also formed to aid in visualization where the false colour composite did not suffice. The composites were in geotiff format for easy display and manipulation by ERDAS IMAGINE 8.5 and ArcView 3.3 software. For better visualization, standard deviation stretch was applied on the image composites.

3.5.2 Geo-referencing of the imageries

Topographical map of Kibera was used in geo-referencing of satellite imageries. Four well distributed ground control points (GCPs) in UTM coordinate system, with Arc 1960 as the datum and Clark 1880 (modified) as the spheroid in the referencing system, were identified on both the imagery and the map. Based on the four GCPs transformation matrix was computed and used in geo-rectifying the imagery, with root mean square error of 0.3545m.

This was acceptable error according to Drury (1998) that considered root mean square error of 0.5 to be acceptable. Geo-referenced master imagery was used to register the remaining imageries. This enabled various GIS analyses to be performed on the imageries such as image differencing and overlay operations.

3.5.3 Ground survey

Reconnaissance was carried out and subsequent field trips followed for ground verifications. GPS receiver was used to collect sample points together with descriptive accompanying notes which assisted in classification of Kibera Landsat imageries. Aerial photographs acquired also provided secondary “ground truth data”.

3.5.4 Generating spatial information on environmental change in Kibera

This involved vectorization of Kibera QuickBird imagery to delineate the area of interest (AOI). The 2004 QuickBird imagery for Kibera was displayed on ArcView 3.3 program window (image 3.6). New polygon theme, the area of interest (AOI), was then created using QuickBird imagery for Kibera. Result of this process was as in figure 3.2, defining extent of Kibera as at 2004, and the year of acquisition of the QuickBird image.



Image 3.6: Digitized boundary of Kibera

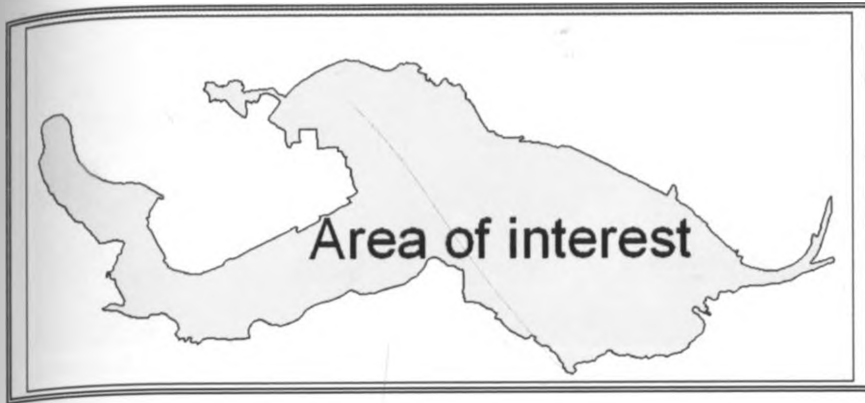


Figure 3.2: Area of interest (AOI), based on 2004 QuickBird imagery

3.5.5 Generating environmental change information using area of interest

The AOI (figure 3.2) was used to clip the Landsat false colour imageries in ERDAS imagine 8.5 software environment. TIFF format imageries to be clipped were opened one at a time on ERDAS imagine Viewer window. On the same Viewer, shape file of the AOI of Kibera was displayed. The TIFF format imagery was then clipped based on Kibera AOI using ERDAS imagine image clip tool, creating an output image file. This procedure was performed consecutively for all false colour Landsat imageries, starting with 1976, 1987, 1995 and finally 2002. Results of the clipped imageries based on 2004 Kibera AOI, were displayed (image 3.7, 3.8, 3.9 and 3.10).

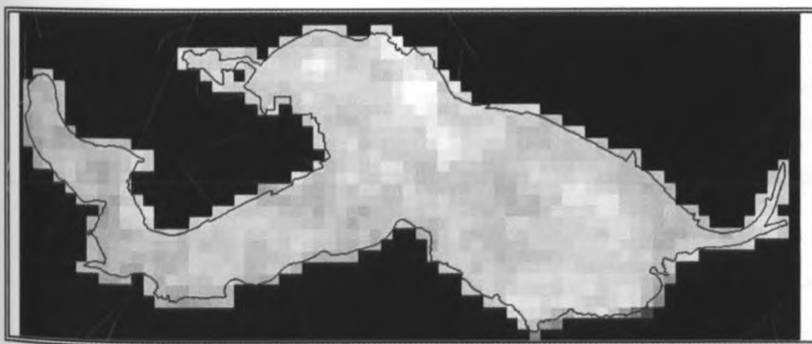


Image 3.7: Kibera 1976 clipped Landsat imagery

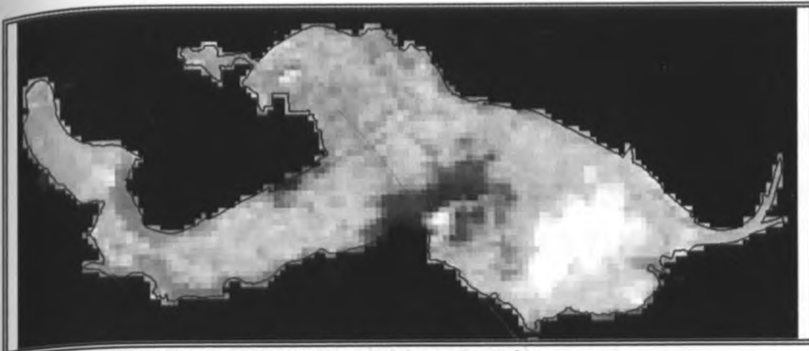


Image 3.8: Kibera 1987clipped Landsat imagery

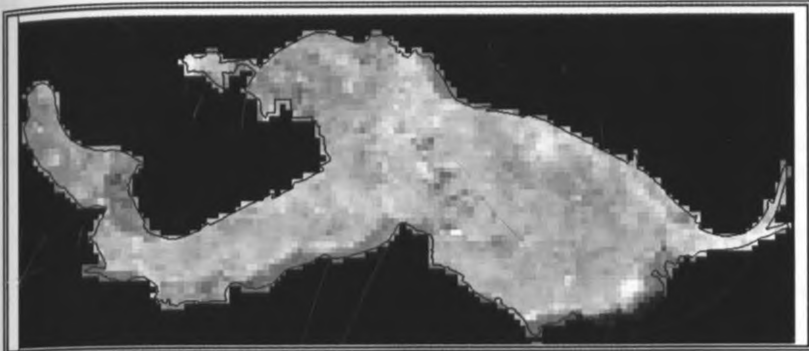


Image 3.9: Kibera 1995 clipped Landsat imagery

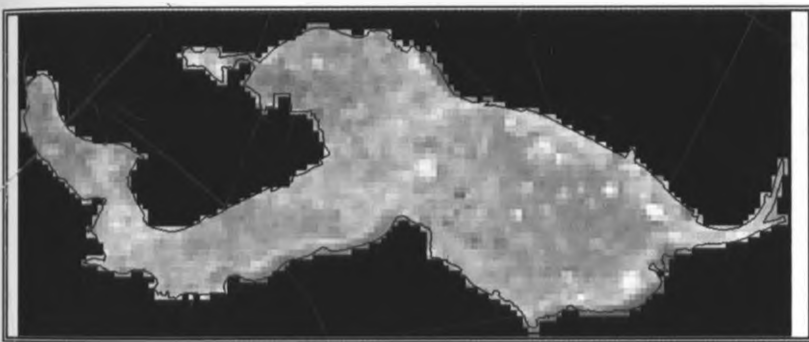


Image 3.10: Kibera 2002 clipped Landsat imagery

3.5.6 Time series spatial delineation of Kibera

Delineation of Kibera was successively done based on 1976, 1987, 1995, 2002 Landsat imageries and finally on 2004 QuickBird imagery. The 1976 false colour composite Landsat imagery was opened in ArcView program. New polygon theme for 1976 Kibera boundary was created with general snap environment set to 0.0004m. Onscreen interactive digitization of the boundary was then performed based on visual image interpretation of the false colour, true colour composites and classified thematic classes of 1976 Landsat imagery. This resulted in Kibera spatial boundary delineation based on 1976 Landsat imagery.

The above procedure was performed on 1987, 1995 and 2002 Landsat imageries, each at a time, to successively obtain Kibera spatial boundary delineation at each image date. Final results were displayed alongside Kibera delineated area of interest earlier based on vectorization of the 2004 QuickBird imagery (figures 3.3, 3.4, 3.5, 3.6 and 3.7).

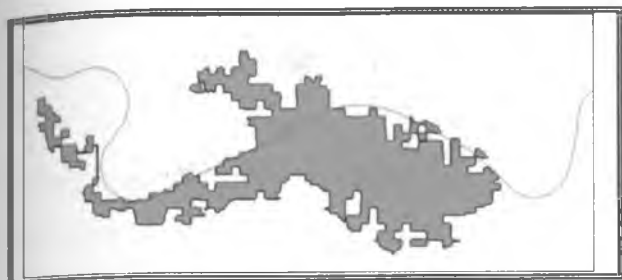


Figure 3.3: Kibera 1976 spatial boundary

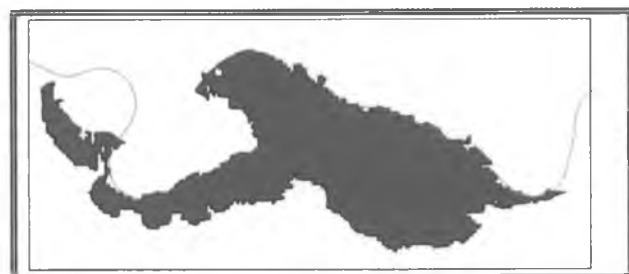


Figure 3.4: Kibera 1987 spatial boundary,

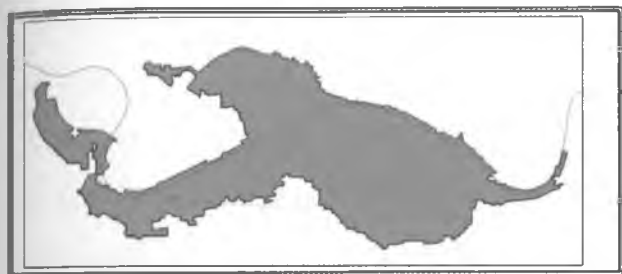


Figure 3.5: Kibera 1995 spatial boundary

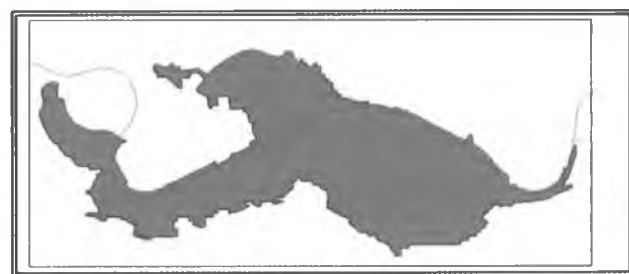


Figure 3.6: Kibera 2002 spatial boundary

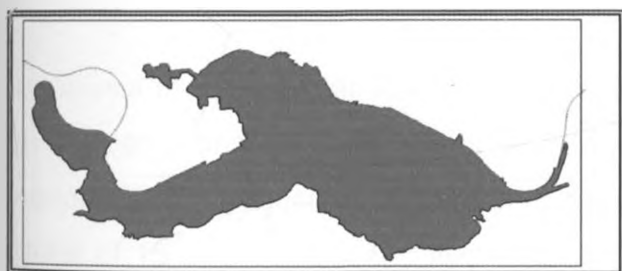


Figure 3.7: Kibera 2004 spatial boundary

3.5.7 Time-series spatial change analysis of Kibera

Time series analysis of Kibera spatial sprawl and change was considered in two ways: first, in terms of spatial expansion of the slum extent (external boundaries) and; secondly in terms of land use and land cover changes that occurred within the bounds of Kibera over time. QuickBird and Landsat imageries were used in both of these aspects of the spatial sprawl analysis as further explained in the following subsections.

Overlay operations

Figures 3.2, 3.3, 3.4, 3.5 and 3.6 of Kibera spatial boundaries were used to depict areal expansion of the slum overtime between each two dates of image acquisition. Overlay operations were performed on various Kibera delineated boundaries in ArcView environment. First, the registered 1976 Kibera boundary was overlaid on 1987 Kibera boundary. Subsequently, the operation was repeated between 1987 and 1995 spatial delineated boundaries; 1995 and 2002 delineated boundaries and finally between 2002 and 2004 delineated boundaries. Results of the above overlay operations were shown in chapter four (figures 4.1a, 4.1b, 4.1c and 4.1d).

Image classification

Strong arguments in the recent years have stressed the application of unsupervised approach, in regions with more natural, non-agricultural terrain. Townshend (1981) argued against the use of supervised methods even for land use surveys because of difficulty in obtaining unique spectral signatures, as a result of differences in, for example, scene illumination, atmospheric conditions, crop maturity, plant health or variation between species.

In analysis of Kibera spatial sprawl and land use and land cover change studies, the clipped Landsat false colour composite imageries were classified using unsupervised approach in ERDAS imagine 8.5 software. The classifier generated a total of 15 spectral classes in the output cluster layer file. Using ground truth data and information, the classes were later combined to obtain three major thematic cover classes: built-up, forest/ vegetation cover and bare ground. This procedure was performed for all clipped false colour composite Landsat imageries, starting with the 1876, 1987, 1995 and finally 2002 imageries for a subsequent cover change analysis. Figures 4.2a, 4.2b, 4.2c and 4.2d in chapter four indicate thematic cover classes obtained for each image date.

Quantification of cover class areas

Three main land use and land cover classes used in image interpretation and subsequent analysis included: forest/vegetation, built-up area and bare ground. ERDAS imagine software used in the unsupervised classification of the Landsat imageries, generated the three cover classes and their respective areas in hectares in the attribute table. Table 3.2 indicates the areas of thematic classes obtained from classification of 1976, 1987, 1995 and 2002 clipped Landsat imageries. Respective cover class areas in each of the image classification results, indicated in table 3.2, were later used in quantification of land cover and land use change discussed in chapter 4 of this report.

COVER TYPE CLASS	1976 AREAS (HECTARES)	CLASS	1987 AREAS (HECTARES)	CLASS	1995 AREAS (HECTARES)	CLASS	2002 AREAS (HECTARES)	CLASS
Built-up	111.3142 (42%)		143.4434 (55%)		183.9747 (70%)		209.3169 (80%)	
Light vegetation	130.5086 (50%)		74.1585 (28%)		37.4447 (14%)		19.8189 (8%)	
Bare ground	20.4434 (8%)		44.6738 (17%)		40.9374 (16%)		33.2088 (12%)	
TOTAL AREA (hectares)	262.2662 (100%)		262.2757 (100%)		262.3568 (100%)		262.3446 (100%)	

Table 3.2: Thematic class areas, 1976, 1987, 1995 and 2002 classified imageries

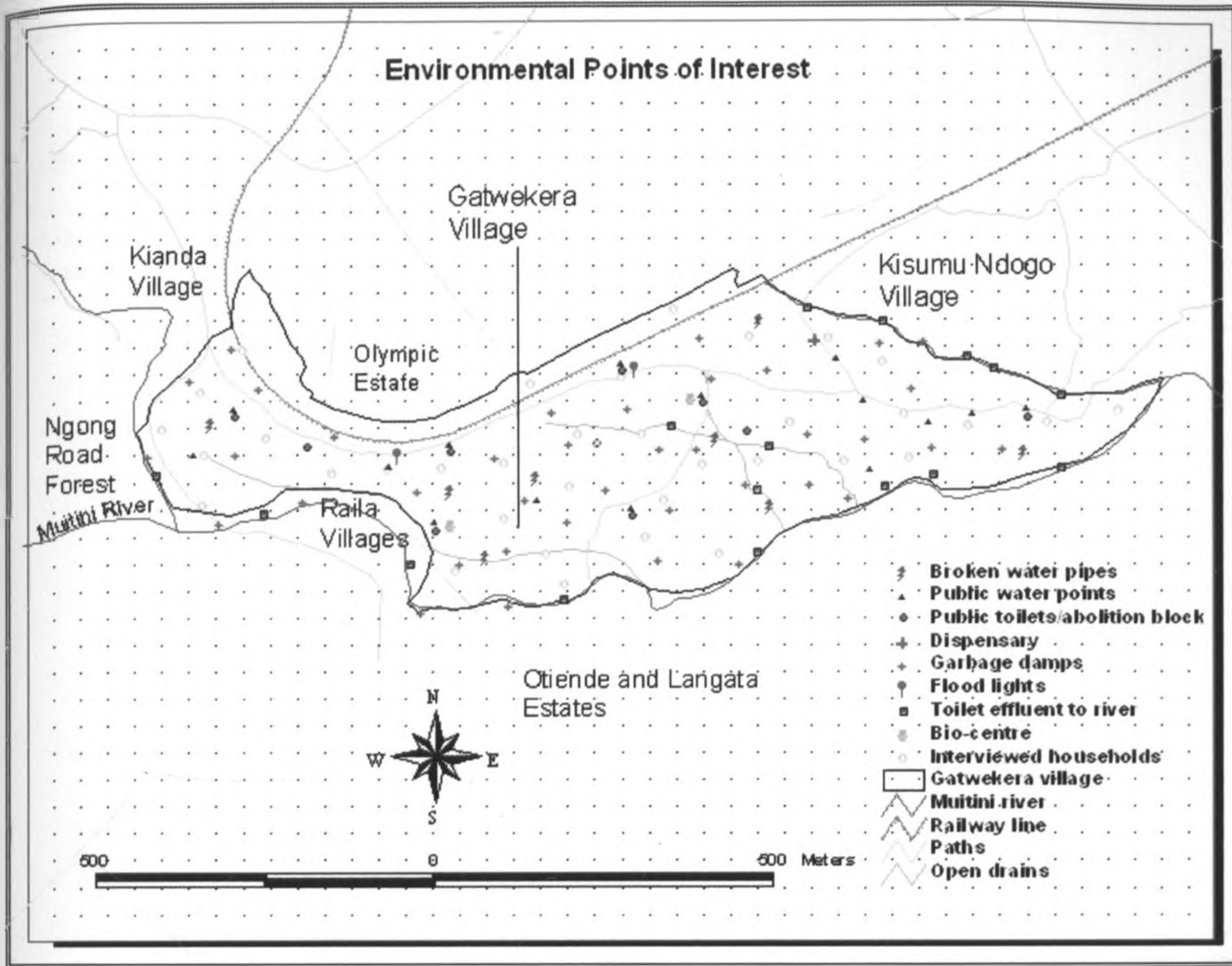
Image differencing

Geo-referenced clipped Landsat imageries were used in detection of land cover and land-use changes that had occurred within boundary of Kibera between 1976 and 2002 (delineation based on 2004 QuickBird imagery). ERDAS imagine 8.5 software was used to perform image differencing operations for change detection. First, "the before image" (1976 clipped false colour composite imagery) and "the after image" (1987 clipped false colour composite imagery) were loaded. Secondly, the image difference file image and the highlight change file image were specified, thereafter the software left to run.

This procedure was repeated between successive dates of the clipped false colour composite imageries as follows: 1987 and 1995; 1995 and 2002. The image difference files and the highlight change files obtained were displayed in chapter four (figures 4.3a, 4.3b and 4.3c)

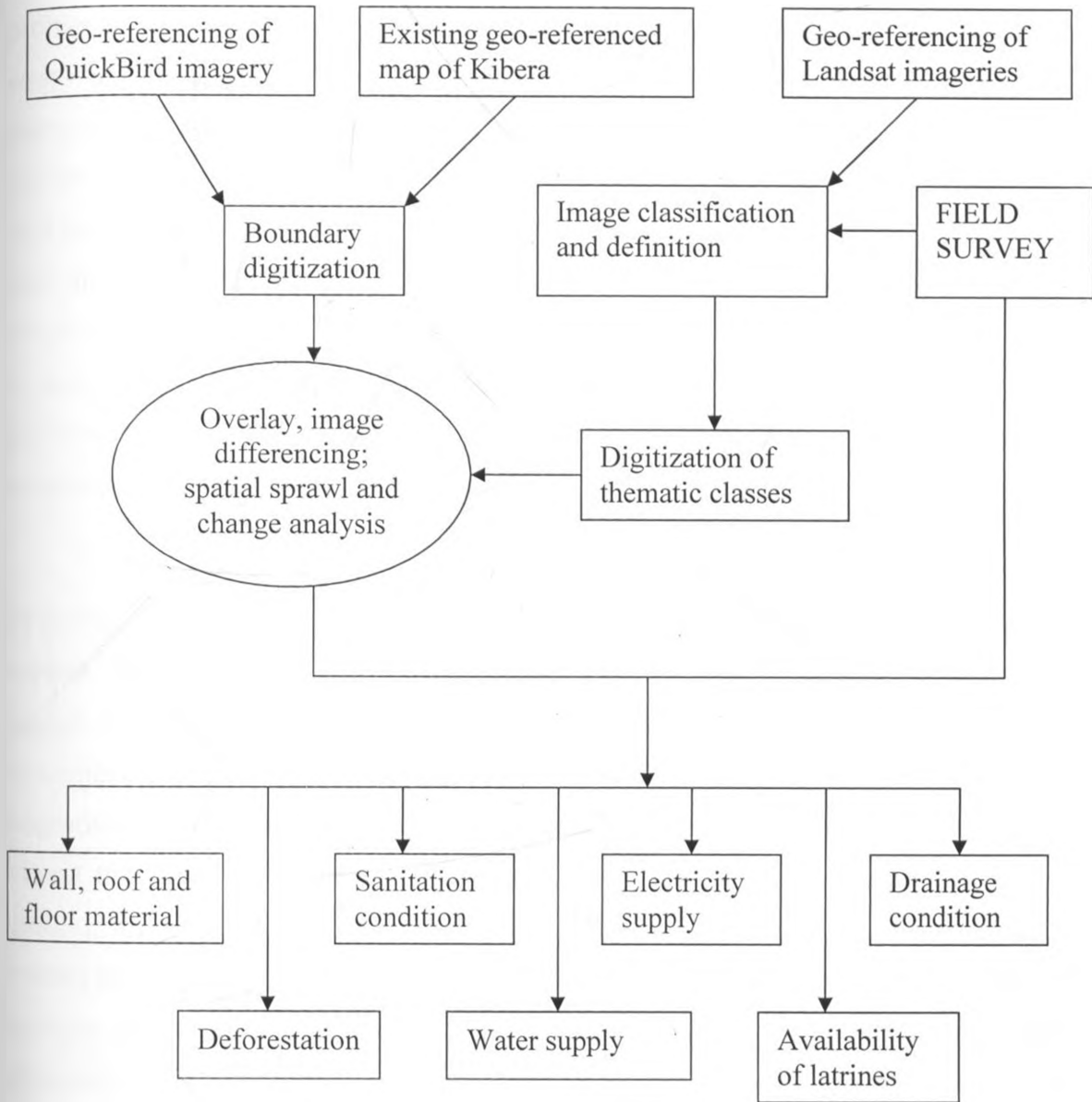
3.6 Analysis of Field Data

Analysis of questionnaires results exploited the use of Statistical Package for Social Sciences (SPSS) software. First, data entry scheme was prepared in SPSS in accordance with the coding of the questionnaires. Coded questionnaire data was entered into computer environment for analysis by SPSS software. Both frequencies and descriptive statistics were applied in the analysis of different variables. Related data were also cross-tabulated to establish how they changed with time. The field data results were used to evaluate factors which had influenced Kibera spatial sprawl pattern. Based on the established pattern of expansion and factors behind it, environmental impact of Kibera and its spatial expansion were evaluated and documented.



Map 3.4: Environmental points of interest in Gatwekera village (Source: Field work)

Figure 3.8: Methodology for spatial analysis of Kibera sprawl and environmental impact



3.7 Study Limitations

Various limitations were encountered in this study. First, this study had intended to make use of satellite imageries of anniversary (same calendar) dates. Due to problems in data sourcing and availability this could not be achieved for all the years of image acquisition. Only Landsat imageries of 1976, 1987 and 2002 were of the same month of February, while 1995 Landsat imagery was of the month of January. In analysis of Kibera spatial sprawl and monitoring of land use and land cover change, the accuracy of results obtained for spatial sprawl, land-use and land-cover changes could have been lowered, since other changes introduced by seasonal atmospheric variation, may have manifested themselves in areas where no cover change had actually occurred. Jensen (2000) advised on use of imageries of anniversary dates to reduce the effect of seasonal variation in monitoring of cover change.

Secondly, the resolution of 1976 Landsat imageries was about 50x50 square meters, while those of 1987, 1995 and 2002 Landsat imageries were 30x30 square meters. This made it difficult to apply various spatial GIS analyses unless re-sampling procedures was carried out, which had consequent effect of degrading the qualities of original imageries. Moreover, both of these resolutions meant that one pixel represented reflectance from a very large portion of the ground; and given the sizes of housing units in Kibera being limited to about 5 meters by 5 meters, the reflectance captured on a pixel could be of an average of various land-covers. This could lower the accuracy of monitoring information obtained especially when the area of study was small and predominantly constituted of small and mixed structures like in Kibera. The QuickBird imagery of 2004 used was of a high resolution, and was utilized in delineation of Kibera boundary. However, for detailed spatial sprawl analysis and monitoring of land use and land cover changes in Kibera; other QuickBird imageries could not be obtained. This left no option except to use the coarse resolution Landsat TM imageries in the spatial sprawl analysis and cover change detection.

This study had also intended to use decadal image dataset to establish and project Kibera spatial expansion trend and the land use and land cover changes that occur between definite time periods. However, as already indicated due to problems in data sourcing in addition to cloud cover in some of the imageries, decadal image datasets could not be used. Instead 1976, 1987, 1995, 2002 and 2004 images were used in this study.

Finally, the study had intended to make use of latest available QuickBird and Landsat imageries as at 2008 in the analysis, to obtain most up to date information on Kibera spatial sprawl, lands use, land cover change and the environmental impact. However, as already indicated, this study used Landsat imageries of 1976, 1987, 1995 and 2002 being the latest; and QuickBird imagery of 2004 which could be acquired. Therefore, the results obtained may not accurately represent the actual spatial sprawl; land use and land cover change in Kibera as at the present or time of writing of this report.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Kibera Spatial Sprawl

Various analyses performed on Kibera Landsat and QuickBird imageries indicated that Kibera has been expanding over time. The spatial sprawl of the settlement has been two fold. First, spatial analysis indicated external expansion of Kibera into the immediate neighbourhood. Secondly, internal expansion (densification) of the settlement had also occurred over time period considered in this study. The following subsections details these two aspects of Kibera spatial growth.

Kibera spatial boundary change

Kibera boundary had undergone rapid spatial expansion over time frame considered in this study. First, overlay of 1976 Kibera spatial boundary onto 1987 boundary (figure 4.1a) indicated that Kibera had expanded in area. The boundary expansion was rapid along the railway line to the north of the settlement. In the overlay for 1987 and 1995 boundary delineation (figure4.1b), boundary of the settlement continued to expand along the railway line and Mwitini River and its tributaries. This trend in spatial boundary sprawl continued over the periods 1995 -2002 and 2002-2004, as illustrated in figures 4.1c and 4.1d. The following section further discussed the land use and land cover changes that had occurred within Kibera as its external boundary spatially expanded.

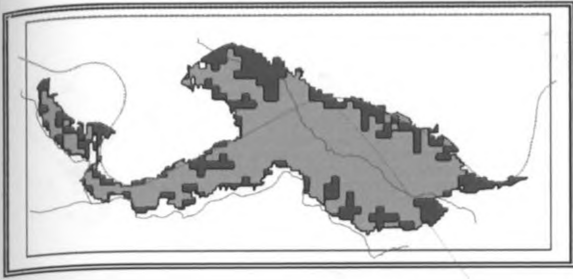


Figure 4.1a: Overlay, 1976 and 1987 Kibera spatial boundaries

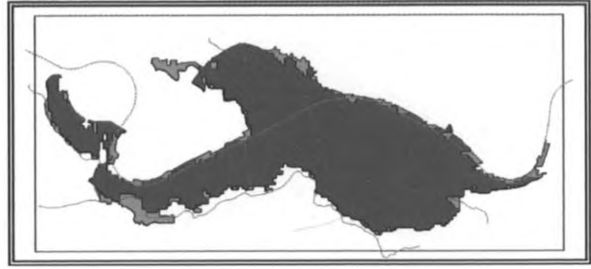


Figure 4.1b: Overlay, 1987 and 1995 Kibera spatial boundaries

Key for boundaries

1976 Kibera boundary 1987 Kibera boundary 1995 Kibera boundary

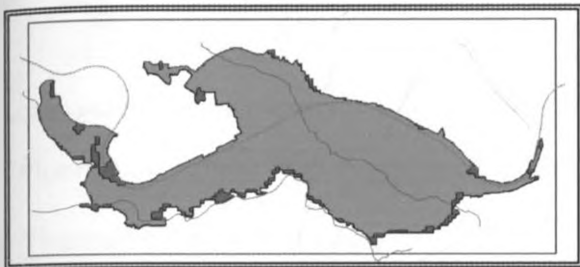


Figure 4.1c: Overlay, 1995 and 2002 Kibera spatial boundaries

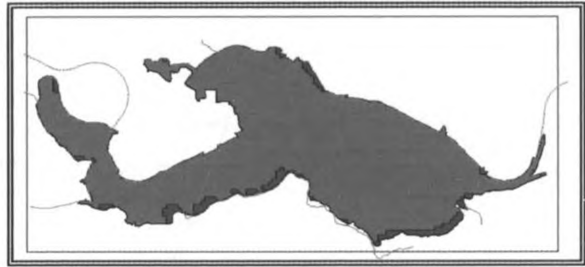


Figure 4.1d: Overlay 2002 and 2004 Kibera spatial boundaries

Key for boundaries

1995 Kibera boundary 2002 Kibera boundary 2004 Kibera boundary

4.2 Kibera Land Use and Land Cover Change

Landsat imageries of 1976, 1987, 1995 and 2002, revealed massive land use and land cover changes that had occurred within Kibera. The result of post classification visual and area comparison; and image differencing discussed below, highlight and quantified land use and land cover changes that had occurred in Kibera between 1976 and 2002.

Post classification visual comparison

Three thematic cover classes used in Kibera spatial sprawl and cover change analysis included: built-up area, forest/vegetation cover and bare ground. Figures 4.2a, 4.2b, 4.2c and 4.2d illustrate thematic class display of classification results of 1976, 1987, 1995 and 2002 Kibera Landsat imageries.

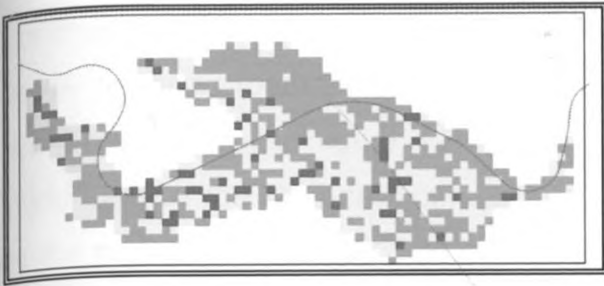


Figure 4.2a: Kibera 1976 thematic class map Figure 4.2b: Kibera 1987 thematic class map

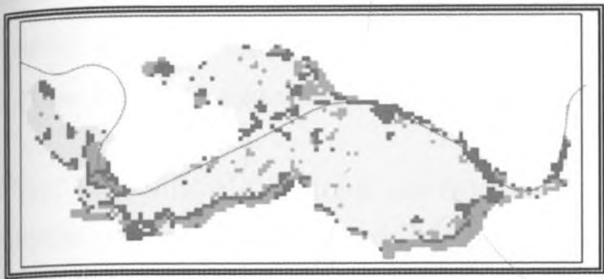





Figure 4.2c: Kibera 1995 thematic class map Figure 4.2d: Kibera 2002 thematic class map

Thematic class map key

-  Built-up area
-  Forest/Vegetation cover
-  Bare ground

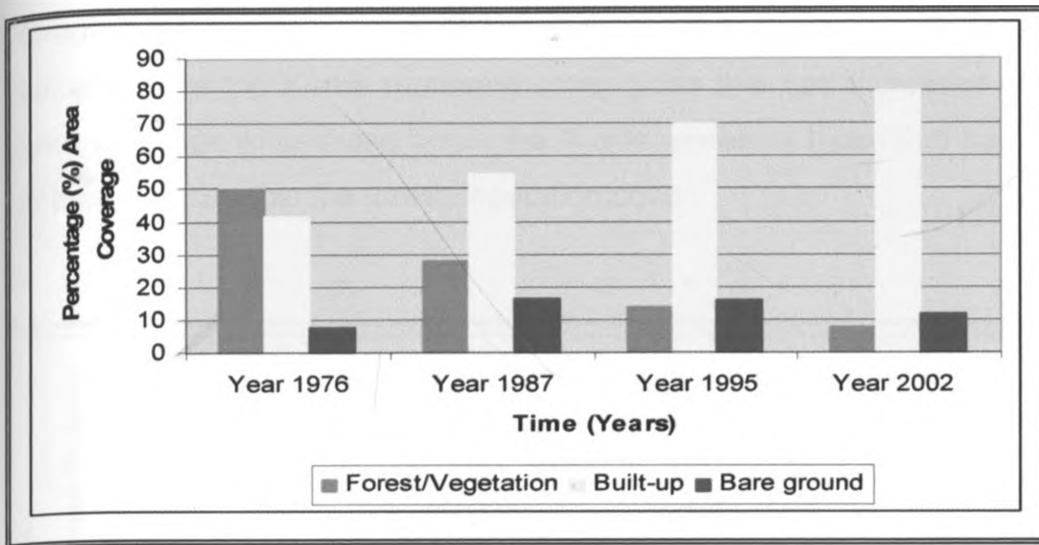
From 1976 Kibera thematic class map (figure 4.2a), more than a half of current Kibera area was covered by forest, dotted with few housing units and hardly any bare ground, which confirmed history of the area as having been forested hence given the Nubian name *kibra*, meaning forest. By 1987, rampant land cover and land use changes had occurred within the settlement.

Previously bare ground areas were settled and vast portions of forest cover was cleared to give room for building of housing units, with part remaining bare (figure 4.1b). More than half of the total land area had been converted into built-up area with less than a quarter of the total area remaining under forest/vegetation cover (figure 4.2c). The few forest/vegetation cover was found at the edges of slum as indicated in figure 4.1d.

Continued settlement after 1987 led to more destruction of forest and vegetation cover to give room for building of shelters. According to 1995 Kibera classification results, (figure 4.2c), only remnants of vegetation cover could be found towards the southern boundary of the settlement. Most of vegetation cover on the northern part of 1987 classified image (figure 4.2b) had been cleared and settled or remained bare awaiting settlement. Between 1995 and 2002 Kibera spatial growth became more internal, density of the settlement increased with hardly any bare grounds left within the settlement due to restricted space for further outward expansion and sprawl (figure 4.2d).

Post classification area comparison

Kibera occupied an area of 262 hectares as at 2004. In 1976, 50% of this area was under forest cover, while 42% was built-up with 8% remaining bare. As Kibera expanded spatially, forest were cleared to give room for settlement and had decreased to 28%, whereas built-up and bare ground areas increased to 55% and 17% respectively, of the total area in 1987. By 1995 vegetation cover had further reduced to 14%, built-up area expanded to 70% and bare ground decreased to 16%. Continued settlement led to further shrinking of the vegetation cover to a mere 8%, the built-up increased to 80% and bare ground reduced to 12%. There was hardly any vegetation cover and very little bare grounds within Kibera by 2004 according to QuickBird imagery (image 3.1). Graph 4.1 illustrates percentages of cover class areas in each of the years considered in the spatial change analysis.



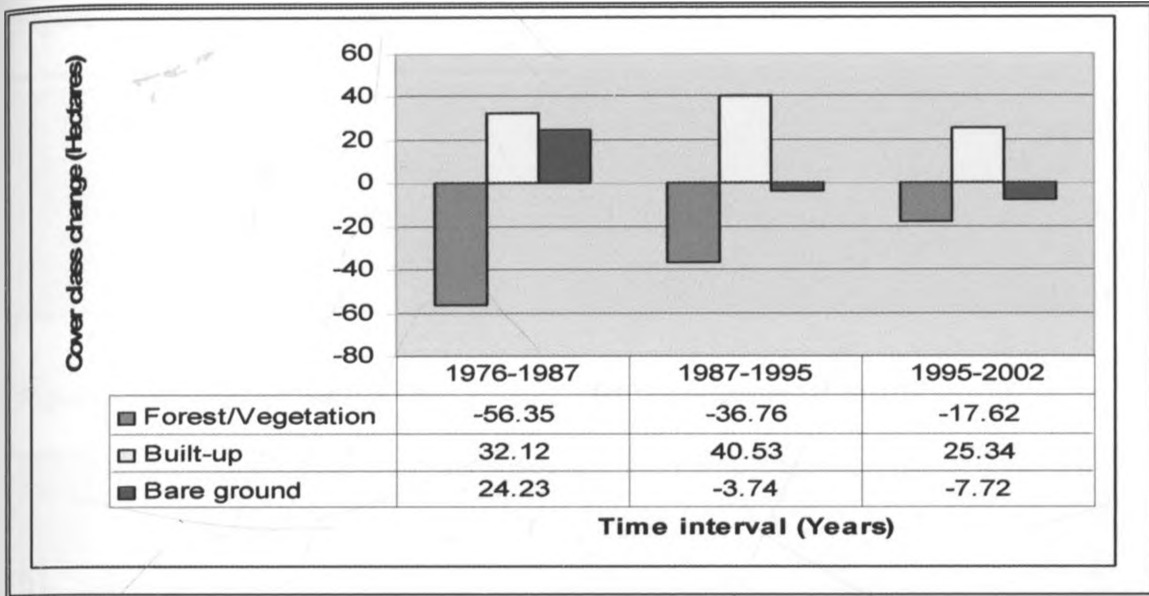
Graph 4.1: Percentage cover class areas against time

Cover change area quantification

Between 1976 and 1987, forest cover had decreased by 56.35 hectares, built-up increased by 32.13 hectares while bare ground increased by 24.23 hectares in coverage. Between 1987 and 1995, continued settlement in Kibera led to further loss of 36.71 hectares of forest cover to built-up area which increased by 40.53 hectares and bare ground reduced by 3.74 hectares, as part of it got settled. Further forest cover loss of 17.63 hectares, gains in built-up area of 25.34 hectares and loss of 7.73 hectares of bare ground area, occurred between 1995 and 2002.

This research established that between 1976 and 1987, 56.35 hectares of forest land lost, had in part been converted to built-up and part remained bare ground which increased in area coverage by 32.12 hectares and 24.23 hectares respectively. However, after 1987 both forest land and bare ground together lost 36.71 hectares and 3.82 hectares respectively, to built-up area which increased by 40.53 hectares. This trend continued between 1995 and 2002 in which, 17.62 hectares of forest and 7.72 hectares of bare ground were converted to built-up which increased by 25.34 hectares.

Graph 4.2 indicates change of cover class area in hectares against time. The values above the X-axis represent cover types that had increased over time in area coverage while those below the X-axis represent those that had decreased in area, for example the forest/vegetation cover.



Graph 4.2: Cover class change against time

Image differencing analysis for land use change

The image difference and Kibera highlight change files (figure 4.3a, 4.3b and 4.3c), indicate the areas within Kibera, where cover changes had occurred between the years 1976 and 2002. According to the interpretation key used, colour black indicates unchanged areas, which were either forested, built-up or bare ground and had not undergone any change between dates of the differenced imageries; green colour indicates areas of decrease, which in this study were previously forested but had been cleared and either settled or remained bare awaiting settlement; and finally, the red colour indicates the areas of increase, these were built-up areas which have increased in density and area coverage between the dates of the differenced imageries.

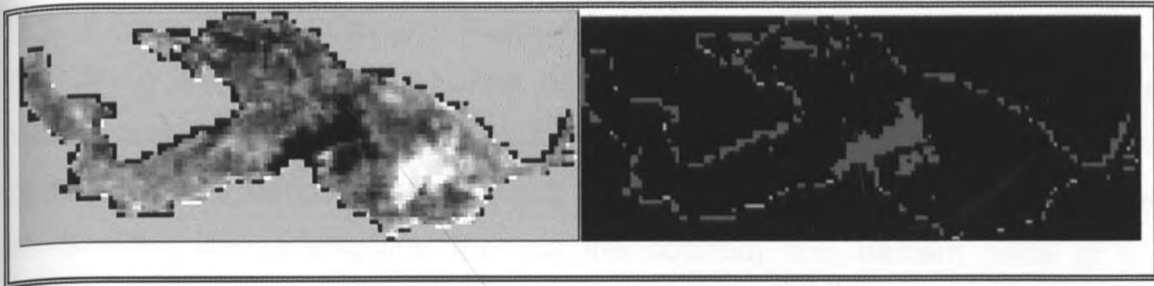


Figure 4.3a: Image difference file;

1976-1987 Kibera highlight change areas

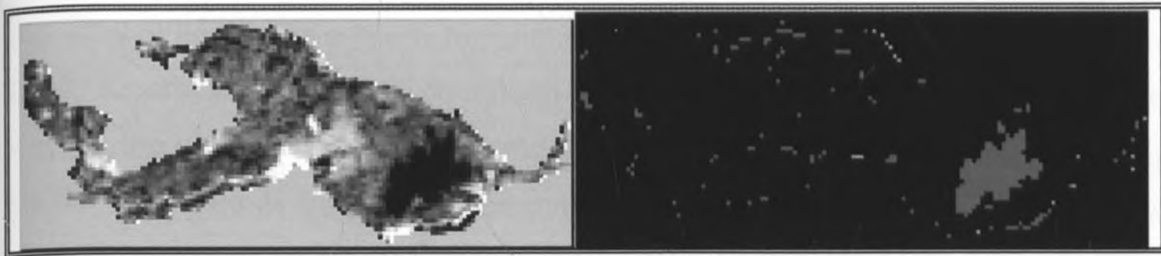


Figure 4.3b: Image difference file;

1987-1995 Kibera highlight change areas

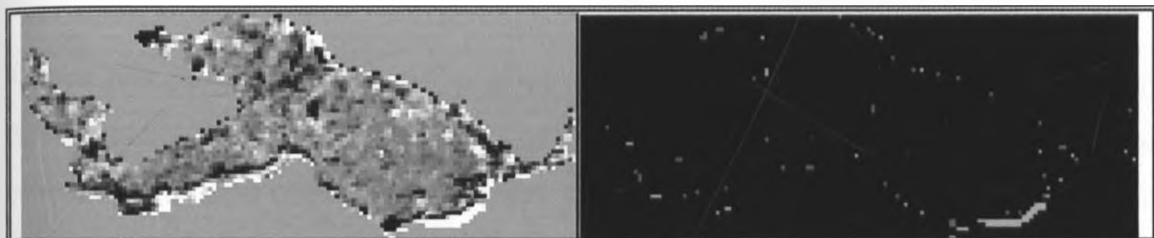


Figure 4.3c: Image difference file;

1995-2002 Kibera highlight change areas

Highlight change map key

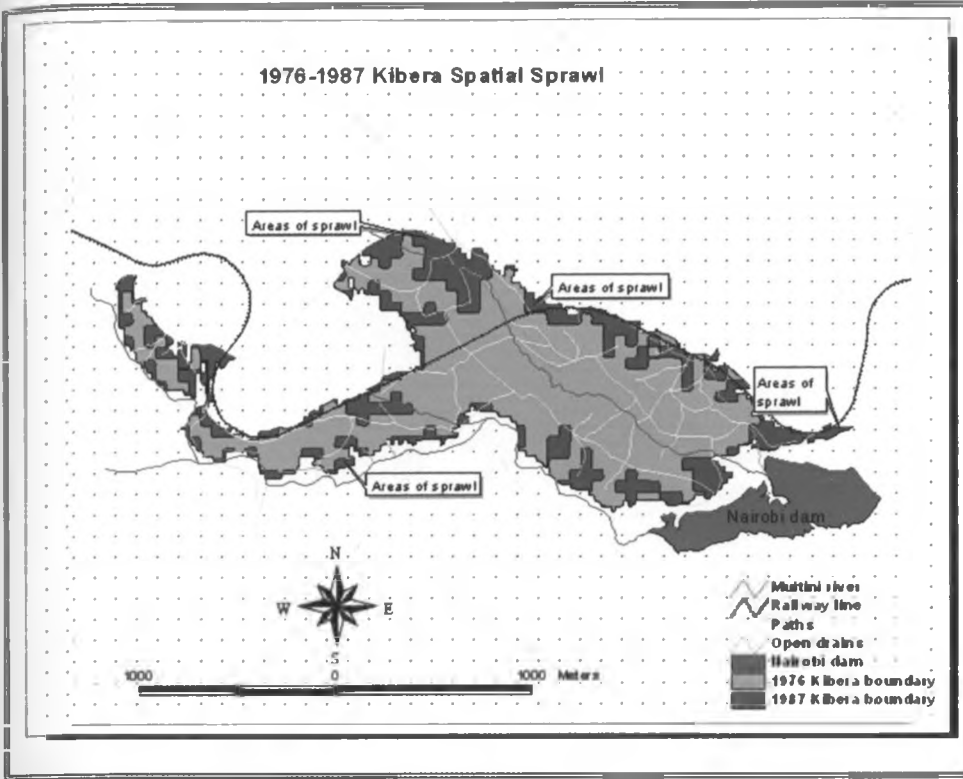
Areas of increase
 Areas of decrease
 Unchanged areas

In summary, the results of post classification visual comparison, post classification area comparison, cover change quantification and image differencing techniques used in spatial sprawl analysis, land-use and land-cover change studies all indicated that massive cover change had occurred in Kibera. Vast portion of forest cover were cleared and converted to built-up areas, leaving hardly any sign of vegetation cover within the bounds of Kibera, one of the biggest slums in Africa.

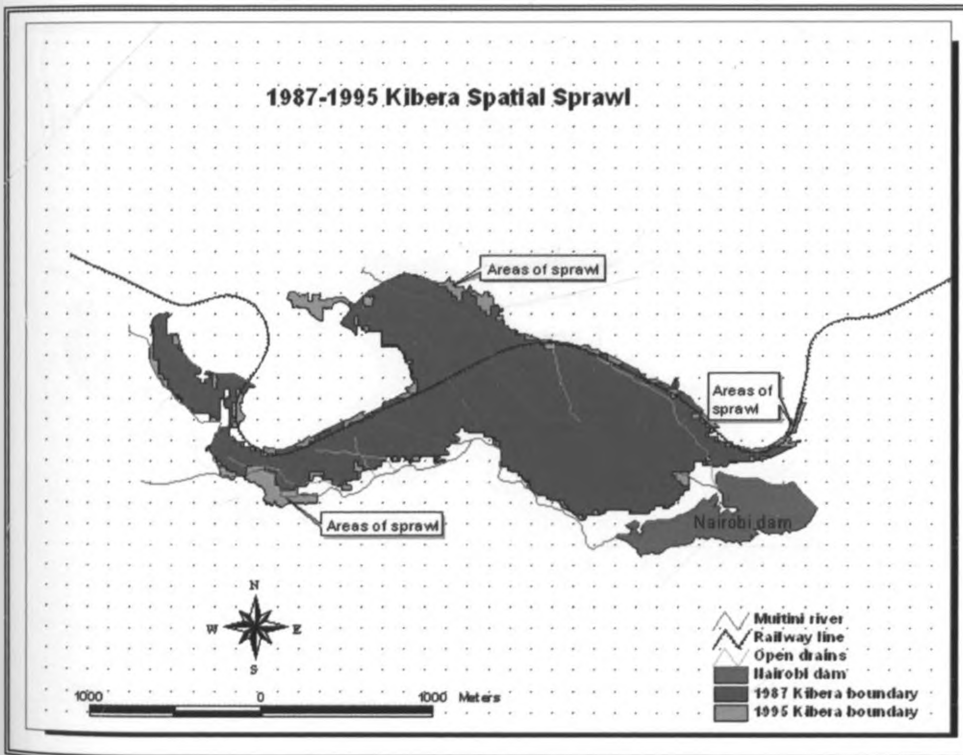
4.3. Kibera Spatial Growth Pattern

This study established that Kibera had undergone both external and internal spatial growth between 1976 and 2004. Remarkable spatial sprawl of Kibera occurred in the period between 1976 and 1987. The expansion tended to be more along the railway line towards the northern and eastern parts of the settlement (map 4.1). Classified imageries of 1987 (figure 4.2b), also indicated that big chunks of forest in 1976 (figure 4.2a) had been cleared especially along the railway line to give room for settlement. In the year 1987 through 1995 to 2002, Kibera spatial sprawl continued along the railway line towards Mbagathi way. At the same time Kibera expanded on the southern part towards and along Mwitini River and its tributaries (see maps 4.2, 4.3 and 4.4). Classified imageries of 1995 and 2002 indicated same spatial expansion trend (growth pattern) along the river on the southern part, which led to conversion of forest land into built-up.

Kibera also tended to expand spatially towards Nairobi dam; however, this had been checked by frequent flooding of the dam that forced the dwellers to move seasonally. Image differencing results, though not very distinctive, also indicated that most areas of increase and decrease were either along the railway line or Mwitini River on the southern part of the settlement. According to classified imageries results (figure 4.2a, 4.2b, 4.2c and 4.2d); Kibera spatial sprawl had led to massive destruction of forest cover to give room for building of housing units. This research observed that Kibera spatial sprawl and expansion seem to be of a definite pattern, mainly along the railway line, Mwitini River and its tributaries through the settlement. Therefore, the spatial growth pattern has been lineal along the railway line and river Mwitini and its tributaries being the main growth nuclei. Maps 4.1, 4.2, 4.3 and 4.4 highlight growth pattern of Kibera based on the satellite imageries.

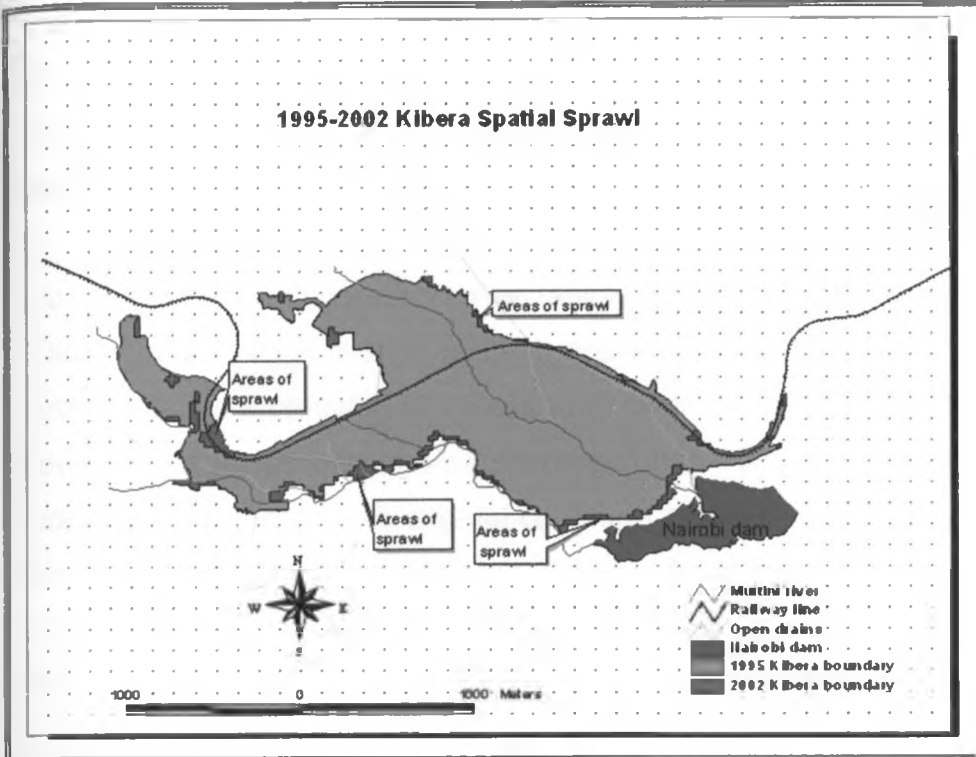


Map 4.1: 1976-1987 Kibera spatial sprawl



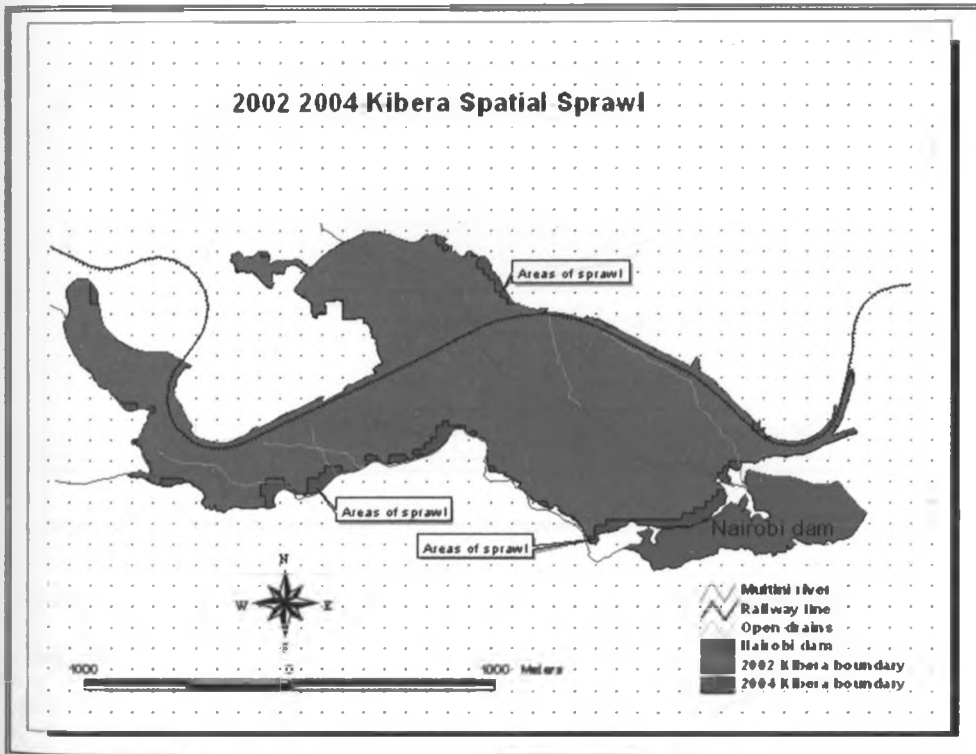
Map 4.2: 1987-1995 Kibera spatial sprawl

1995-2002 Kibera Spatial Sprawl



Map 4.3: 1995-2002 Kibera spatial sprawl

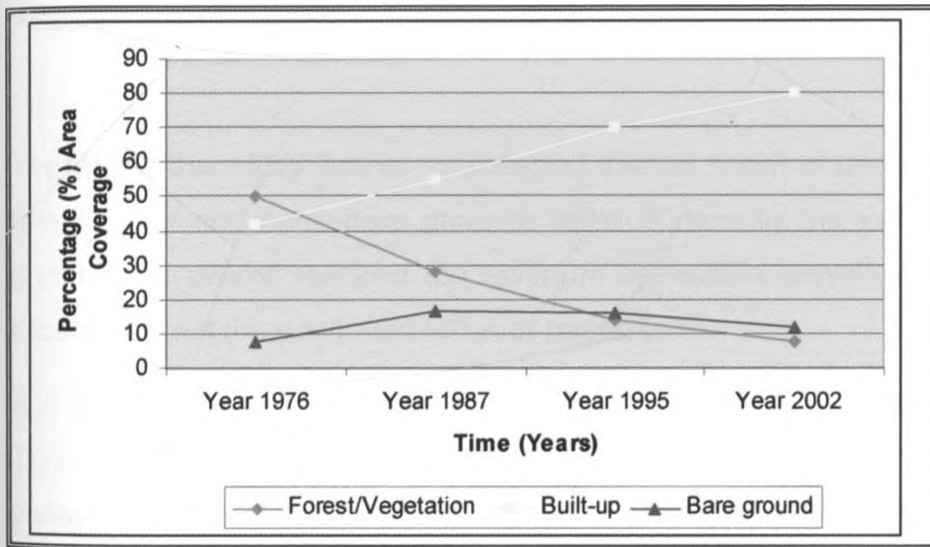
2002-2004 Kibera Spatial Sprawl



Map 4.4: 2002-2004 Kibera spatial sprawl

4.4.1 Spatial expansion trend

The trend in spatial sprawl and inward growth of Kibera has brought about a lot of changes in land use and land cover. Out of 262 hectares of land area in Kibera currently, in 1976 more than half of this was under forest cover; about 42% and 8% constituted built-up and bare ground areas respectively. As population in Kibera increased, vegetation cover rapidly reduced to less than 8% by the year 2002. On the other hand, built-up areas spatially expanded into previously forested areas increasing in coverage to over 80% by 2002. The bare ground, however, increased only in area coverage up to 1987, after which it continuously reduced much close to its original coverage of 8% by 2002. Graph 4.3 indicates the trend in this spatial land cover change. As at the present and going by the cover change trend, built-up area could have surpassed 90% of the total area while vegetation cover and bare ground jointly occupy remaining less than 10% of the total area.



Graph 4.3: Trend in land use and land cover change against time

In graph 4.3, the green line representing forest/vegetation cover drastically reduced, running almost parallel to the X-axis as it approached zero area coverage. This same trend applied for the bare ground represented by the brown line; whereas the yellow line representing built-up area increased steadily to over 80% and approaching 100% area coverage.

The only open spaces left within Kibera were narrow pathways hardly one meter in width (photo 4.1) for accessing the shanties and elements of scanty vegetation almost right inside the dirty and heavily littered watercourses.



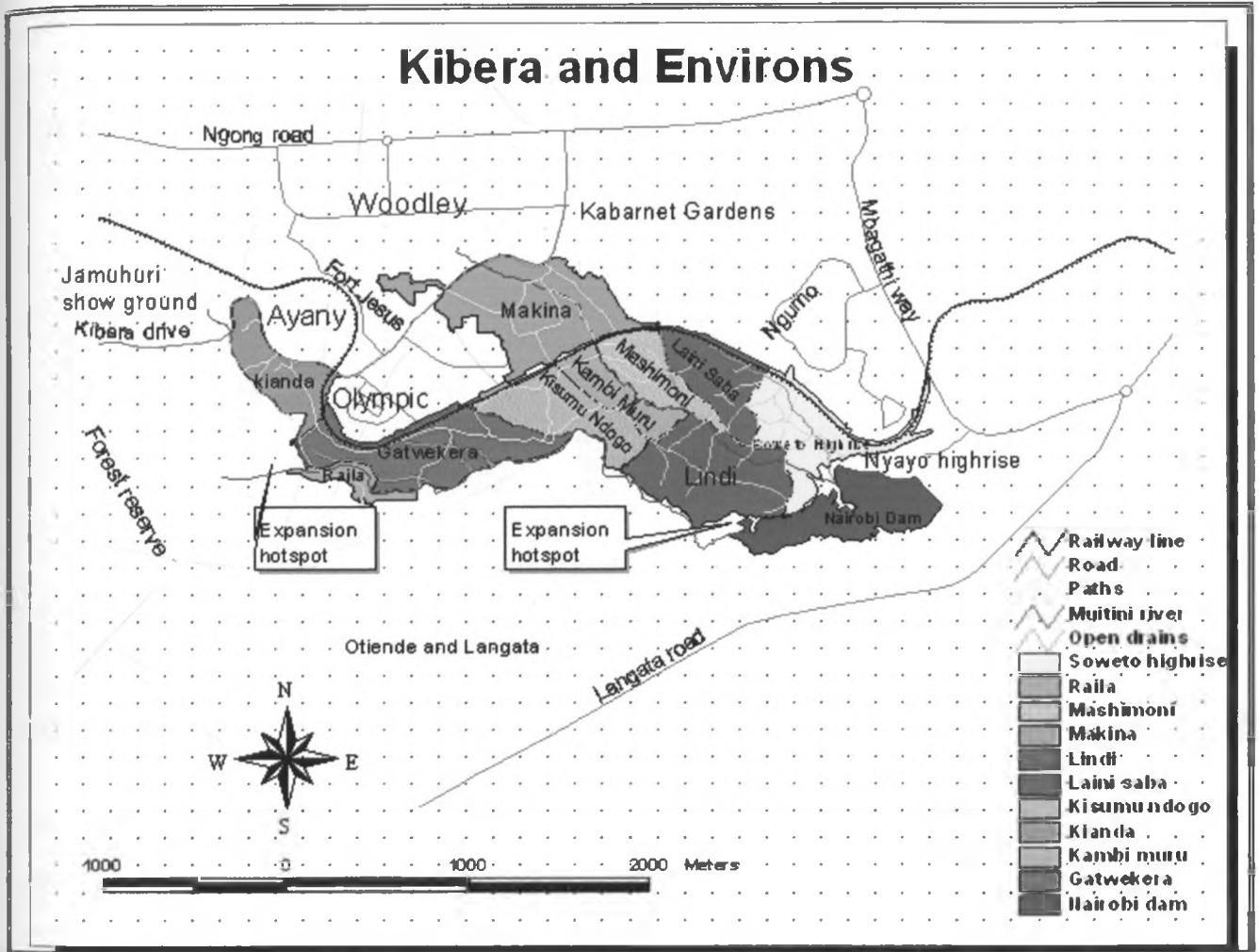
**Photo 4.1: Narrow pathways hardly one meter in width
(Source: Fieldwork)**

Therefore, this study further established that as result of barely any more of the forest cover and open bare grounds within Kibera by the year 2002, its inward growth had almost reached the optimum settlement densities. How then would Kibera contain the continued influx of migrants?

4.4.2 Spatial expansion hotspots

To make room for increasing immigration, Kibera spatial sprawl crossed over the valleys of Mwitini River towards Otiende and Langata estates, this area became the current spatial expansion hotspot. Raila Village is one of the new villages found across the river; however, this spatial sprawl was limited by establishment of a by-pass road between Kibera and Otiende/Langata estates. Soweto-highrise and Lindi villages also have had seasonal but constant spatial expansion towards Nairobi dam, thus affecting survival of the dam which continues to shrink in size; however, occasional flooding of the dam has checked the spatial sprawl in this direction.

Spatial growth of Kianda village if not checked may also cross over the tributary of Mwitini River towards the Ngong Road forest reserve leading to further loss of the remaining forest cover. Map 4.5 illustrates the current Kibera spatial expansion hotspots.



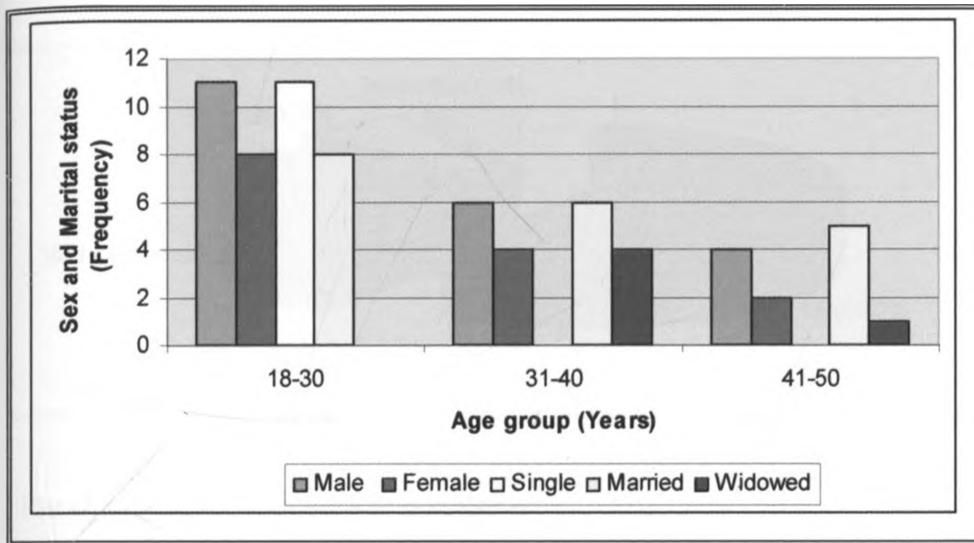
Map 4.5: Kibera and environs; expansion hotspots

4.5 Kibera Household and Neighbourhood Characteristics

Continued densification and spatial expansion of Kibera, has led to a number of environmental problems affecting both the residents and the natural physical environment. Primary data collected were used to study various aspects of the slum and its impact on the environment. This considered the state of household characteristics and immediate neighbourhood environment.

4.5.1 Kibera households

A total of 35 adult respondents were interviewed in Gatwekera village, of which 21 were male and 14 female. Majority of the population in Kibera were youths since 54.3% fell within the age bracket of 18-30 years; the rest 28.6% and 17.1% were aged between 31-40 and 41-50 years respectively. Graph 4.4 shows cross tabulation of the respondents' sex and marital status against their respective ages.



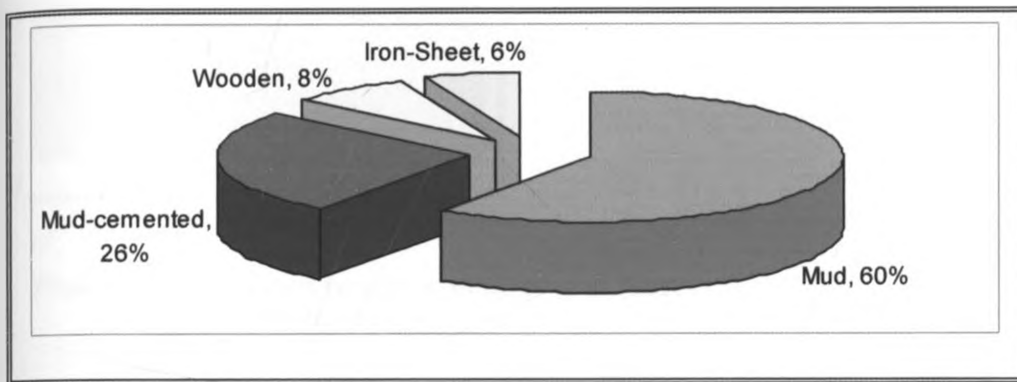
Graph 4.4: Sex and marital status against the age group

The study established that majority of Kibera residents were male in their youthful age of between 18-30 years, confirming the gender imbalance in Kibera in favour of men earlier reported by Muthoni (1999); on the basis of marital status, there were higher number of single people in the age group of 18-30 years, than the married counterparts, however, those aged 31 years and above were all married with a few widowed (graph 4.4).

Most Kibera residents lived in rented single rooms of dimensions limited to about 5 by 5 square meters, much close to the dimensions of housing units in Mukuru kwa Njenga slum, in Nairobi reported by Gichuki (2005). All houses were iron-sheet roofed, with each having one wooden door and just one window; however, a few houses had no windows.

Housing materials

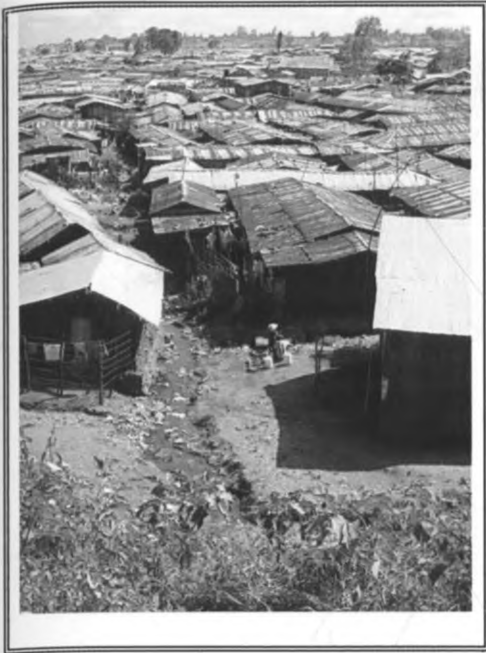
All houses in Kibera were semi-permanent, the dominant wall construction material was mud: more than half remained just mud-walled, about one quarter were mud-cemented the remaining being wooden and iron-sheet walled. Nearly all houses in Kibera had cemented floors. However, in most cases, these floors were quite cracked and their conditions were in bad state as the few (14%) earth-floor houses. Pie chart 4.1 further illustrates the housing construction materials in Kibera.



Pie chart 4.1: Wall construction material

Condition of Kibera houses

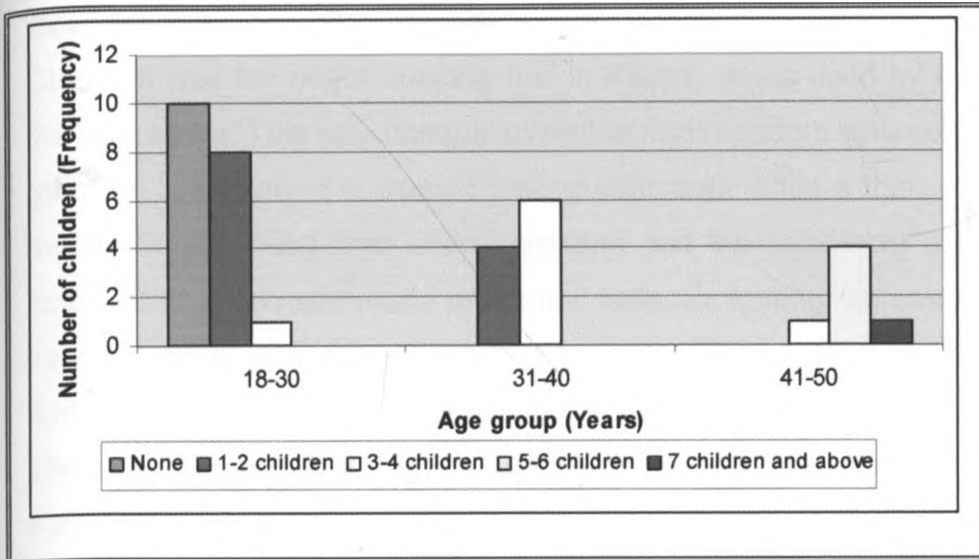
The general conditions of housing units were bad and in some cases worse (photo 4.2). The rent paid for these houses ranged between Ksh 300 and Ksh 1000; the average being Ksh 607, with a standard deviation of Ksh 164. This was quite on the higher side given the poor and unmaintained state of both houses and neighbourhood environment. The finding was in resonance with that of Kahinde (2002), who estimated the range of inadequacy of housing in African cities from minimum of 30% to 90% in each of the cities.



**Photo 4.2: Dilapidated condition of houses in Kibera
(Source: Fieldwork)**

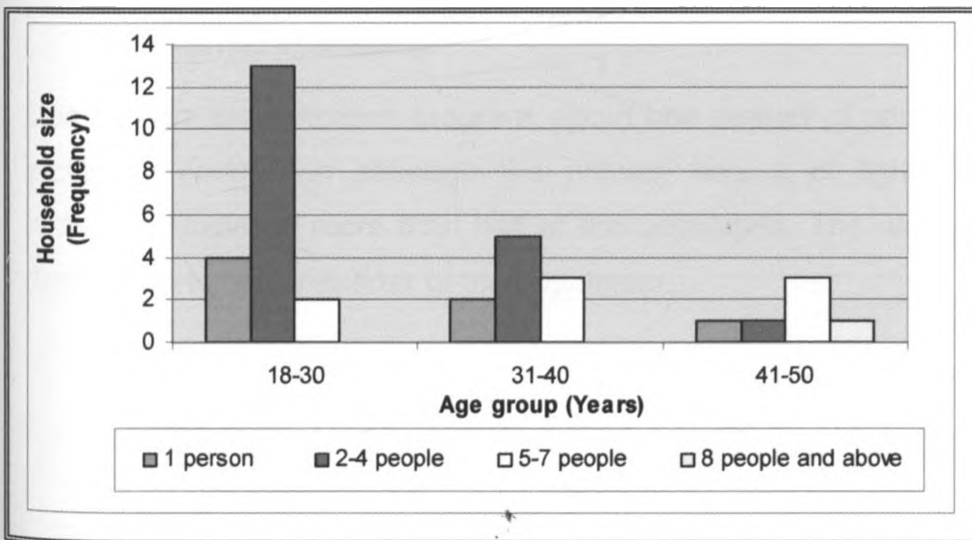
Family and household size

Most of households in Kibera had between 1 to 2 children (34%); whereas 23% had 3 to 4 children, 11% had 5 to 6, 29% had none and only 3% had more than 7 children. These results were different from the findings of Gichuki (2005) in study of “Environmental problems and human health in urban informal settlement, case study of Mukuru kwa Jenga,” which had put the average number of children per household at 8 above in the slums.



Graph 4.5: Frequency of number of children against age group

This small number of children could be attributed to the fact that more than half of Kibera residents were in their youthful age of 18-30 years and had just got married; while about one third were single. Graph 4.5 indicates the frequency of number of children per household against age of the respondents. On the contrary, the dominant household size also fell in this age group of 18-30 years where occupants lived between 2 to 4 persons per household. This was due many single youths who resided in shared rooms as they seek employment opportunities in the city. This is illustrated in graph 4.6.



Graph 4.6: Frequency of household size against age group

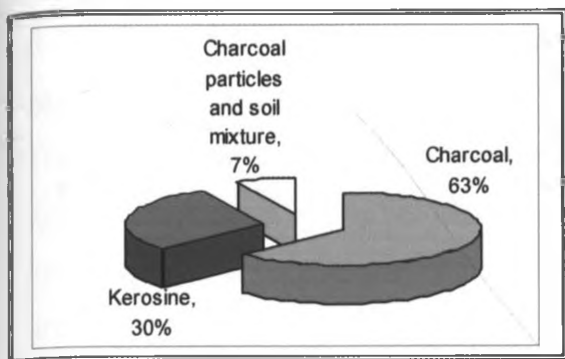
Cooking fuel and light sources

Charcoal was the major cooking fuel in Kibera, being used by more than half of the population. This was cheaply available from vendors who sold a tin at Ksh 20 (photo 4.3, picture of a woman selling charcoal); while a third of the population mostly single young men used kerosene and the remaining used a mixture of charcoal dust and soil made into small balls. In lighting, kerosene was the main source energy with more than half and one fifth of the population using it, in lanterns and tin lumps respectively; while a quarter of the population used electricity. Pie charts 4.2 and 4.3 show the proportions of cooking fuel and light sources used in Kibera.

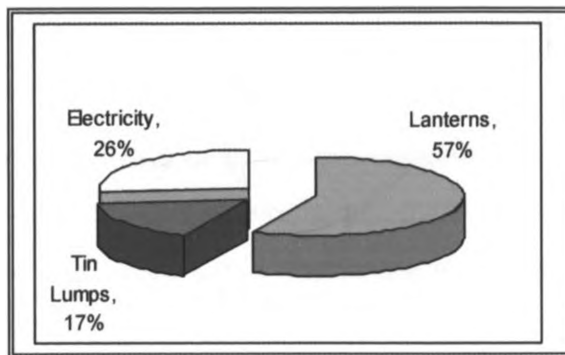


**Photo 4.3: A woman selling charcoal in Gatwekera village
(Source: Fieldwork)**

Due to slum electrification program, about one quarter of people in Kibera have electricity connection although the primary source of lighting still remained lanterns utilized by more than half of the population. The use of tin lumps had diminished to below quarter of the population.



Pie chart 4.2: Cooking fuel used in Kibera

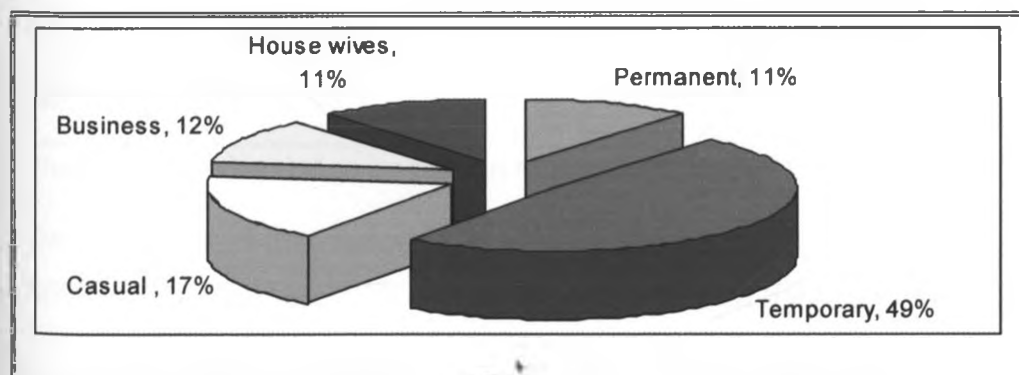


Pie chart 4.3: Light source used in Kibera

The fact that all houses in Kibera double as living room and kitchen, smoke and other gases generated from burning of charcoal, especially in these small congested and poorly ventilated houses, can be a potent source of indoor pollution. This may make the residents susceptible to respiratory track infections.

These energy sources were popular in Kibera given the low income base which had 60% employed; of which about half were on temporary basis and only less than one quarter on permanent job employment.

The remaining 40%, who were unemployed were casual labourers, small business operators or house wives who depended entirely on their husbands for upkeep. Pie chart 4.4 illustrates the types of employment and income sources in Kibera. Of those employed 50% worked outside Kibera, and each of the remaining quarter worked either locally within Kibera or at construction sites moving from place to place.



Pie chart 4.4: Types of employment and income sources in Kibera

4.5.2 Service provision

Modes of transport

The working group in Kibera uses three main means of transport: walking, train and matatu. This group of residents forms 60% of the whole population and found Kibera a convenient residential place due to its proximity to the industrial area where majority of them work and therefore could utilize any of the three means of transport to work. Those who depend on walking and rail transport entirely were found to be 30% and 10% respectively while the rest used matatu.

Water sources and quality

Main source of water in Kibera is communal water point where an average of Ksh 3.00 is paid per 20 litres of water (photo 4.4). The water points were well distributed within the settlement and all residents were able to obtain water in less than 30 minutes. This finding was different from that of Gichuki (2005) which reported that most slum dwellers lacked water and sometimes were overcharged to as high as Ksh.30.00 per 20 litres of water. UNDP had initiated a number of projects for provision of piped water and public sanitary facilities in Kibera.



Photo 4.4: A communal water point in Kibera (Source: Fieldwork)

Despite the fact that water supply and adequacy in Kibera was found to be over 60%, on the contrary 52% of the residents felt that this water was of poor quality since it was suspected to get mixed up with latrine effluent at points of broken water pipes, a commonplace in Kibera. None of Kibera resident obtained water from vendors, boreholes or wells.

Methods of human waste disposal

This study established that the primary method of human waste disposal in Kibera is the use of 'pit latrine' utilized by three quarters of the population and paid toilets utilized by the remaining quarter who paid between Ksh 3 to 5 and on average of Ksh 4.30 per call. The number of pit latrines was quite overstretched as 95% of those who utilized them reported sharing each pit latrine for over 10 households, with only meager 5% sharing between 6-10 households. This had greatly lowered the level of cleanliness of these facilities and 80% of those who used them felt that their sanitation level were worse and health-threatening. To note further, is the fact that close to three quarters (70%) of the 'pit latrines' had the effluent drained directly into either river or other open drain system in Kibera (photo 4.5). This made their use a further potent source of water and general environmental pollution.



**Photo 4.5: Direct drainage of latrine effluent into river/open drain
(Source: Fieldwork)**

On the contrary, few people who used the paid toilets (photo 4.6) confirmed that the sanitation levels were fair and well maintained by proprietors of these sanitary services.

As much as the use of flying toilets was not revealed through field interview, this unhygienic method of human waste disposal could still be in use. In the fieldwork and ground survey, a lot of human defecation in open spaces between houses, pathways and drainage channels was found a commonplace. This could be as a result small children who did not use the latrines, relieving themselves in these open spaces and possibly even some of the adults who had no access to any latrine and could not get money to pay to use the paid-latrines, and yet 'the call of nature must be answered'. Therefore, despite the fact that no respondent confessed the use of flying toilet in Kibera, common open-site defecation observed in ground survey, strongly suggested continued use of this unhygienic and health-threatening form of human waste disposal.



Photo 4.6: Public paid toilet facility in Kibera (Source: Fieldwork)

In general, the use of flying toilets in Kibera as reported by UN Habitat (1997) in most slums in Nairobi due to lack of pit latrines has greatly reduced. This could be attributed to the fact that those who initially had no sanitary facilities now could access the private-paid toilets at a small fee.

Handling of solid waste

The other source of environmental pollution in Kibera could be uncontrolled disposal of solid waste. More than half of residents in Kibera disposed of their solid waste at any open spaces between houses; one quarter disposed of their waste just outside the house, while the remaining quarter claimed to dispose of the waste at central dumping place, a statement which seemed inaccurate as this study did not ascertain existence of any central dumping place.

Three quarters of solid waste was uncollected with only one quarter collected through community participation which confirmed the findings of Muthoni (1999), in study of Community Participation in Solid Waste Management within Urban Informal Settlement, case study of Kibera. Photo 4.7 shows garbage heaps scattered all over within Kibera.

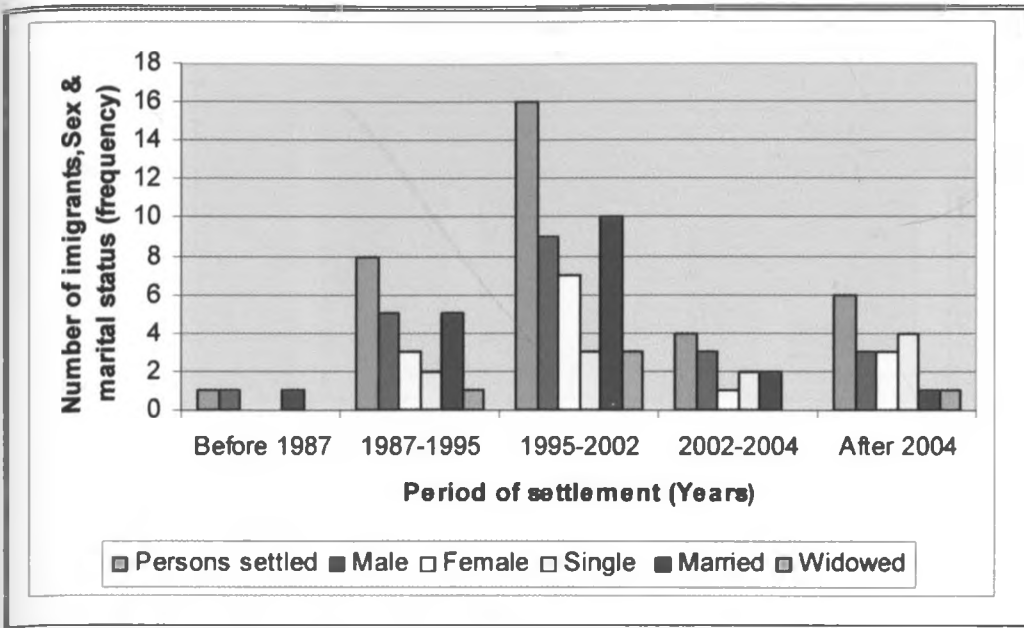


**Photo 4.7: Garbage heaps in Kibera
(Source: Fieldwork)**

The stakeholders involved in service provision in Kibera include: United Nations, church organizations, non-governmental organizations (NGOs) and constituency development fund (CDF) committees. Some NGOs provided health centers within the slum. UNDP and CDF committee initiated projects for provision of piped water and sanitary facilities; however some projects stalled when CDF finances got exhausted.

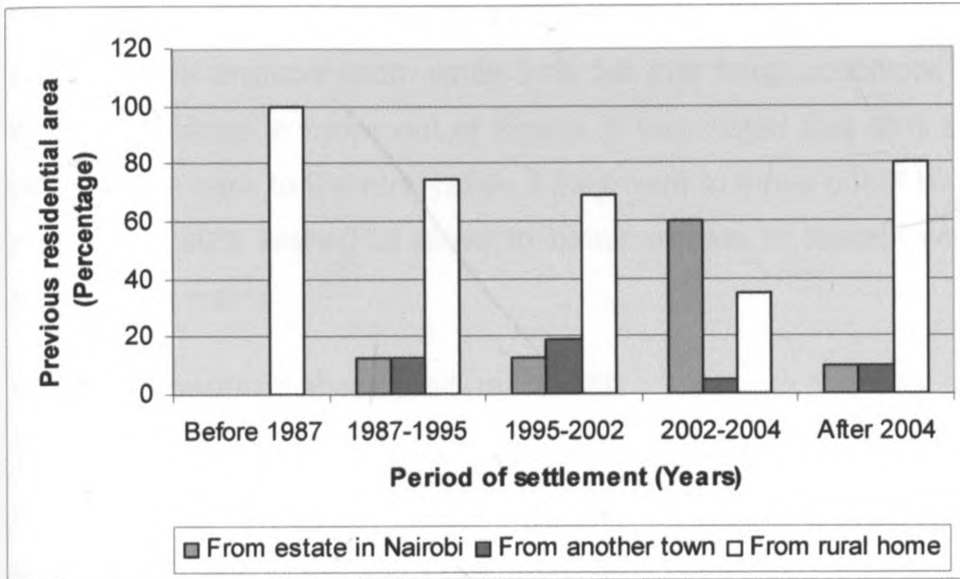
4.5.3 Migration pattern

In the period between 1995 and 2002, 48% of respondents settled in Kibera. This could be associated to the fact that majority of Kibera residents were youths in age group of either 18-30 or 30-40 years, and it was around this period (1995-2002) that most of them would seek job opportunities in the city; 23% settled between 1987 and 1995, 11% and 17% between 2002 and 2004 and after 2004 respectively. Graph 4.7 indicates the number of immigrants that had settled in Kibera in terms of sex and marital status against the period of settlement (before 1987, 1987-1995, 1995-2002, after 2004).



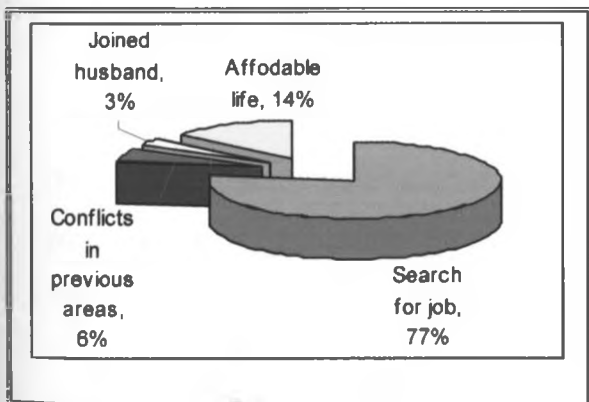
Graph 4.7: Immigrants sex and marital status against period of settlement

This study also attempted to establish previous residential areas of those who had settled in Kibera between periods considered in this study. In the year 1987 and earlier, nearly all those who settled had come from their rural homes. However, in subsequent years there were a few people who moved from other estates in Nairobi and other towns to settle in Kibera. Graph 4.8 illustrates the previous residential areas of these immigrants against the respective period of settlement in Kibera.

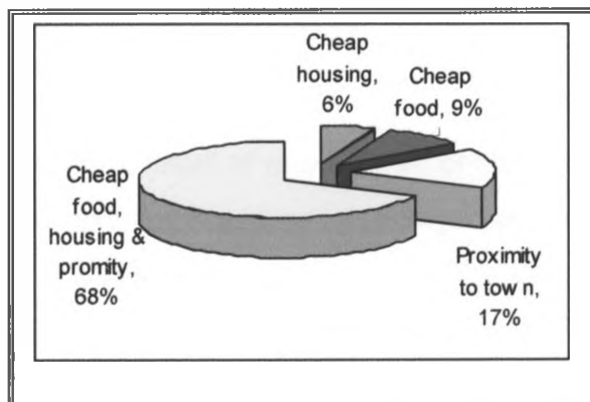


Graph 4.8: Previous residential areas against period of settlement in Kibera

Majority of residents in Kibera had come from rural homes and found Kibera a convenient residential area in which they could reside as they searched for employment opportunities. As shown in pie chart 4.5, a few people had also moved from other towns or estates in Nairobi to settle in Kibera because of affordable life style. Those who considered cost of living as a factor for settling in Kibera considered the following parameters: cheap housing, cheap food and proximity to town, as indicated in the pie chart 4.6 with respective percentages.



Pie chart 4.5: Reasons for settling in Kibera



Pie chart 4.6: Factors considered by the residents in settling in Kibera

This study further established that 66% of Kibera residents did not plan to move out of Kibera anytime soon, while 34% felt that living conditions were poor and therefore wished to move out of Kibera. It was noted that 40% of the residents would move back to the rural home if they were to move out of Kibera. The same proportion, 40% wished to move to better estates in Nairobi while 20% would prefer other towns.

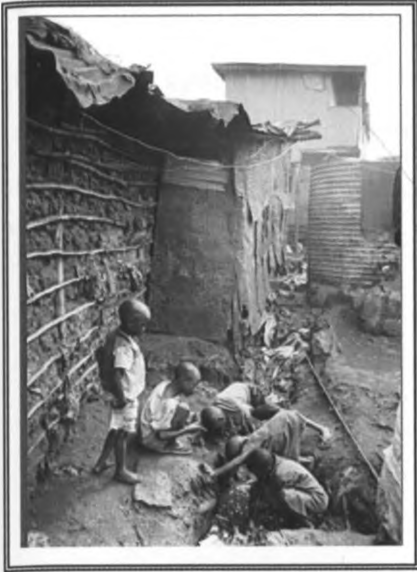
4.5.4 Perception and personal health

This study established that Kibera residents could be prone to attack by various diseases due to poor living conditions; 80% of the residents had suffered from various illnesses in the last three months of which the dominant diseases were malaria, fever, typhoid and cholera.



**Photo 4.8: A lady suffering from malarial attack seated next to her house
(Source: Fieldwork)**

The prevalence of malarial attacks could be as a result of many pools of standing water (photo 4.8), and damp places favourable for breeding of mosquitoes and vast environmental decay from pollution.



**Photo 4.9: Children exploring wastewater/ solid waste drain
(Source: Fieldwork)**

On the other hand, children who normally play and look for various things in open drains (Photo 4.9) and even older people who occasionally wade through flowing dirty streams and rivers in search of valuables brought from upstream may remain susceptible to cholera attacks. This is due to high pollution potential of these waters from direct toilet effluent disposal and rotten solid waste materials that find their way into the water system. People afflicted by these diseases undergo different treatment with medication from health centres and self diagnosis from chemist forming primary forms of treatment.

More than half of Kibera population felt that the water they have access to, was of poor quality since it could occasionally get mixed up with open latrine effluent drains at points of broken water pipes and poorly connected illegal water connections which are both common site in Kibera. Moreover, about half of Kibera residents felt that quality of water they have access to affected their health negatively.

The menace of uncontrolled disposal of garbage and lack of wastewater drainage system remains a big source environmental pollution in Kibera. Garbage heaps are scattered all over and mixed with all forms of solid wastes in the open drains causing such an eye sore (Photo 4.10).

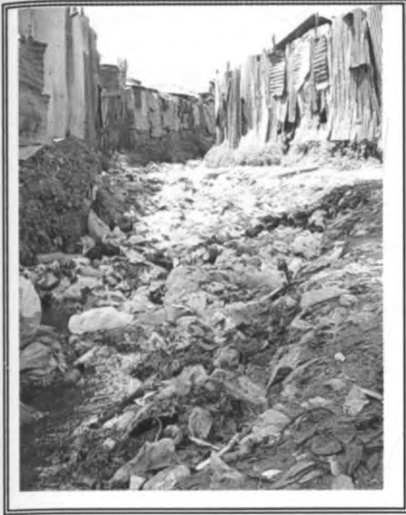


Photo 4.10: Hazardous disposal of solid waste and wastewater (Source: Fieldwork)

Any open spaces between buildings were used as dump sites and there was virtually no form of collection services except in few cases where community participation had arranged for cleaning of their immediate neighbourhood. Generally the sizes of the rooms in Kibera were quite small and in poor state of disrepair with hardly any maintenance. The state of environment was equally poor: these conditions acting unison could affect the residents, and may make the attacks by various vector borne and poor sanitation diseases more frequent.

4.6 Environmental Impact of Kibera Spatial Sprawl

Both internal and external spatial sprawl of Kibera has had different impact on physical and human environment as discussed hereunder:

Destruction of forest cover

Successive overlay of Kibera boundary, in this study, established that from the year 1976 to 2002, Kibera had mainly expanded towards and along the railway line and Mwitini River emanating from Ngong Road forest in the eastern side of the settlement (maps 4.1- 4.4).

This result was confirmed by image classification (figures 4.2a-d), which indicated that large tracks of forest cover, along and around the railway line, Mwitini River and its tributaries had been cleared to make room for building. Figures 4.3a-c of the differenced imageries of Kibera, further illustrated an increase in built-up areas especially along these features and within the settlement bounds.

Overcrowding

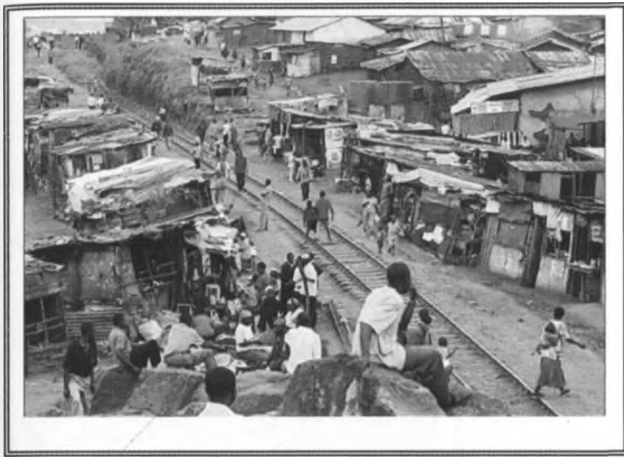
Between the years 1976 to 2002 hotspots for cover change had mainly been along Mwitini River and the railway line. After 1995, outward spatial sprawl of Kibera became limited due to neighbouring estates. On the northern part Ayany, Fort Jesus, Woodley, Kabarnet Garden and Ngumo estates limited further sprawl of the slum in that direction. On the western and eastern sides, its further expansion was checked by Jumhuri show ground and Nyayo highrise estates respectively. To the south, Mwitini River marked the boundary of the slum. Therefore, after 1995, Kibera growth became more inward with density of housing units increasing (photo 4.11). This led to overcrowding, outstretching of various sanitary facilities and increased degradation of the environment.



Photo 4.11: Overcrowded housing and hardly any vegetation cover
(Source: Fieldwork)

Settlement in unfit and risky areas

The few vegetation cover within Kibera in 1987, (figure 4.2b) slowly reduced by 1995, (figure 4.2c). By the year 2002, there was hardly any vegetation cover within Kibera that could be cut to give room for more buildings (as depicted in figure 4.2d and Photo 4.11). As internal expansion of Kibera tended towards its optimum density, to cater for continued influx of migrants the settlement extended into areas precarious, risky and unfit for human habitation, such as railway, road reserve, Mwitini river valleys and swampy parts of Nairobi dam.



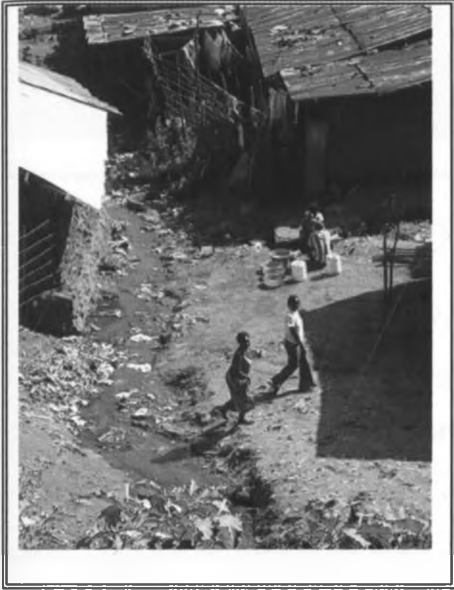
**Photo 4.12: Buildings and concentrated human activities within railway way-leave
(Source: Fieldwork)**

This was in agreement with report by WRI *et al* (1996), which observed that majority of poor people in urban centres of developing world lived in shanties, some built on land that no one wants. Buildings were put up in close proximity to the railway line occupying nearly all the required way-leaves (photo 4.12). Only narrow strip hardly enough for train to pass were left. This poses a serious risk to human life in cases of train accidents and derailing.

Lack of space for dumping refuse

Continued spatial sprawl of Kibera, both external and internal densification has led to reduced and lack of space for dumping of both solid and wastewater. The amount of solid waste generated by the resident population in Kibera was far much beyond the resilient level for natural ground assimilation of these wastes.

Most wastewater remained stagnant or flowed all over the settlement in open-earth channels passing in between the congested houses. These formed small streams of dirty and littered water criss-crossing the slum (Photo 4.13). UN Habitat (1997) as cited earlier shared similar opinion that most of the watercourses through Kibera were open sewages and dumpsites of all manner of solid and wastewater.



**Photo 4.13: Small streams of dirty and littered water criss-crossing the settlement
(Source: Fieldwork)**

Pollution of the environment

One of the ripple effects of uncontrolled and hap-hazard disposal of solid waste and wastewater in Kibera has been pollution of the environment. This came mainly from three different point sources: solid waste, wastewater and direct drainage of latrine effluent into open drains and watercourses. The most common types of pollution created by these three menaces acting in unison included: watercourse pollution; soil pollution and air pollution, illustrated in photo 4.14. This confirmed the findings of Skinner and Rodell (1983) which observed that in most slum settlements everywhere, a lot of solid and liquid wastes were produced due to high human population.



Photo 4.14: Pollution of the environment
(Source: Fieldwork)

Since slums lacked waste collection services and sewage system, most of the wastes were left on garbage dumps or any available space which caused serious pollution to watercourses through the slums as exhibited by heavily polluted Muitini River in Kibera.

Proneness to infectious and vector borne diseases

Lack of toilets, clean water, drainages, state of disrepair of housing condition and the environmental decay, due to spatial growth and densification of Kibera could lead to increased susceptibility (proneness) of the slum community to disease infection. Diseases such as malaria, cholera, and typhoid may afflict large proportions of Kibera residents, prevent them from working, taking care of themselves and their families, and could result in death. These diseases could be caused by lack of sanitation facilities, and may get spread along a combination of vectors. The following issues could contribute to spread of these diseases:

Cholera and Typhoid cases in Kibera could be direct result of lack of safe toilet facilities. Both Cholera and Typhoid are transmitted through ingestion of feces contaminated with bacteria (WHO, 1981). Contamination usually occurs when untreated sewage is released into waterways or into groundwater, affecting the water supply, or any foods washed in the water.

Both Cholera and Typhoid are very debilitating, and could last for weeks at a time, and without treatment caused death in between 10% to 50% of infected persons, (UNDP, 2003).

How could lack of toilet facilities enhance the spread of cholera and typhoid? Without access to safe toilet facilities, many Kibera residents may be forced to use public areas, most often drainage routes, to relieve themselves. These drainage waste channels were unprotected and it may be common for people, especially children (photo 4.9), to come into contact with the waste as it traveled out of the slum. Once a person came into contact with Cholera or Typhoid infected waste, if they did not wash their hands with clean water before cooking or eating, the bacteria would spread into their body, and the cycle begun again.

Secondly, lack of clean water could facilitate spread of these diseases in the following ways: As residents of Kibera lived in structures without any plumbing facilities, clean water was only accessed from communal water points, which were often controlled by private vendors, and expensive for some residents to use. Since clean water was difficult to obtain, some residents may not observe proper hygiene before preparing food or eating, this could cause diseases to enter their bodies. In addition, water from contaminated water sources could sometimes be used for cooking or cleaning, and this also might spread the diseases. Lack of clean water was the second in ranking for causes of water-borne diseases problem in Kibera (UN Habitat, 1990).

Thirdly, the spread of malaria in Kibera could be enhanced by lack of proper drainages. Malaria is a severe problem in Kibera, and is particularly damaging to the community because it often caused people to be so sick that they were unable to work. This sometimes precipitated into the loss of jobs occasionally, or business revenue that was vital to the family's survival. Malaria is also especially deadly in children.

Malarial parasites are transmitted from person to person through the bite of female anopheles mosquitoes, which require blood to nurture their eggs. According to WRI *et al* (1996), there were at least 300 million acute cases of malaria each year globally, resulting in more than a million numbers of deaths per year. Around 90% of these deaths occurred in Africa, mostly in young children. Malaria killed and kills an African child every 30 seconds (UNDP, 2003). Many children who survive an episode of severe malaria may suffer from learning impairments or brain damage. Pregnant women and their unborn children are also particularly vulnerable to malaria, which is a major cause of prenatal mortality, low birth weight and maternal anemia (WHO, 1977).

How could lack of effective drainage system enhance spread of Malaria and other diseases in Kibera? One of the primary factors in Malaria spread in Kibera might be the ineffective wastewater drainages that run through the slum. In many parts of Kibera, drainages were simply channels dug into the earth, and they quickly became muddy and clogged with waste. Residents used and continued to use these drainages to remove wastewater and solids from their household area. As the drainages were simply dug into the earth they did not flow very effectively; pools of water and waste formed in these channels once they were clogged, and this is where mosquitoes could lay their eggs. As drainages collected waste, they could also become breeding grounds for cholera and typhoid, as well as other diseases. Since these drainages were unprotected from human contact, transmission of the diseases could occur very easily, especially in children who played nearby. Drainages could also overflow and spread into the surrounding area, causing further contamination and disease risk.

CHAPTER FIVE

5.1 Summary of Research Findings

The following were the summary of research findings obtained in the spatial analysis of informal settlement sprawl and its environmental impact: a case study of Kibera:

1. Kibera spatial sprawl has been of a definite pattern; majorly along the railway line, Muitini River and its tributaries traversing the settlement.
2. Three main land use and land cover in Kibera were: vegetation, built-up and bare ground areas.
 - i. Between 1976 and 1987, forest cover reduced by 56.35 hectares, of which 32.13 hectares and 24.23 hectares were converted to built-up and bare ground areas respectively.
 - ii. Between 1987 and 1995, both forest cover and bare ground reduced by 36.72 hectares and 3.71 hectares respectively while built-up area increased by 40.43 hectares.
 - iii. Between 1995 and 2002, both forest cover and bare ground further reduced by 17.62 hectares and 7.73 hectares respectively whereas built-up area increased by 25.35 hectares
3. The factors identified as responsible for the spatial expansion of Kibera included the following:
 - i. Cheap housing
 - ii. Cheap food
 - iii. Close proximity to city center and industrial area where majority walk to their work places
 - iv. Cheap available rail transport and sometimes matatu transport utilized by majority

4. Kibera spatial sprawl had various impact on the environment which included the following:
- i. Destruction of forest cover to give room for construction of houses
 - ii. Overcrowding as small housing units were put up on any available open land when external expansion became limited
 - iii. Settlement in areas precarious, risky and unfit for human habitation such as railway and road reserves and river valleys due to high demand for cheap housing by the immigrants.
 - iv. Reduced and lack of space for dumping of solid and wastewater which were produced beyond the natural ground assimilation.
 - v. Pollution of the environment from: solid waste, wastewater and direct drainage of latrine effluent into river and open drain system.
 - vi. Lack of toilets, clean water, and state of despair of housing condition and environmental decay.
 - vii. Increased susceptibility (proneness) of the community to disease infection such as cholera, typhoid and malaria.
 - viii. Loss of man power due to frequent illness and even loss of life as a result of death from these diseases.

In summary the findings of this study were in line with under-mentioned working hypotheses earlier formulated to guide the study:

1. There is definite pattern of spatial expansion of Kibera
2. There are specific factors behind the rapid spatial expansion of Kibera
3. There are land-use and land-cover changes in Kibera
4. The growth and expansion of Kibera has had impact on the environment

5.2 Conclusion

This study established that Kibera had undergone spatial sprawl overtime due to different factors. Expansion of the settlement has been accompanied by land use and land cover changes subsequently causing various environmental impacts.

The research answered the following questions:

1. What is the pattern of spatial expansion of Kibera?
2. What are the factors that have influenced expansion of Kibera?
3. What are the land-use and land-cover changes that have occurred in Kibera?
4. What are the environmental impacts of Kibera growth and expansion?

The study concluded that:

Kibera spatial sprawl has been of a definite pattern; majorly along the railway line, Muitini River and its tributaries traversing the settlement. Two factors could have led to this pattern of expansion of the settlement along the river and railway line: First, the river could have been the only major source of water for the early inhabitants of Kibera; this could have encouraged the growth along the proximity of Muitini River and its tributaries. Secondly, in the early days of growth of Nairobi city, road transport network was not quite elaborate. The spatial growth of Kibera therefore tended to be along the railway line which in the early days could have been the major mode of transport to the city centre and Nairobi industrial area. As the settlement continued to expand spatially, the growth of other neighbouring estates limited further sprawl of Kibera. This could have again left the railway reserve as the only vacant land left for putting up more houses hence the pattern.

Various factors identified as responsible for spatial expansion of Kibera included: cheap food, cheap housing, proximity to city center and cheap rail transport. The rent paid for houses in Kibera ranged between Ksh 300 and Ksh 1000; the average being Ksh 607, with a standard deviation of Ksh 164. This ranks Kibera among places with cheapest sources of housing in Nairobi.

Generally, the cost of living in terms of food is cheap and readily available as established in the field survey. The location of Kibera in close proximity to city center and industrial area where majority of residents walk to their work place and cheap available rail transport utilized by majority of the residents, together with cheap housing and food acting in unison as pull factors, made Kibera an attractive settlement for thousands of low income earners causing high rate of its spatial expansion witnessed over time.

Built-up, Vegetation and bare ground areas were the three main land use and land cover identified in Kibera. Long history of settlement in the area has been occasioned by slow but consistent clearing of forest cover to give room for putting up of more houses. The major land use changes in Kibera have been conversion of forest land to built-up areas, due to continued influx of immigrants from rural areas, other towns and other estates in Nairobi.

The spatial sprawl of Kibera has caused different environmental impacts as indicated by analysis of satellite imagery and field survey data. The impact has been two fold in which the inhabitants have exerted excess pressure on the natural environment, which consequently may get strained beyond resilient levels and therefore affects the inhabitants. Destruction of forest cover to give room for housing, overcrowding due to limited space for further spatial expansion, settlement in areas precarious, risky and unfit, lack of space for dumping of solid and wastewater, environmental pollution, lack of toilets, clean water and state of despair of housing condition were the main environmental impact of Kibera spatial sprawl.

In conclusion this study achieved its objectives which were to:

1. Establish the pattern of spatial expansion of Kibera
2. Identify the factors responsible for the spatial expansion of Kibera
3. Identify and quantify the land-use and land cover changes in Kibera
4. Determine the environmental impacts of Kibera growth and expansion

5.3 Recommendation

This study noted that Kibera spatial growth has been fast and uncontrolled. The provision of essential services has lagged behind this high growth rate. This has led to pollution, lack of water, electricity connection, high unemployment and critical housing shortage. Nearly all of the slum's rubbish was left to rot. In a study in Mexico City, Davidson and Myers (1992) shared the same sentiments, as earlier cited in the literature review. Uncontrolled spatial growth of slums and associated environmental problems afflicting the dwellers were not just a confine of developing world, though they were most hard-hit. Finding solution to the uncontrolled spatial sprawl and environmental problems in Kibera, as in deed, in other slums of the world; both developed and developing countries is not an easy task! But as it was once said, 'the journey of a thousand miles begins with just a step'. This research study made the following recommendation to assist Nairobi City Planning Authority and Kibera residents in controlling further spatial sprawl of the settlement and preserving the environment; and to improve the lives of thousands of the inhabitants:

1. Put adequate legislative measures to contain further sprawl of Kibera into the forest reserve and the neighbouring areas
2. High resolution QuickBird satellite imageries to be constantly used in monitoring the state of the informal settlement and the environmental hotspots for change.
3. Consider possibility of providing low-cost high-rise housing units that occupy less land area and affordable by the low income earners
4. Provision of adequate toilet facilities and adequate clean water supply
5. Construction of drainage system for proper disposal of wastewater
6. Provide solid waste collection and management system
7. Put legislative measure to bar habitual draining of toilet effluent into rivers
8. Provide alternative settlement for people living in precarious, risky and unfit environments
9. Further studies to be carried out to establish economic use of the bio-waste as manure and channel for recycling of non-biodegradable materials.

10. The residents should be encouraged to organize their own means of cleaning the environment through community participation regularly.
11. Discourage residents from the hap-hazard waste disposal and encourage the use of defined central dumping places.
12. The landlords to be sensitized on the risk posed by direct drainage of toilet effluent into water system and be discouraged from this act
13. The UNDP and other affiliate United Nation and church organizations should continue with provision of essential services such as water and sanitary facilities
14. Langata member of parliament should ensure that part of constituency development fund is used in provision of clean water, public toilet facilities and electricity connection

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APPENDICES

APPENDIX 1:

Questionnaire

Spatial analysis of informal settlement sprawl and its environmental impact using remote sensing and GIS: A case study of Kibera slums

I am a student of the University of Nairobi. My name is.....

We are carrying out research in Kibera to analyze the sprawl of the slum and the various resulting environmental impacts over time. We are requesting you to grant us some of your time to ask you few questions that will enable us understand some of the factors behind the expansion of this slum and the various environmental problems experienced. The information that you will provide us with will be confidential and will be utilized for purposes of this research only.

Respondent number:

A) Household characteristics

1. Sex of the respondent A) Male B) Female (by observation)
2. How old are you? A) 18-30 B) 31-40 C) 41-50 D) 50 and above
3. Is this a rented or own house? A) Rented (Ksh.....) B) Own house
4. Are you single or married A) Single B) Married C) Widowed
5. How many children do you have? A) 1-2 B) 3-4 C) 5-6
D) 7 and above (State Number)..... E) None
6. What is your main cooking fuel? A) Electricity B) gas C) paraffin
D) Firewood E) Charcoal F) solar G) others (state).....
7. Where do you cook? A) Separate kitchen B) Same living room
C) Outside the house
8. How many people stay in this house? A) Alone B) 2-4 C) 5-7
D) 8 and above: (state number).....
9. Are you employed? A) Yes B) No
(i) If yes: A) Permanent or B) Temporary

- (ii) If No, how do you earn a living? A) Manual labour
B) Small business C) others (state).....

10. Where do you work? A) Within Kibera B) Outside Kibera (state).....

B) Service provision

1. How do you get to work? A) Walking B) Train C)Matatu D)All the above
2. What is your main type of lighting? A) Electricity B) Pressure lump
C) Lantern D) Tin lump E) solar C) Others (state)
3. What is your main source of water? A) Tap in-house B)Well
C) Vendors D) Communal water point E) bore hole
F) Others (state).....
4. How long do you take to get to the communal water points/ wells/ bore holes?
A) Less than 30 min B) 30min-1hour C) More than 1hour
5. How much do you pay for the water?
(i) At communal water point ksh.....
(ii) At the wells Ksh.....
(iii) To vendors ksh.....
(iv) At the boreholes ksh.....
6. What is your main method of human waste disposal? A) Main sewer
B) Septic tank C) Pit latrine D) Bush/field E) Paid toilet (Kshs.....)
F) Drains G) others (state).....
7. How many households use the toilet/latrine? A) Private B) 2-5 C) 6-10
D) 10 and above
8. How do you dispose of your solid waste? A) Just outside the house
B) At any open spaces between houses C) At central dumping place
9. Who collects the garbage? A) Not collected B) Community participation
C) City council
10. Do you treat your water before drinking? A) Yes B) No C) Treat rarely
11. How do you treat your drinking water? A) Boiling B) Use water guard
C) Others (state).....

C) Migration

1. When did you start staying in Kibera? A) Before 1987 B) 1987-1995
C) 1995-2002 D) 2002-2004 E)After 2004
2. Where did you stay before moving to Kibera? A) Estate in Nairobi
B) Another town C) Rural home D) others (state).....
3. Why did you move to Kibera? A) Landlessness at rural home
B) Search for job C) Conflicts in rural place
D) Conflicts in previous estate/town F) Others (state).....
4. Are you planning to move out of Kibera anytime soon and why?
A) Yes..... B) No.....
5. Where would you settle next if you were to move out of Kibera?
A) back to rural home B) another town C) estate in Nairobi.....
D) Others (state).....

D) Perception/personal health questions

1. Have you or any member of your family suffered any illness in the last three months? A)Yes B) No
2. What illness? A) Malaria/Fever B) Diarrhea/Stomach problems
C) Skin disease D)Others (state).....
3. Was treatment seeked? A) Yes B) No
4. How was the illness treated? A) Traditional herbs B) Medication from health centre C) Self diagnosis from chemist D) Others (state).....
5. Do you think the inadequate provision of sanitary services increase the frequency of such disease in (2 above)? A) Yes B) No
6. Do you think availability/scarcity of water affects your sanitation/level of cleanliness? A) Yes B) No
7. In your opinion, what is the quality of water you have access to?
A) Good B) Bad C) Don't know
8. Are there any proper arrangements for garbage collection and disposal within the slum? A) Yes B) None (common sites of garbage heaps)
C) others (state).....

9. Do you think the quality of water you use affect your health negatively?
 A) Yes (reason)
 B) No (reason)
 D) Don't know
10. In your opinion how do rate the condition and the cleanliness of the toilet/ latrines you use (give reasons)? A) Good B) fair C) bad D) worse

11. In your opinion do you think the water supply is adequate for the entire slum population? A) Yes B) No
12. How do you think the number of public toilets provided compare to the population they serve? A) Adequate B) outstretched
13. Are there common sites direct draining of toilet effluent into open drains/rivers? A) Yes B) No
14. Are there common sites of broken water pipes? A)Yes B) No
15. Do you consider the street lights provided in this village to be adequate?
 A) Yes B) No
16. Why did you choose to stay in Kibera? A) Cheap housing B) Cheap food
 C) Proximity to town (walking) D) To utilize rail transport
 E) All the above F) Others (state).....

E) Housing conditions

Observation table

Housing unit	Approx size(M ²)/No. of rooms	Item	Construction material	Conditions of:	
				Housing	Environment
		Roof			
		Wall			
		Floor			
		Windows (No.)			
		Door			