"VISUALIZATION OF URBAN GROWTH: A CASE STUDY OF NAIROBI"

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DECLARATION

This project is my original work and has not been presented for a degree in any other university to the best of my knowledge. No part of this work should be produced without the prior permission of the author and/or University of Nairobi

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Dedicated to my loving mother and father

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ABSTRACT

Current urban growth planning initiatives for Nairobi city mainly rely on single-epoch static maps as base data in conjunction with other non-spatial attribute information. This approach falls short of offering an optimal interactive environment to planners that is helpful in making decisions about the best mix of land uses, and their temporal and spatial dimensions. With increasing availability of cartographic multimedia tools for handling spatial-temporal data, urban growth phenomena can be analysed through cartographic visualization. Cartographic animation has emerged as a potentially effective visualization technique that has an intuitive power in representing dynamic geographical phenomena through its ability to show interrelations amongst geospatial data components, location, attribute and time. Whereas cartographic animations have featured prominently in communicating geospatial information, their use as visual exploration tools is hampered by lack of necessary functionality that is capable of allowing users to interact with the dynamic display. This report gives the findings of a research study for visualizing Nairobi's urban growth, from 1995 to 2002, through cartographic animation. Showing a series of images in sequence generated an animation of land use change for an area of approximately 1600 sq. km. The animation was created on the basis of the number of original data frames available, the optimal animation display speed, the number of intermediate frames to create between the known frames and the media on which the animation was to be displayed. Urban growth spatial themes identified for the study were built-up, unbuilt and vegetated areas. Creating the animation involved generating raster images for the temporal and spatial land use themes, converting them to bitmap thematic frames and subsequently importing the frames to a movie file. The results of this study are useful for visual thinking and communication of information on temporal and spatial components for the land use categories. The results from this animation can be improved by analyzing them in conjunction with other non-spatial urban growth data for Nairobi.

Key Words: Urban Growth, Visualization, Animation

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LIST OF ABBREVIATIONS

DN	Digital Number
Gif	Graphics interchange file
GIS	Geographic Information Systems
GPS	Global Positioning System
Jpeg	Joint photographic expert group
MPEG	Moving Picture Experts Group
PC	Personal Computer
PCA	Principal Component Analysis
RCMRD	Regional Centre for Mapping of Resources for Development
R.I.M	Registry Index Map
Tiff	Tagged image file format
USGS	United States Geological Survey
VRML	Virtual Reality Modelling Language

1. INTRODUCTION

1.1 OVERVIEW

There are few natural landscapes remaining on the earth's surface that have not been significantly affected by human activity. These influences result in shifting patterns of land use and thus land use and land cover change form a primary component of many current environmental concerns. Changes in land use and land cover are pervasive, increasingly rapid and are, therefore, bound to have adverse impacts and implications at local, national, regional and global scales. This means that any conception of global change must include the pervasive influence of human action on land surface conditions and processes. Urban growth is one example of human-induced changes to the natural environment.

Urban growth is defined as a socio-economic change in the use of land from purely rural to urban and involves the manner a community uses space to organize their ways of life. Urban growth is a complex phenomenon involving the interaction of a variety of processes and systems, both natural and human-induced. Therefore, planning for urban growth requires combination of various skills to generate optimal planning models for an urban centre. Today urban planning processes incorporate planning policies and priorities, land use plans and other non-spatial datasets such as demographic data and land value. (City Council of Nairobi, 1973). National and regional objectives constitute important general conditions for the formulation of planning processes. Critical factors to the process are local planning staff and finance. While collecting data and information, institutions and organizations that are active in the field of planning are analysed. In addition, existing plans and individual development activities are reviewed. This information is taken into account when plans are drawn up. In the process of drawing up and negotiating plans, conflicts between local development objectives in land use and other local interests, as well as superior planning objectives, are identified. Population projections help to determine facilities to be provided for the estimated population in the planned period.

The current approach to planning for urban growth relies mainly on statistical and computational models based on land use maps. This approach is not suitable for temporal spatial analysis, as it requires the planner to go through large collections of maps, reports and statistical data to be able to generate hypotheses. These maps and reports may get damaged in the process or get lost altogether. Such large volumes of data can impose memory overload to the decision maker, thereby affecting the results from his/her efforts. Also, this methodology does not allow for interactive exploration of the data involved. In this manner, the planner is likely to generate less efficient planning models.

Remote Sensing and GIS now provide new tools for urban ecosystem management. The collection of remotely sensed data facilitates the synoptic analysis of earth-system function, patterning and change at local, regional, and global scales over time. Such data also provide a vital link between intensive and localized urban planning research and the regional, national and international planning and management of urban ecosystems. In addition to these two technologies, visualization happens to occupy a centre stage in the management of natural ecosystems, and goes beyond collection and presentation of earth-related data. The visualization process is considered to be the translation or conversion of geospatial data from a database into graphics by applying appropriate cartographic methods.

Planning for urban centres is a complex process and requires a combination of various distinct players such as city planners, engineers, architects, politicians, civilians etc. These stakeholders often differ on the optimal approach to planning for the towns whose driving factors range from political, administrative to socio-economic. Urban planning applications require map data at relatively lager scales. However, existing maps in many urban planning authorities lack up-to-date data to facilitate efficient planning. This makes earth observing satellite images suitable candidates particularly where security restrictions, cost and time prohibit the use of other data sources. Besides, these satellites are suitable sources of time-dependent mapping data (Karanja and Lohmann, 2000). An optimal urban planning model must incorporate temporal data.

Today, an increasing number of users of cartographic data are interested in the temporal resolution of geospatial data. Hence the information the cartographer intends to communicate determines the mode of representation to be used. Until recently, cartographic products were read-only medium and cartography was the sole responsibility of highly trained experts. However, with democratisation of cartography and associated new mapping tools, map design need not be reserved for cartographers only. Many existing cartographic tools offer interactive and manipulation functionalities. These in turn offer visual exploratory capabilities where the user can search for unknown hidden information in the data. This type of exploration enables the user to come up with hypotheses about the mapped data (Ogao, 2002). In exploratory cartography the map is perceived as a tool that engages the user in an undirected search for geospatial structures and trends.

This research proposes a new method to handle temporal spatial data for urban growth through cartographic visualization. Cartographic animations are a suitable method for presentation of dynamic and temporal spatial data. Gahegan (1996) outlines the goals of cartographic visualization analysis as search for trends and correlation in spatial data, and the discovery of combinations of variables that are critical in pattern separation and concept identification. Besides, cartographic visualization can provide understanding and insight into visual exploration of data and phenomena. Visualization offers a complementary technique to computational data analysis with the crucial function of uncovering meaning in multivariate and multidimensional data (Ogao, 2002). This new tool provides the means to interpret internal and external visual representations of phenomena that may or may not be visible to human sight. According to Blok (2005) analysis of spatio-temporal data through visualization also helps to prompt thinking, identify and compare patterns, analyse changes and generate models. This approach can still be used to effect estimation and predict future patterns.

1.2 BACKGROUND

A variety of problems are associated with the expansion of urban centres. These range from crime, lack of adequate housing giving rise to informal settlements, poor sanitation, deforestation, traffic congestion etc. There is, therefore, a need for collaborative efforts by all stakeholders in addressing these challenges. It may call for systematic radical surgery and new ways of thinking and doing things (Nabutola, 2004).

Major cities in Africa are experiencing rapid urban growth. At the start of the 20^{th} century 95 per cent of Africans lived in rural areas. By 1960, Africa had about 19 per cent of its population living in urban areas. According to Ottichilo (2003) this percentage doubled by 1966 and between 1970 and 2000 the average annual growth rates in Africa were the highest in the world, at more than 4 per cent. There is, therefore, keen interest in urban development mapping and monitoring of urban sprawl.

A need is therefore highlighted to collect up-to-date information for urban growth, the determination of land use suitability for future land demand and a means of monitoring how land use and land cover changes affect the environment. This also calls for research efforts in understanding how land use patterns change and the development of policies that could encourage or discourage certain land use activities.

It is important to recognize that Nairobi is one of the fastest growing cities in Africa (see Table 1.1). New structures and facilities are coming up to cope up with the needs of the increasing population. On the other hand, there is an unending pressure on natural environmental resources. This situation calls for proper planning before the policies are implemented.

Table 1.1: Population of Nairobi for selected years, between 1906-1989(Source: East African Statistical Department (1986); Republic of Kenya-Kenya Population Census, 1962, 1969, 1979 and 1989)

Year	Area (ha)	Population	% Increase p.a.
1906	1,813	10,512	4.4
1928	2,537	29,864	17.1
1931	2,537	47,944	6.5
1936	2,537	49,606	6.5
1944	2,537	108,900	6.5
1948	2,537	118,976	2.2
1962	2,537	266,795	5.9
1969	68,945	509,286	9.8
1979	68,945	827,775	5.1
1989	68,945	1,324,570	4.8

In this regard, RCMRD has developed a geospatial database for Nairobi city for purposes of demonstrating urban sprawl (Khamala and Ottichillo, 2005). This suggests that a larger part of current initiatives in mapping Nairobi city lack the temporal component. If properly addressed this aspect of mapping will ease the persistent constraints to efficient urban planning in the area.

1.3 STATEMENT OF THE PROBLEM

Currently most, if not all, of urban planning initiatives in Kenya are based on single-epoch data, particularly maps as base data. As a result, urban planners do not get an opportunity to explore future trends in the development of these urban centres. This leads to deficiency of information necessary to address several unknown questions concerning the dynamic aspect of such human induced phenomena. Urban planners and policy makers need to explore and uncover trends in the temporal nature of these urban ecosystems so as to come up with optimal planning models that can conform to the intended policy goals.

There is, therefore, a need to establish a comprehensive time-varying mapping system for urban centres that will enable policy makers to define long-term strategic plans for the growth of the towns. Because of the challenges involved in planning for rapidly expanding urban centres, dynamic mapping of Nairobi city's urban growth is of critical importance. Most studies in this area have concentrated on one-epoch map analysis of the city's growth without integrating temporal considerations. This approach falls short of accounting effectively for the future trends of the city's expansion.

The last couple of years have witnessed a high rate of expansion of urban centres all over the world, the fastest growth being in developing countries. Kenya's capital city, Nairobi, is a case worth reckoning with its unplanned urban sprawl due to economic, social and political pressure from its large population. This expansion is due to, among other factors, rural-urban migration, increase in urban activity and population growth. According to Ndung'u (2002), efforts need to be focused on trying to accommodate this alarming phenomenon with the aim of promoting sustainable urban planning and development, as well as healthy living conditions for the population.

1.4 OBJECTIVES OF THE RESEARCH

Currently, the use of only map data for geospatial applications is not sufficient. Whenever time effects are involved there arises a need to manage dynamic spatial data in an efficient way. Cartographic visualization harnesses the ability of human mind to impose order and identify patterns (Peterson, 1994). In particular, cartographic animations are suitable for presentation of geospatial patterns over time and enable the exploration of such data in continuity.

Animation is a form of visualization involving creating the illusion of movement or change by rapidly displaying a series of single frames. The objective of temporal cartographic animation is to show change over time. Cartographic animations can be used as an exploratory tool to detect similarities or differences in distribution within a series of maps. This is particularly suitable when one can interactively access the individual frames in an animation and quickly switch between individual maps or map sequences.

In view of this, temporal spatial occurrences can be presented suitably through spatial visualization. This research aims at contributing to better urban planning strategies for a fast growing city by developing a visualization model that mimics the growth pattern. The specific objectives of this research study are:

(a) To review the roles and uses of animations as a form of cartographic visualization in enhancing geospatial data exploration, and

(b) To develop a prototype cartographic visualization model, using animation, which represents the growth of Nairobi city between the year 1995 and 2002.

1.5 ORGANIZATION OF THE REPORT

The work presented in this thesis is organized into five chapters. The first chapter is the introduction, which gives an overview of the background knowledge for the research work, statement of the problem, objectives of the study and organization of the report. Chapter two explores the literature review for theoretical basis for the representation of spatio-temporal data. In this chapter, an outline of the concept, operation and role of visualization of geospatial data, together with cartographic animation as a form of visualization, is given. Chapter three outlines the research methodology for the study. In chapter four, an outline of the results and their analysis is given. Lastly, chapter five identifies the main contributions and conclusions from the research. Also included in this chapter are recommendations for improvement on the results of the research study. References and appendices, as used in the thesis, are given at the end of the report.

2. LITERATURE REVIEW

2.1 INTRODUCTION

Temporal geospatial phenomena and processes are common in day-to-day life. They affect the natural ecosystem in many ways and, therefore, are of great concern in current global research efforts. They include flooding, desertification, spread of diseases and urban growth. Data characterising these processes exists in different forms including remotely sensed images, maps, plans, and coordinates. These datasets require effective representation for accurate interpretation and use. Cartographic visualization is an efficient approach for representing geospatial phenomena. Animations and virtual reality are forms of visualization commonly used for handling geospatial processes. In particular, cartographic animations are helpful in representing temporal changes in spatial data. Currently, there is a proliferation of systems and tools that offer an environment for creating and using animated maps. These systems find applications in different studies, including urban growth.

2.2 REPRESENTATION OF SPATIO-TEMPORAL DATA

Currently, there exists a large volume of geo-spatial data that must be continually updated to give useful information for their effective use. Geographic phenomena evolve over time, both spatially and temporally. As such knowledge extracted from spatio-temporal data can help users have better prediction of dynamic spatial processes and events. To both explore spatio-temporal data and derive meaning from it, greater focus needs to be put on its representation. Temporality in geospatial data can be static, sequential, time-stamped and fully temporal. Hence, among the current challenges to cartographers and geographic scientists is how to handle phenomena with characteristics distributed over space and time. MacEachren (1998) identifies representational tasks as one of the challenges to cartography for the 21st century. These include extending the object and forms of geographic representation as well as cognitive aspects of dynamic representation, 3D representation and virtuality.

Cognitive processing enables one to understand the information represented in a particular format. It is a process that requires the integration of both the internal and external forms of representation. In cartography, maps do not represent the world directly and transparently. Maps re-represent the world by providing truths for human mind to understand and, in this way, serve as important communication tools in cartography. As Montello (2002) points out, cognitive theories such as *Gestalt* theories of perceptual organization and *Jean Piaget's* constructivist theories have been applied by map-design researchers to aid in understanding cognition of mapping and map use. Cognitive issues in cartography arise from the potential of cognitive science to provide insights on how to develop a richer theoretical basis than can be provided by Euclidean geometry and graph theory. Maps must, therefore, provide accurate information to be useful. Besides, they must have an understandable message. Cognitive considerations include use of colour on maps, use of visualizations to discover patterns, the design and use of interactive maps and map animations.

To understand temporal and spatial changes in space or maps, cognitive models of dynamic spatial representations are necessary. Besides, such models are vital in the manipulation of temporal data and for navigation through changing spaces. At a database level, the major concern is on matters such as forming discrete representations of continuous phenomena or continuous representations of discrete phenomena. In cartography, emphasis is on animation. However, the use of dynamic and manipulative interfaces is becoming commonplace. Such tools must be integrated within the same conceptual framework used for observing dynamic phenomena in the real world.

2.2.1 Characteristics of Spatio-temporal Data

Phenomena that vary in both spatial and temporal domain are gaining prominence in geographic and scientific environments. As a result, various methods of studying dynamic phenomena are coming up. Visualization is one of them. A strategy of designing visualization is to transform the data in such a way that it creates an easy and comprehensive environment for obtaining information on the real world. Advanced computing technology has opened up numerous approaches to create visual displays, which ultimately facilitate thinking and problem solving.

The visualization of spatio-temporal data involves transferring information about characteristics and nature of data to the human brain by exciting the sensory systems through the proper use of graphics. In the real world, many geographic data and processes are dynamic in nature. Here, users are interested in viewing the changes over time, besides analysing the characteristics of the phenomena. Therefore, the user has to interact with the data. Methods used to interact with such data include visualization of interactive static maps and animations.

On the earth's surface, existing phenomena comprise of complex physical processes that vary spatially and temporally. Earth observing satellites currently form the best modes of collection of spatio-temporal data and phenomena. To study these complex processes, advanced statistical and computational modelling have been used by cartographers to explore and understand how geographic systems function. Nowadays, to monitor, explore and analyse different geographic phenomena, spatio-temporal data plays a major role. Therefore, a comprehensive understanding of spatio-temporal phenomena is necessary in the representation of complex geographic processes. Graphic representation is one of the ways used to analyse and explore the data. In cartographic visualization graphic representation depends on characteristics of the data and user needs.

2.2.2 Representation for Cartographic Visualization

Representation is a set of conventions about how to describe a set of things. The potential of any computation system is, therefore, dependent on representation. A good representation makes important features explicit while exposing the natural constraints inherent in the problem. The study of geospatial phenomena is dependent on the manner in which the data is represented. Though geographic phenomena often embrace high spatial and temporal variations over a large area with varying degrees of detail, their representation can only signify certain characteristics at a particular level of abstraction.

Cartographic visualization, on the other hand, is based on what form representations should take and how the representations are used. Conventional interpretive aids such as legends and scales are widely applied in cartographic representations. As used in animations, such cartographic tools should reflect the graphical variables used in the representations. To design effective map graphics, it is critical to understand the role and nature of graphic displays. The challenge then becomes that of assessing the strengths and effectiveness, together with the suitable applications of visual variables, sound and other tactile variables in representation. It is also necessary to establish how users of cartographic products interact with visual displays. Users of cartographic products are in different categories. They include experts and novices, and single users versus multiple or group viewers. Sex and age of the map-reader also determines the level of information the user can gain from the map and, subsequently, its design.

For the handling of geographic phenomena, the representation chosen influences interpretation and analysis. Therefore, the choice of a representation will depend on purpose of the analysis, data available and the level of abstraction of the actual phenomena being represented. According to Yuan et al. (2000), Geographic Information Systems and spatial analysis are influenced by representations at three levels: data models, formalization and visualization. In this sense, visualization, on the users' end, offers a graphical means for data exploration, analysis and interpretation. It integrates cognitive and semiotic approaches to facilitate scientific understanding of geospatial environments.

Given the various types and properties, and methods of collection and storage that geospatial data exist in, their representation and exploration require varying approaches. For instance, sonic data, dynamic and animated data all require special considerations. On the other hand an evaluation of optimal methods of incorporating them into representations for visualization is important. Equally fundamental are issues related to the quality and uncertainty of the data.

Time has properties distinct from those of space, hence incorporation of the temporal component into geospatial representation presents an extra challenge. Limitations of geospatial representations to current cartographic paradigm, for instance, constrain GIS support for information query, analysis and visualization. They include volumetric and temporal objects, heterogeneous type of geospatial data, dynamic geographic processes and their interactions, and data quality and uncertainty. The representation of dynamic geospatial phenomena is based on the use of different visual variables and the ability of human-computer interfaces to allow users to interact with these representations. This enables the user to explore the visualization to identify patterns and generate new hypotheses.

Although there exists a wide range of applications for map-based representations, in all these scenarios, the mode of representations should be brought under user control. A classification of the methods of representation and their potential applications can enable efficient exploitation of geospatial data. It is important to ensure that an appropriate level of data abstraction for that representation is displayed. Once displayed, navigation and effective linking to other data from within the representation is desirable. This enables the representations to offer effective tools in addressing various problem solving and data exploration tasks.

2.2.3 Exploratory Cartography

Most of the existing interactive map displays and manipulation cartographic tools fall short of offering visual exploratory capability where users can search for unknown hidden information in the data. This type of exploration can enable the user come up with hypotheses about the mapped data. Instead, existing tools only favour goal-oriented search for patterns and structures in geo-spatial datasets. This results in the map user only being able to examine existing hypotheses about the data. According to Ogao (2002) visual exploratory tool design should not be based only on data characteristics and anticipated tasks users are prone to undertake. Rather, exploratory visualization tool design should be enacted from the acquired understanding of the cognitive pathways. Therefore, knowledge of the underlying cognitive model for exploratory cartography is fundamental to effective design and evaluation of exploratory visualization tools. In exploratory cartography the map is perceived as a tool that engages the user in undirected search for geospatial structures and trends. However, most emergent visualization tools only offer elaborate interactive and dynamic data manipulation capabilities derived from presumed conceptual and perceptual user goals. They serve goals that are already anticipated and predetermined. Hence they cease to function as exploratory techniques.

Cartographic cognition is concerned with active processing of the map and incorporates such cognitive structures and processes as memory, thinking, imagery, motivation and attention. A map comprises of multiples of graphic elements that the map-reader interacts with. To optimise on the map reading process, it is essential to understand the mental processes involved in these interactions. Different and distinct needs are necessary to study spatio-temporal data. These vary from presentation to exploration of the data. The needs comprise of a series of tasks or a list of processes that are undertaken and involved within the confines of the users thought processes. For example, to study urban growth the user would prefer to work with demographic data for evaluation of the rate of population growth in the area, vacant land adjacent to the town, vegetation cover, water supply and waste disposal systems among other variables. This will ensure that a balanced urban ecosystem is realised. In this case, the user may apply statistical operations in order to achieve the above objectives. However, statistical techniques are not suitable for exploration of temporal datasets. In cartographic visualization numerous techniques can be applied for the exploration of spatio-temporal characteristics. Linking between maps and different datasets, and interactive manipulatable maps are some of the techniques that can be applied for these types of datasets. For analysis of spatio-temporal datasets basic visualization operations widely used are: identify, locate, associate and compare. All these operations enable users to explore and analyse the datasets with the help of a definite process to reach a conclusion.

2.3 CARTOGRAPHIC VISUALIZATION

Recent developments in cartography have led to incorporation of visualization in mapping through use of the potential of human visual system. Through the use of computers and enabling technologies such as image processing, computer graphics, animation, multimedia and virtual reality, geospatial information can be handled more efficiently. Such a new way of presenting cartographic information enables patterns to be revealed, and the map user can easily understand the data content to enable easier solution of problems. This method of handling geospatial data can be beneficially applicable to all levels of cartographic problem solving. These range from hypothesis development, analysis, knowledge discovery, presentation and evaluation.

The goal of information visualization is to develop a greater understanding of the interactions of a system or distribution. This is achieved through the use of computers to generate interactive representations of multiple variables, often in linked formats. Understanding the interactions in geospatial systems involves exploration of the data. Exploration involves expert users being engaged in ill-defined tasks such as hypothesis formulation.

Cartographic visualization, therefore, can be considered broadly as computer-dependent methods of data display for expert users who are mainly interested in exploration of very large geospatial datasets. Cartographic visualization also incorporates other media (e.g. paper and film), other non-spatial datasets, different user groups, cognitive processes of visualization and other computer configurations (e.g. mobile computing). As the volume of data in our geographic environment continues to increase, there exists more data to visualize. With the advances in technological capabilities, there are more ways to visualize the large datasets. Therefore, in understanding our environment, there is more need to comprehend how visualization works. For geospatial scientists to contribute effectively to the development of visualization a thoughtful and directed approach to structuring their efforts to issues in cartographic visualization is necessary. It is becoming increasingly difficult to explore, understand, analyse and communicate geospatial information due to the vast increase in availability of digital geospatial data. Through visualization, new methods of addressing these difficulties are offered in a manner that harnesses the expertise of the cartographer.

Interactivity in cartographic visualization is analogous to symbolization in static map design. The two parameters serve to aid in the interpretation of the data and inform the knowledge that is acquired from the visual display. Static maps have minimal interactivity and, therefore, only serve to communicate the designers' ideas, rather than those of the users. However, current cartographic paradigm favours active exploration of information for the discovery of knowledge, and not mere communication. Symbolization is synonymous with interaction in systems that study spatio-temporal phenomena. A pseudo-three-dimensional button in a Web map interface, for instance, draws the users attention to the information available upon clicking on the button. A hotlink without a three-dimensional effect, however, may fail to divert the user's attention on the opportunity to gain more information.

Visualization aids in cognition by offloading inferences from the cognitive to the perceptual system. This can also be achieved through reducing the search for relationships by grouping related information visually. For the representation of large amounts of data, dynamic visualizations are more effective since they are manipulatable and interactive. Hence, the user's attention can be restricted only to a portion of data at a time for in-depth assessment. Dynamic representations are also useful in the monitoring of processes based on temporal and locational schemata. Therefore, understanding the processes by which spatial and temporal relationships are obtained and stored in the mind is fundamental in spatio-temporal visualization as this helps in interface design of visualization tools. The cognitive framework for representation is applied in visualization interface design, temporal GIS and legend design for animated maps.

2.3.1 Visualization Strategies

Within cartography and other geoscience disciplines, visualization finds application in presentation and evaluation tasks. Besides, cartographic visualization serves as an important link between the human and the machine (tools) by facilitating data exploration and fostering human-computer interaction. Graphical techniques are usually employed in visual approaches to uncover structures in geospatial data. A typical methodology involves the process of exploration, confirmation, synthesis and presentation. Portrayal of data in visual form stimulates pattern recognition and hypothesis generation. It can, therefore, be hypothesized that visual approaches to geospatial data analysis and mining attempt to harness the human abilities to perceive patterns and structures in visual form and make sense of what is seen.

Visualization is used as a technique for exploratory data analysis due to its ability to provide insight into complex data. By visual analysis, the data is presented to the user in a way that the task of interpretation is made easier. Also, visualization provides opportunities for authentic discovery. However, the cognitive processes involved in learning with visualization as well as the manner in which such visualizations impact comprehension processes are essential for their optimal design.

An optimal visualization environment should offer a fine level of control over the stimulus space. This can be used to promote visual attention allocation and to enable more data to be included within the visualization. In this way, other variables such as colour, texture and orientation can be used effectively. Static graphical presentations are not suitable for exploratory data analysis. Dynamic manipulation refers to any action that makes a data component change in real-time. Interactive manipulation, on the other hand, applies to actions that result in non-temporal changes in data components. Andrienko and Andrienko (1999) identify three categories of manipulation techniques as follows:

- Navigation tools: these provide basic opportunity for both viewing and manipulation. However, they do not directly address data exploration issues. Examples include zooming, panning and rotation.
- Query and search tools: in these systems graphical presentation reflects the result of querying a database and is instantly updated when the user changes the query conditions. They include dynamic queries and attribute explorer.
- Focusing/linking/brushing techniques: these comprise of several linked displays of the same dataset presenting different projections of multidimensional data. These techniques support exploration of individual groups. However, they do not support comparison of groups. Examples include scatter plots and bar charts.

Various combinations of these dynamic display tools can be more effective for exploratory visualization of geospatial data.

Different interactive manipulation tools are designed for different presentation methods. This is based on intended data features and relationships, and the graphical means the method employs. The aim, here, is to reinforce visibility of the features so that they can easily be identified. Moreover, addition of redundant visual variables increases the legibility and expressiveness of the visual display.

2.3.2 Visual Approaches to Data Exploration

Two categories of techniques are used by geoscientists and statisticians in exploratory analysis, namely chart-based and map-based techniques. Map-based techniques allow the mapped data and its visual appearance to be changed actively. A common application is the use of map legends as the basis for interaction. They allow the user to change the appearance of the objects mapped and thereby defining and explaining clusters. In chart-based techniques, the data is plotted on a chart or graph. Common examples are scatter plots and parallel co-ordinate plots. Often, these techniques are accompanied by linking and brushing methods that allow selected data points to be viewed in different ways or within different axes.

Dynamic classification employs colour hue as an associative visual variable that promotes the perception of multiple graphical elements as a single image. Combining dynamic classification with presentation of class statistics by diagrams increases the level of knowledge acquisition from the diagrams. Other variables that aid in dynamic separation in exploratory visual analysis are colour, shape, narration, text, texture and orientation (Krygier, 1994).

2.4 VISUALIZING SPATIO-TEMPORAL DATA THROUGH CARTOGRAPHIC ANIMATION

There exists a common saying that a picture is worth a thousand words while a map is worth a million bytes. Maps are static displays, which support several types of spatial data simultaneously in order to compare and relate them. Animation is a dynamic visual statement that evolves through change in display of the graphic art. Map animation, on the other hand, pulls out only certain features from the map and uses animation techniques to express the function looked for. The dynamic presentation of complex geospatial data is efficiently done through cartographic animation. Currently, there is increased need for use of cartographic animations, particularly while dealing with real world processes as a whole. This is due to the unique potential of these animations to handle spatio-temporal processes. Animations explain processes, tell a story, reveal patterns and relationships and show trends in geospatial phenomena. In this sense, animating maps can give insight into apparent spatial relationships and patterns.

Early forms of cartographic animations were on film and video. However, with the advent of computer technology and related data communication developments such as the World Wide Web, cartographic animations can now be found in a variety of forms and data formats. Although the use of animations in cartography is gaining prominence among geoscientists, it is yet to be fully integrated in software for GIS. Cartographic animation also faces a number of conceptual and methodological hurdles. Studies of the development of animation in cartography consider the means of animated map production, modes of use and the method of distribution. The history of animated map production, therefore, fits into three overlapping eras, namely: manual, computer-assisted and computer-based production (Harrower, 2004).

The mode of storage, distribution and use of animated maps can be considered in four distinct phases, beginning from the early 1950s. These comprise of the celluloid film (1950s to 1970s), magnetic videotape (1970s to 1980s), floppy diskettes and CD-ROM (1980s to present) and finally online distribution (1990s to present). Each progressive step in the development of media for the storage, distribution and use meant a reduction in cost and time of producing animated maps. However, online distribution still suffers major obstacles to its optimal use. These drawbacks concern the standard file formats for digital video, software that can read and playback digital video, and hardware capable of decoding video at sufficient frame rates for animation. Nevertheless, there has been coalescence of digital video around a few standard formats such as MPEG and QuickTime. Indeed, the success of these file formats has been considerably great since many of the software needed to view these files are free and come preinstalled on most desktop computers.

Today, the success of computer-based animated cartography can be attributed to the wider developments in computer science. These have given rise to real-time interactivity in animated map use, state-of-the-art user interfaces that meet the needs of the map users, and the Internet. These three attributes allow cartographers and users to create and use animated maps effectively, view and work with, store and distribute animated maps faster and economically. Of particular importance has been the development of the World Wide Web, which is used for various cartographic applications such as on-demand Web mapping. However, there still remain a number of technological hurdles in cartography with regard to the PC and Internet revolutions. Other concerns include the cost of animated map production, both in terms of time and personnel, and their mode of distribution to the public, which requires fast Internet network connection. Solutions to these problems have been addressed through bandwidth (broad-band connection), streaming technology, vector-based animations and introduction of interactivity in animated map environments.

2.4.1 Types of Cartographic Animations

Two types of cartographic animations can be identified. These are temporal and non-temporal animations. Temporal animations show change over time e.g. the growth of a city. Such cartographic animations show change through maps as a time lapse. Non-temporal map animations, on the other hand, show a series of oblique views of a landscape displayed in quick succession to provide the appearance of flying through the terrain e.g. a fly-through. Non-temporal cartographic animations can also be classified into four as: cartographic zoom, classification animation, generalization animation and spatial trend animation. Dynamic variables used in non-temporal cartographic animations are re-ordering and changing the pace of animation.

On the other hand, Dorling (1992) proposes three types of cartographic animations namely:

- animating space or panning and zooming around two-dimensional static images,
- animating time or time-series animations of two-dimension images, and
- three-dimensional animation.

Time-series animations can be created as two-dimensional planimetric animations or three-dimensional perspective animation with fixed and moving viewpoints respectively. Another classification identifies three different categories of cartographic animations. These comprise of time-series (e.g. weather broadcast), successive build-up (e.g. map layers in the structure of a city) and changing representations (e.g. a fly-by). In all these classification schemes, the goal is to deal with real world processes as whole rather than single-time slices.

2.4.2 Cartographic Animation Environment

The migration of cartographic theory from expert users to general audience is one characteristic aspect of current cartographic visualization systems. Though varied in applications, Emmer (2001) outlines three different goals of visualization as follows:

(i) Visualization for presentation purposes: involve high quality representations that display fixed facts.

(ii) Visualization for confirmation purposes: serve to confirm or reject an already postulated hypothesis.

(iii) Visualization for exploration purposes: the main aim is hypothesis generation. This involves interactive processes aimed at undirected search for structures and trends in geospatial data.

The visualization methods realizing these goals are summarized in Table 2.1. It follows from the table that interactivity and link to other data in a cartographic animation improves its exploratory function. Interactivity, on the other hand, is enabled in animated maps through design of interface, map image, legend and link to database. Other methods of viewing cartographic animation through the World Wide Web have been developed using JavaScript (Peterson, 1999).

Table 2.1: Characteristics of visualization (Adapted from Emmer, 2001)

Complexity	Visualization Method	Use
Low	Single map	Presentation
	Series of single maps	
	Animation	Confirmation
	Interactive animation	
High	Dynamically-linked animation	Exploration

2.4.3 Design of Animated Maps

Cartographic visualization involves huge data sets containing large numbers of items from which measurements are made. However, cartographers find themselves dealing with limited time, space, money and material to process these datasets and come up with the required visualization. Aggregation is a technique used in cartography to enable the handling of datasets manageable in size.

In representing process, map animation is a suitable compromise among most visualization methods. However, a number of problems are associated with animations, particularly as concerns their cartographic use in geospatial applications. Finally, there is a limitation of visual working memory in the interpretation of change as movement. Also, limitations exist due to popular animation formats designed for passive linear viewing, where there is little or no level of interactivity required for visualization. Complexity of datasets represented through animation is an additional constraint.

According to Morrison (2000), there exist four major challenges to designing effective animated maps. These comprise of disappearance of graphic images in the animation during play, attention focus, complexity of map data, and level of confidence of knowledge being conveyed by animations. An animation that addresses these challenges gives an optimum communication of the dynamic process being mapped. A map animation with simple individual frames, decay images, and with temporal and spatial exaggeration overcomes the problems of losing task of process during disappearance.

Dynamic map symbols, sequencing and voice-overs can serve to direct the user on where to look at as the animation plays (Harrower *et al.* 2000). A high level of generalization, on the other hand, can reduce the complexity of the map data. These aspects can also be handled by provision of interactivity in the animation, and also through a facility to enable users turn on one particular theme at a time. Other map animations use larger texts, brighter colours, thick line heights and less detailed base maps to enhance the confidence of knowledge being conveyed. This can also be achieved through multimedia functionalities e.g. by providing a short-guided introduction to the interface through a narration or text, before showing the animation.

In cartographic animation design, dynamic variables are used to assist the viewer in understanding the trend or phenomena being mapped. Cartographic dynamic variables include display date, duration, frequency and order. Other dynamic variables are rate of change and synchronization. Animation variables comprise of size, position, orientation, speed, scene, colour, texture, perspective and sound. Dynamic variables serve as visual manipulations and hence critical to the design of animated maps. Besides, dynamic variables are applied in dynamic symbolization to strengthen graphical variables e.g. blinking symbols.

In designing time-series cartographic animations attention need to be directed to the number of original data frames. Other factors that ensure that the animation approximates the natural geospatial phenomena being mapped, as closely as possible, include the level of temporal interpolation of intermediate frames, number of animation frames and the display speed of the animation. In animating urban growth pattern a display speed of 5-10 years per second (yps) is favourable (Acevedo and Masuoka, 1997). However, this can vary depending largely on the viewer's objective in the animation design.

2.4.4 Applications of Cartographic Visualization to Urban Growth Studies

The manner in which users of geospatial data explore and understand relationships among the datasets is continuously changing. Consequently, new visualization methods and techniques to implement them are being developed. The graphical user interface enables the user of a geovisualization system to interact with the datasets of the system. Various conceptual methods have been adopted in development of geovisualization systems. These have led to the development of specific tools such as linked geographic displays, coupled statistical-geographic representations and flexible on-screen classification techniques. However, many of the tools developed for visualization of geospatial data are suited for different tasks and data requirements. Besides, they do not offer optimum value for users in their domain of application. Reports of usability studies and controlled experiments are helpful to understand the potential and limitations of these tools and systems.

Based on conceptual methods, a number of specific tools have been developed to aid in exploration of geospatial data. Some of the techniques adapted for exploratory data analysis comprise of brushing, focusing, scatter plots, bivariate mapping, dynamic classification and parallel coordinate plots. The tools have been applied in a number of prototype visualization packages. On the other hand, visualization systems for geospatial data are tailor-made visual analysis environments for particular application domains. They address application tasks for users in the domain and handle distinct forms of datasets. A variety of geospatial data analysis techniques are incorporated in their design. Besides, the systems depict different functionalities and operate on varying system platform requirements. Examples of geospatial visualization systems are TerraVision(URL), EarthSystemsVisualizer (Harrower et al., 1999), R-VIS (Howard and MacEachren, 1996) and Descartes(Andrienko and Andrienko, 1999).

Urban growth and planning issues involve complex interactions of events and processes that require an enormous amount of datasets. Animations are a favourable method for the representation of dynamic spatio-temporal phenomena. These visualization techniques can enable planners to have a glimpse of the futurescape of the urban models as proposed by the concerned planning authority. These techniques, therefore, form good decision making tools that can help urban policy makers in making planning tasks easier. The long-term benefits of these visualization tools in urban growth management far outweigh the recurring cost of piecemeal planning and traditional practices.

Cartographic visualization techniques, particularly, animations have been applied in various urban planning studies around the world. The results confirm the huge potential of such tools in urban planning and management processes. In a project by Yildiz Technical University, a 3D visualization of its Ytu Davutpasa Campus area was carried out (Yucel and Selcuk, 2004). The resultant visualization models offer a suitable tool for land planning and management for the campus. Herold et al. (2003) also outline a study to model and analyse the urban growth of Santa Barbara area in California for a period of 72 years beginning from 1930. The result was a SLEUTH urban growth and land use change model that allows the filling of gaps in the discontinuous historical time-series representation of urban spatial extent for the region. When visualized through cartographic animation the model allows a spatial forecast of urban growth to the year 2030. Another study by Henning (2001) involved a spatio-temporal database to create a time-series animation of urban growth in the Copenhagen metropolitan area. The project covered the period from the end of the Second World War in 1945 up to 1995. The resultant cartographic animation tracks the developments of the region over time indicating how minor towns located in and around agricultural areas are becoming large developed cities and continuous corridors. The animation can enable decision makers to perceive the changing spatial patterns of the area e.g. urban growth. Other applications of cartographic animations in urban growth and planning are studies in the Baltimore-Washington metropolitan region (Acevedo and Masuoka, 1997; Clark et al., 1996). In these studies, the animations produced enable the visualization of Baltimore-Washington area's past as well as future land characterizations.

3. METHODOLOGY

3.1 INTRODUCTION

The focus of this thesis is on the application of cartographic visualization concepts to generate an animated map for Nairobi city using identified geospatial datasets. The initial phase of the research identified the theoretical basis for the research study. Inherent in this study is the cognitive effect of using cartographic animations in the representation of spatio-temporal data, and more so, as it relates to urban growth.

The next task involved the design of an effective thematic cartographic animation framework based on suitably identified datasets that would give a representation of urban growth. This was done in consideration of the functionalities of the existing tools and the user tasks they can support. Finally, a prototype animation model for the study area that depicted the cartographic datasets that were identified was produced. The animation was developed to aid in the exploration of the complex dynamic human-induced phenomenon of urban growth. The cartographic animation offers a suitable method of analysis of the time-varying occurrence of urban change.

A diagrammatic representation of the adopted research methodology is given in Figure 3.1.

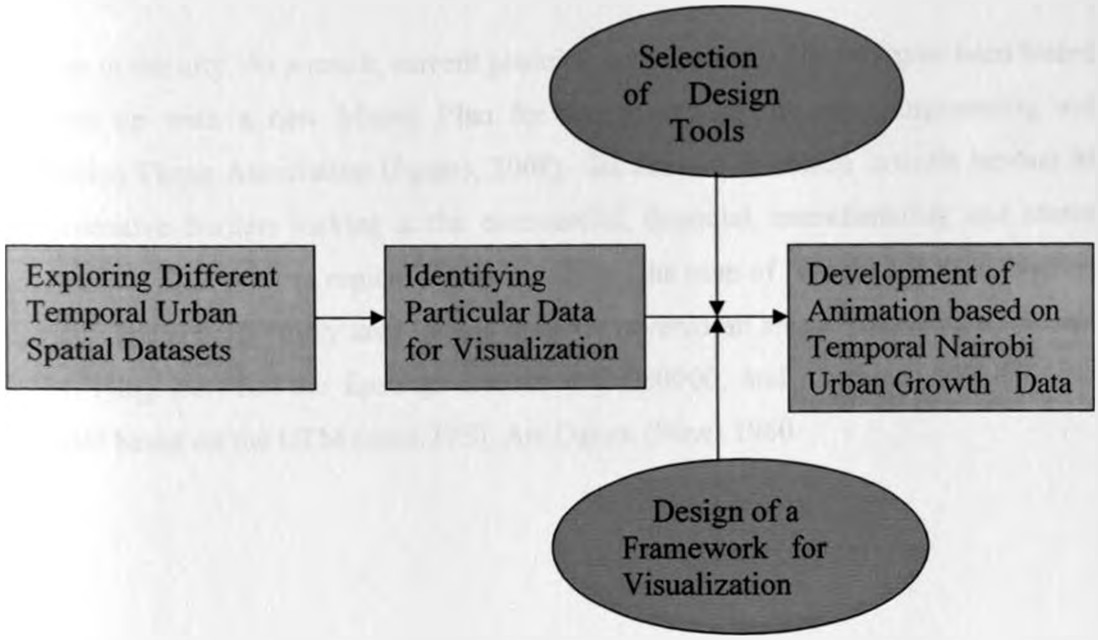

Figure 3.1: Flow chart of adopted methodology

3.2 STUDY AREA

The origin of Nairobi city is linked to the construction of the Uganda Railway by the British engineers. According to Moss (2000), its history dates back to 1899 when the railway engineers found the area suitable for setting up a camp. The site offered convenient level land for construction of rail track siding, while the nearby cooler elevated land provided suitable accommodation for senior railway construction staff. The apparently deserted terrain meant that little resistance could be expected over matters of land acquisition.

Nairobi is located at an attitude of about 1,700 metres. It lies around Longitude 36° 50' East and Latitude 1° 17' South. The city is the crossing point of the Great North Road, from Cairo to Cape Town, and the Trans-Africa Highway, from Mombasa to Lagos.

Nairobi's brief development was planned by the colonial authorities, assigning different functions to specific zones. However, population explosion in search of employment in the years that followed, particularly, after independence, put a lot of pressure on existing services in the city. As a result, current planning authorities for Nairobi have been forced to come up with a new Master Plan for the growth of the city (Engineering and Consulting Firms Association (Japan), 2008). Its zone of influence extends beyond its administrative borders making it the commercial, financial, manufacturing and tourist centre of the East African region. Figure 3.2 shows the map of Nairobi and neighbouring districts. The specific study area for the research covered an area of approximately 1600 sq.km, lying between the Eastings 240000 and 280000, and Northings 9840000 and 9880000 based on the UTM (zone 37S), Arc Datum (New) 1960.

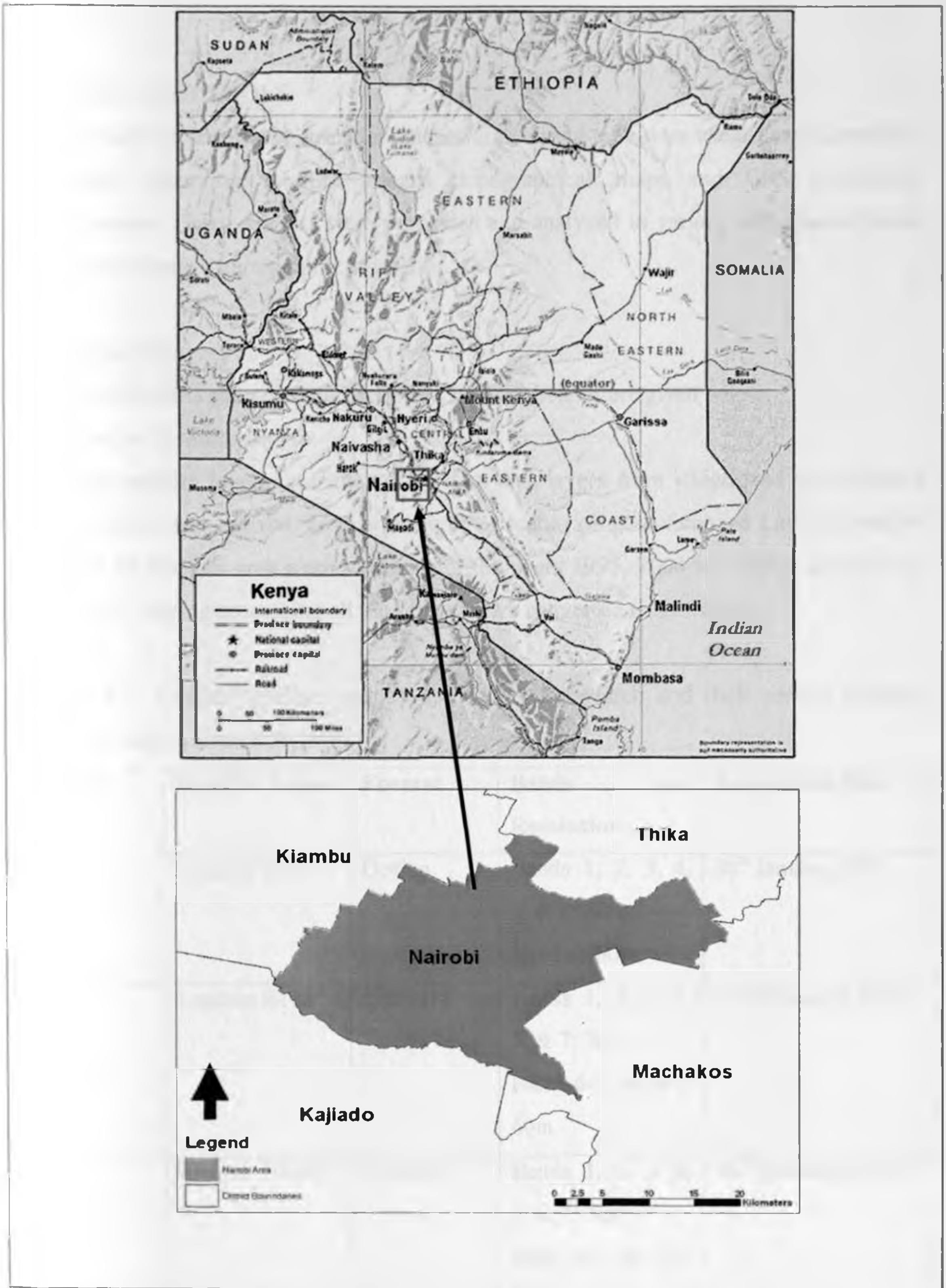

Figure 3.2: Nairobi and neighbouring districts

3.3 DATA AND TOOLS

In this research temporal geospatial datasets for Nairobi area were used. These comprised of earth observing satellite images, topographical maps and GPS co-ordinate observations. These datasets were processed and analysed in various computer software tools to generate a cartographic animation.

3.3.1 Data Sources

The specific data characteristics acquired for the research are given below.

(a) Landsat Satellite Images

Landsat satellite images constituted the base data layers from which land use and land cover maps were derived. In this study three scenes of georeferenced Landsat satellite images for Nairobi area were acquired for the years 1995, 2000 and 2002, as shown in Table 3.1. During processing all the images were converted to Tiff format.

Table 3.1: Landsat satellite images used for the research and their sensor platform characteristics (Source: RCMRD)

Image Scene	Satellite Sensor	Format	Bands and Resolution	Acquisition Date
1	Landsat TM	Dotlap	Bands 1, 2, 3, 4, 5, & 7: 30m Band 6: 60m	30th January 1995
2	Landsat ETM	GeoTIFF	Bands 1, 2, 3, 4, 5, & 7: 30m Band 6-1 & 6-2: 60m	21st February, 2000
3	Landsat ETM	GeoTIFF	Bands 1, 2, 3, 4, 5, & 7: 30m Band 6-1 & 6-2: 60m	10th February, 2002

Composite images of the first three principal components for each of the image scenes are shown in Figures 3.3 (a), 3.3 (b) and 3.3(c) below.

(b) Other Data Sources

Various topographical map sheets for Nairobi area, at scales of 1:50,000 and 1:100,000 and different dates of publication, were acquired for the research (see appendix I). In addition, GPS observations for some points in the area of study were made. The GPS observations were selectively identified to serve as ground truth data for the land cover classes to be used in the image classification process. These observations were made using a 5-metre accuracy Garmin SportTrex GPS receiver, based on the Arc Datum (1960), UTM (Zone 37S). Also, a 2000 georeferenced scene of 0.6m resolution Quickbird satellite image for Nairobi was acquired. The GPS observations used for this research are shown in Appendix II.

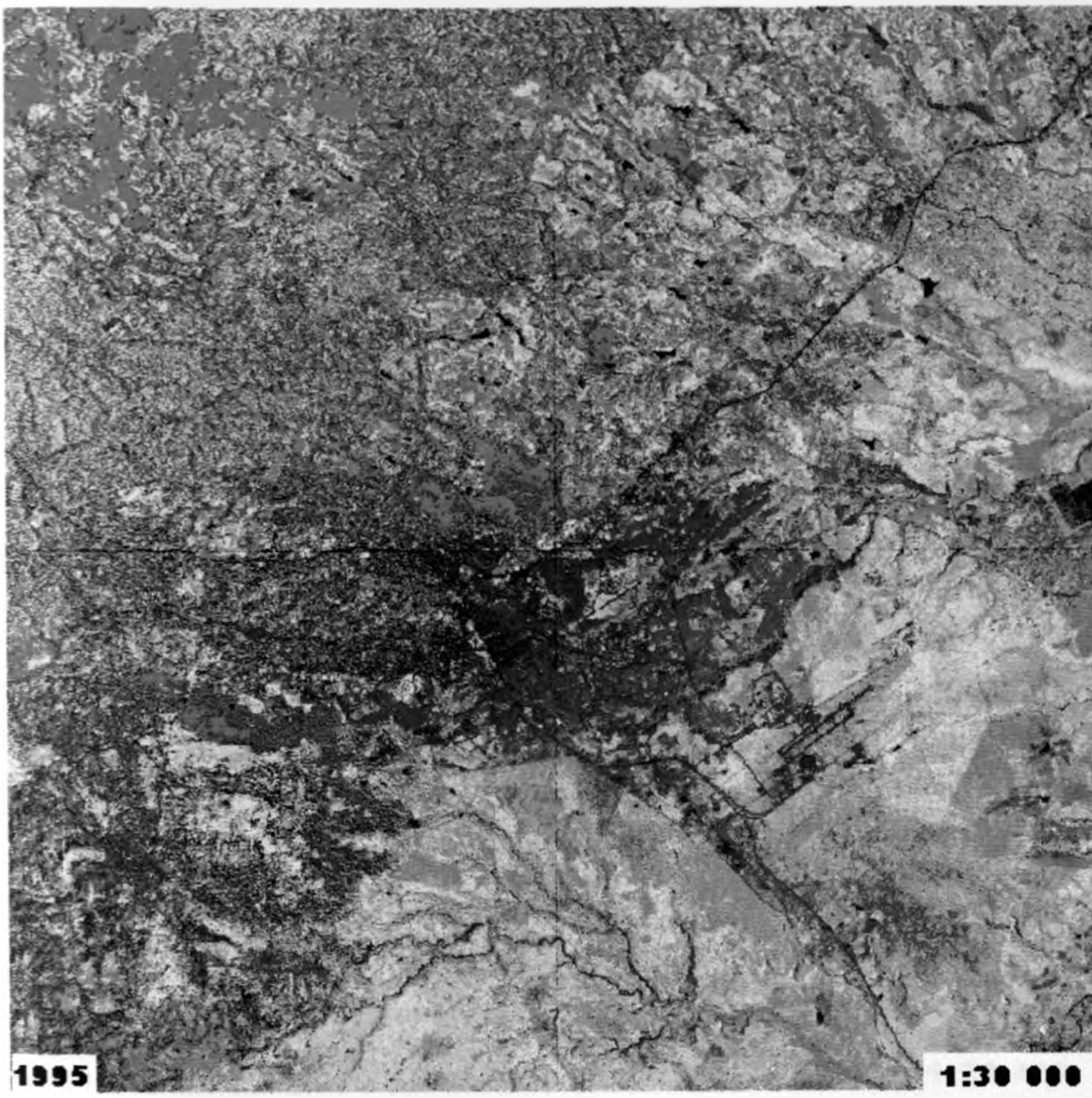

Figure 3.3(a): 1995 Landsat image scene for Nairobi. Blue colour represents urban built areas while green colouration shows vegetated zones. The other colours represent other unbuilt areas.

3.3.2 Tools Used for the Study

Various tools were used in this study for different purposes. The uses comprised of data collection, processing and producing animations. Table 3.2 gives the different types of tools used in the research.

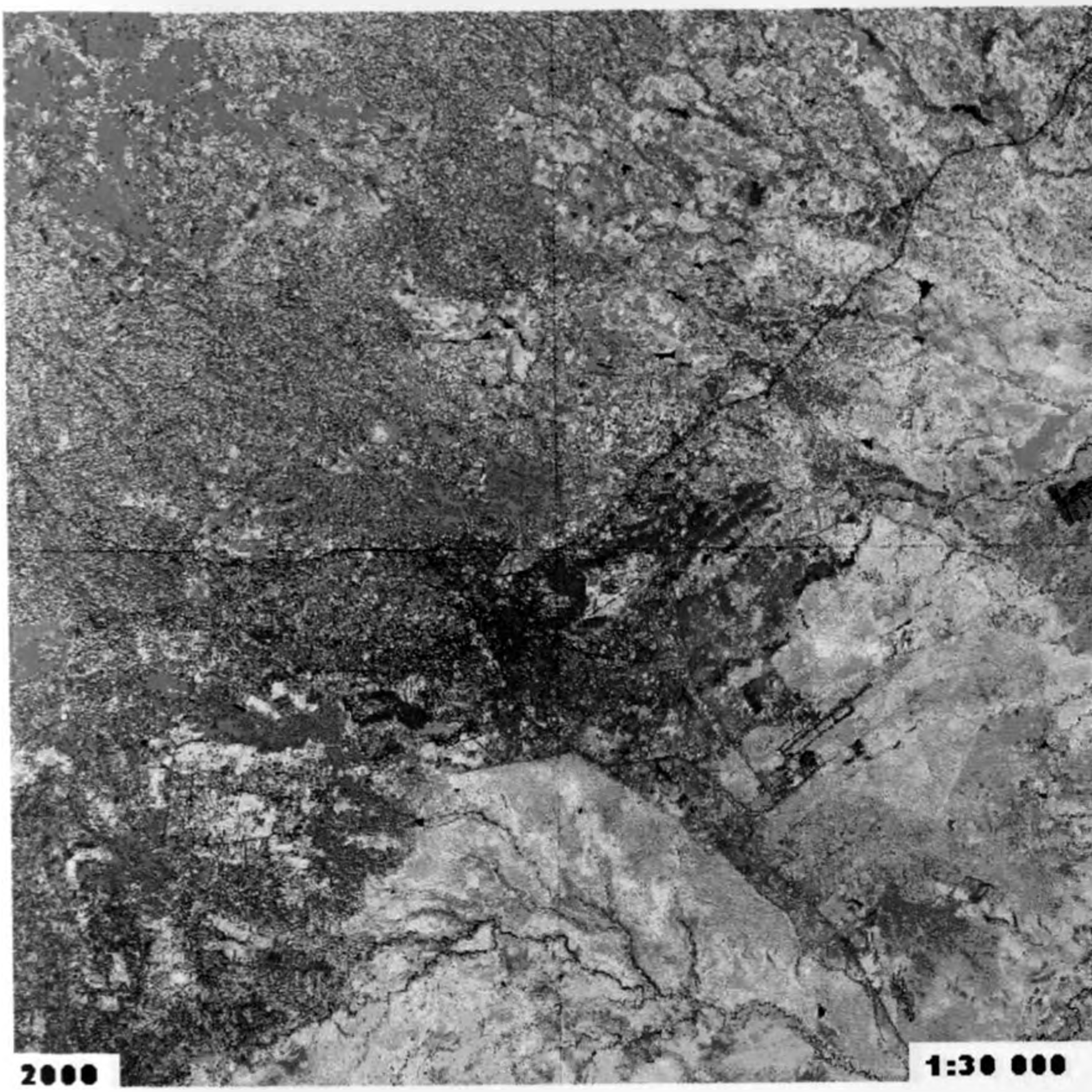

Figure 3.3(b): 2000 Landsat image scene for Nairobi. Blue colour represents urban built areas while green colouration shows vegetated zones. The other colours represent other unbuilt areas.

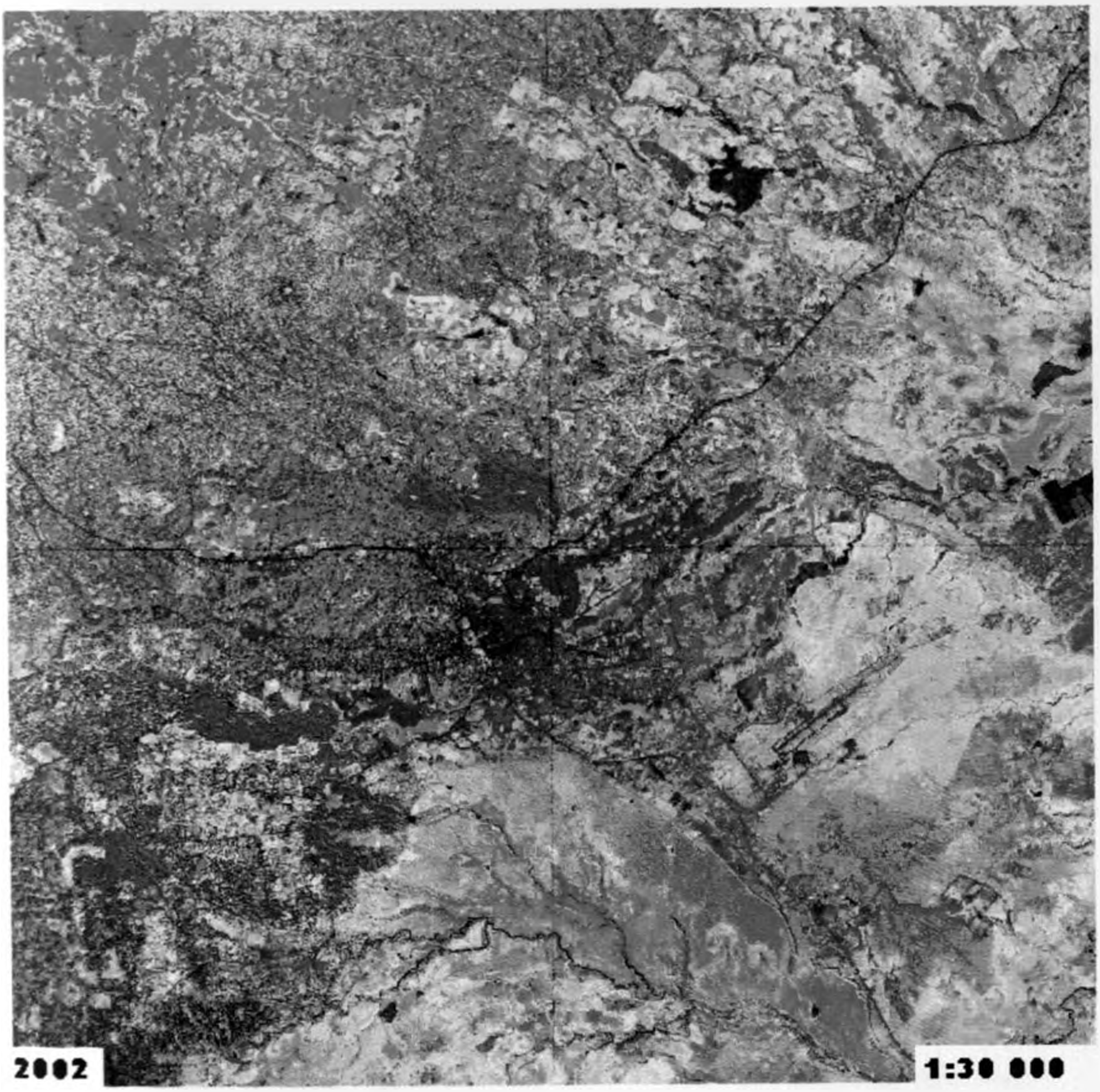

Figure 3.3(c): 2002 Landsat image scene for Nairobi. Blue colour represents urban built areas while green colouration shows vegetated zones. The other colours represent other unbuilt areas.

Table 3.2: Outline of different mapping tools and software used in the research

Tools	Purpose	Hardware Specifications
ArcInfo 9.1	Generating vector maps for Nairobi area	• Windows NT/2000/XP • Pentium chip PC • 128MB RAM minimum • 600MB hard disk space • True colour monitor – minimum 16MB video card • Open GL card for Arc GIS 3D Analyst
Idrisi Kilimanjaro	Image processing	• Windows NT/2000/XP • Pentium based PC (Pentium III or higher) • 128MB RAM Minimum • 600MB hard disk space
Macromedia Flash	Making and playing animation	• Windows NT/2000/XP • 600MHz Intel Pentium Processor or equivalent • 128MB RAM or higher • 347MB available disc space
SportTrex handheld GPS receiver	Making field coordinate observations	

3.4 DATA PROCESSING AND CARTOGRAPHIC ANIMATION DESIGN

This stage of the research involved data preparation procedures and actual image processing. Data preparation involved pre-processing of the image scenes. Landsat satellite images used for the research had already been geo-referenced by the source agency (RCMRD). Initially, geo-referencing had been done on the 2002 Landsat image scene in GeoVIZ 2.1.0. Thereafter, image scenes for 1995 and 2000 had been geo-referenced based on the 2002 Landsat image scene as the reference image. The 2000 Quickbird satellite image scene had also been geo-referenced. Data preparation involved common tasks such as scanning and digitisation of topographical maps for the study area. Topographical maps were used to produce a map of the study area as well as serving as important ground truth data sources. The Quickbird satellite image scene was also used for provision of ground truth data during image classification process.

3.4.1 Data Processing

Data processing was accomplished using the software Idrisi Kilimanjaro. The process comprised of image enhancement, principal component analysis and image classification.

Image enhancement: This was necessary to improve the contrast of the images. Image histograms for each image band were examined revealing uneven shift in the distribution of their digital numbers (DN) well above the minimum value of 0 and maximum value of 255. Contrast stretching was carried out to alter the distribution of the range of DN values for each band. In this case, histogram equalization stretch was used as it favourably expands some parts of the DN range at the expense of the others by dividing the histogram into classes containing equal numbers of pixels. This results in a superior end product compared to other types of image contrast stretching techniques.

Principal Component Analysis: This procedure was necessary to decorrelate image bands in the Landsat image scenes. Scatter plots were generated to identify image bands that were correlated. For the 1995 Landsat scene scatter plots were generated for different band combinations. This was done using contrast stretched bands 1, 2,3,4,5 and 7. Band 6 was not used, as it comprises of mainly thermal radiation and was, therefore, likely to give misleading information for the required image clusters during classification. For the 1995 Landsat image scene, scatter plots for 15-band combinations were generated. In 2000 and 2002 Landsat images, scatter plots for 15-band combination were also generated considering contrast stretched bands 1,2,3,4,5 and 7. Similarly, bands 6-1 and

6-2 that represent mainly thermal radiation, were not considered in the 2000 and 2002 image scenes.

From the scatter plots the band combinations 1/3, 2/3, 2/7,3/7 and 5/7 in the 1995 image were found to be correlated. In the 2000 image correlation was identified in band combinations 1/2, 1/3, 1/7, 2/3, 2/7, 3/5, 3/7 and 5/7. The 2002 image showed correlation between the bands 1/2, 1/3, 1/7, 2/3, 2/7, 3/7 and 5/7. Therefore, the image scenes for 1995, 2000 and 2002 had to be decorrelated through Principal Component Analysis (PCA)

Each image scene generated six principal components. However, from the PCA output statistics, the first three components in the 1995 image carried about 97.78% of the image data. In the 2000 image about 98.2% of the data was found to be represented by the first three components. Similarly, in the 2002 image scene about 98.05% of the image data was found to be represented in the first three components (see Appendix III-V)

Therefore, given that most of the data in each of the Landsat image scenes for Nairobi is contained in the first three principal components, false colour composite images were generated using the first three principal components for each of the three image scenes. The output false colour composite images obtained are shown in Table 3.3.

Table 3.3: Colour composite images

Image Scene	**Bands Used**	**Output Composite Image**
Landsat TM, 1995	PC1, 2, 3	PC1, 2, 3_NRB 1995 COMPOSITE
Landsat ETM, 2000	PC1, 2, 3	PC1, 2, 3_NRB 2000 COMPOSITE
Landsat ETM, 2002	PC1, 2, 3	PC1, 2, 3_NRB 2002 COMPOSITE

Image classification: Both supervised and unsupervised methods of image classification were utilized in this research. Unsupervised classification was necessary to reduce the number of land use classes in the satellite images. With a smaller number of clusters, it was easier to identify training sites that characterise each of the three land use categories that were generated during the final supervised classification process. In the first stage, unsupervised image classification was carried out on each composite image (dropping the least significant clusters). The output images were designated as shown in the Table 3.4.

Table 3.4: Unsupervised classification output images

Image Scene	Composite Input Image	Number of Classes	Unsupervised Output Image
Landsat TM, 1995	PC1, 2, 3_NRB 1995 COMPOSITE	6	Unsupervised Nairobi 1995
Landsat ETM, 2000	PC1, 2, 3_NRB 2000 COMPOSITE	7	Unsupervised Nairobi 2000
Landsat ETM, 2002	PC1, 2, 3_NRB 2002 COMPOSITE	7	Unsupervised Nairobi 2002

Three land cover/land use categories were identified for classifying each of the three Landsat image scenes obtained in the unsupervised classification. Abstraction is a vital requirement in cartographic visualization. It enables the map reader to deal with manageable cartographic themes/land uses that are easier to process and interpret during the visual display. Therefore, identification of three land use classes for Nairobi enabled a more effective representation of the spatial urban growth process for the area. The classes are for built-up, unbuilt and vegetated land cover areas, designated as "built-up", "unbuilt" and "veg" respectively. Built-up land cover category represents those parts of the study area that have built-up developments. Unbuilt land cover category represents bare or open regions that are devoid of any built up developments or vegetation. On the other hand, the vegetated land cover category represents forested and all other areas covered by vegetated matter e.g. parks, coffee and tea plantations.

Ground truthing was used to identify classes in the unsupervised image that fall into each of the clusters identified from the unsupervised classification based on GPS coordinate observations. In addition, topographical maps and a 2000 high-resolution Quickbird satellite image for Nairobi area were used for training site development. GPS coordinates observed in the field were plotted and a map with grids printed. On this map, land use categories for the various GPS points observed were shown. Similarly, maps for the classified images were printed at the same scale. By comparing the map data from GPS observations, topographical maps and the Quickbird satellite image, the various clusters in the unsupervised classification image scenes were easily matched with the corresponding clusters to be generated by the supervised classification. This was possible since the GPS coordinates, topographical maps and Quickbird image were on the same mapping coordinate system as those used for geo-referencing the Landsat satellite images to be classified.

Supervised classification was done based on signatures generated for each land cover category. The Minimum Distance to Mean classifier was used. Given the heterogeneity of spectral classes in the urban study area, the Minimum Distance to Mean classifier was found suitable. This algorithm is mathematically simple and efficient. Though the classifier does not easily recognize differences in the variance of classes, it works best in applications where spectral classes are dispersed in feature space and have similar variance (Lillesand and Kiefer, 1994 and Jensen, 1996). There was difficulty in generating 'good', signatures due to the heterogeneity within the study area and the internal spectral variability within the training sites. The final land cover categories from supervised classification for each of the images were designated as shown in the Table 3.5.

Table 3.5: Final supervised classification output images and their classes

Image Scene	Unsupervised Input Image	Supervised Output Image	Final Classes
Landsat TM, 1995	Unsupervised Nairobi 1995	1995 NAIROBI FINAL CLASSIFICATION	Built-up'95 Unbuilt'95 Veg'95
Landsat ETM, 2000	Unsupervised Nairobi 2000	2000 NAIROBI FINAL CLASSIFICATION	Built-up'00 Unbuilt'00 Veg'00
Landsat ETM, 2002	Unsupervised Nairobi 2002	2002 NAIROBI FINAL CLASSIFICATION	Built-up'02 Unbuilt'02 Veg'02

3.4.2 Prototype Cartographic Animation Design

The classification process generated three multi-temporal categories of land cover for Nairobi area. These datasets form good cartographic products for studying the growth of Nairobi city between 1995 and 2002. The datasets were used to produce a cartographic animation that mimics the expansion of the city. Animation technique is useful for visualizing the spatio-temporal changes within a given area of study. An animation enables the viewer to explore spatial and temporal patterns with the aim of generating insight into the phenomenon under study and hence formulating new hypotheses.

In the design of the animation Macromedia Flash MX was used. This software offers a multimedia environment with video capabilities, enhanced colour management, timeline layer folders and an optimised workspace with a context-sensitive property inspector. It also gives access to advanced scripting and debugging tools, built-in code reference, and Flash components to rapidly deploy Web applications. The computer hardware specifications used for this study are:

- Windows XP
- Intel Pentium III processor
- 2.99GHz, 376MB RAM

- Professional version 2002
- Service Park 2

3.4.3 Creating the Animation

A 2D cartographic animation showing the growth of Nairobi city was created. This was accomplished by merging annotated frames with thematic cartographic frames generated from the final supervised classification process. The stages involved in the production of the cartographic animation are as outlined below.

(i) First and foremost, a map grid was superimposed on each epoch of the final thematic images. This was done at a grid interval of 10,000 metres in both the Eastings and Northings. The grids would be useful in the interpretation of the cartographic themes in the animation frames.

(ii) Given that Macromedia Flash MX does not support Tiff image, the thematic images were converted to Bitmap format. This would enable subsequent manipulations to be carried out on the cartographic images to generate animation frames.

(iii) Yearly annotation frames were created. This involved adding texts representing the respective year of data acquisition for each frame, scale and a legend for the corresponding land cover classes. A thematic image was considered suitable for generating annotation frames for cartographic representation. Thus three text frames were generated for 1995, 2000, and 2002.

(iv) The multi-epoch cartographic thematic frames were merged together with the annotation frames in a sequence to generate 50 frames of the final cartographic animation. Given that the research study addresses the growth of the city within a time span of seven years, 50 animation frames played at a suitable display speed would give a visual representation that approximates the real world as closely as possible

(v) A movie was produced in Macromedia Flash MX to play the bitmap cartographic frames in a sequence. The movie represents a cartographic animation that visualizes the growth of Nairobi city between 1995 and 2002.

4. RESULTS AND ANALYSIS

4.1 OVERVIEW

The final results in this research represent a 2D cartographic animation that visualizes the growth of Nairobi urban area. The animation was created in Macromedia Flash MX, a multimedia tool in a Windows XP environment. The animation represents the growth of the city between the year 1995 and 2002. It offers an efficient tool for urban planners, researchers and other urban policy makers interested in making better and informed decisions on the management of the city. The model can be used to supplement existing criteria in urban planning while bridging the gaps and inefficiencies in those methods. Macromedia Flash MX was used due to its functionalities to support interactive and exploratory animations.

4.2 PROTOTYPE CARTOGRAPHIC ANIMATION FOR NAIROBI

The cartographic animation was created from animation frames representing cartographic land cover themes generated from the temporal spatial datasets for Nairobi area. These were the cartographic themes generated from both the unsupervised and supervised classification of the multi-epoch Landsat images for the years 1995, 2000 and 2002. Figures 4.1 (a), (b) and (c) show the final land cover/land use cartographic image themes obtained after image classification. The images show the three categories of land cover that were visualized in the animation.

The overall accuracy for error matrices was used as a measure of reliability for the classification process. This was achieved through error matrix analysis of the output from unsupervised classification against the final product from supervised classification, for each of the three epoch Landsat satellite images. The overall accuracy is a ratio of the sum of all the correctly-classified to the total number of pixels evaluated. The overall accuracy values obtained are 0.7119, 0.6999 and 0.8324 for the years 1995, 2000 and 2002 respectively (see Appendix VI-VIII).

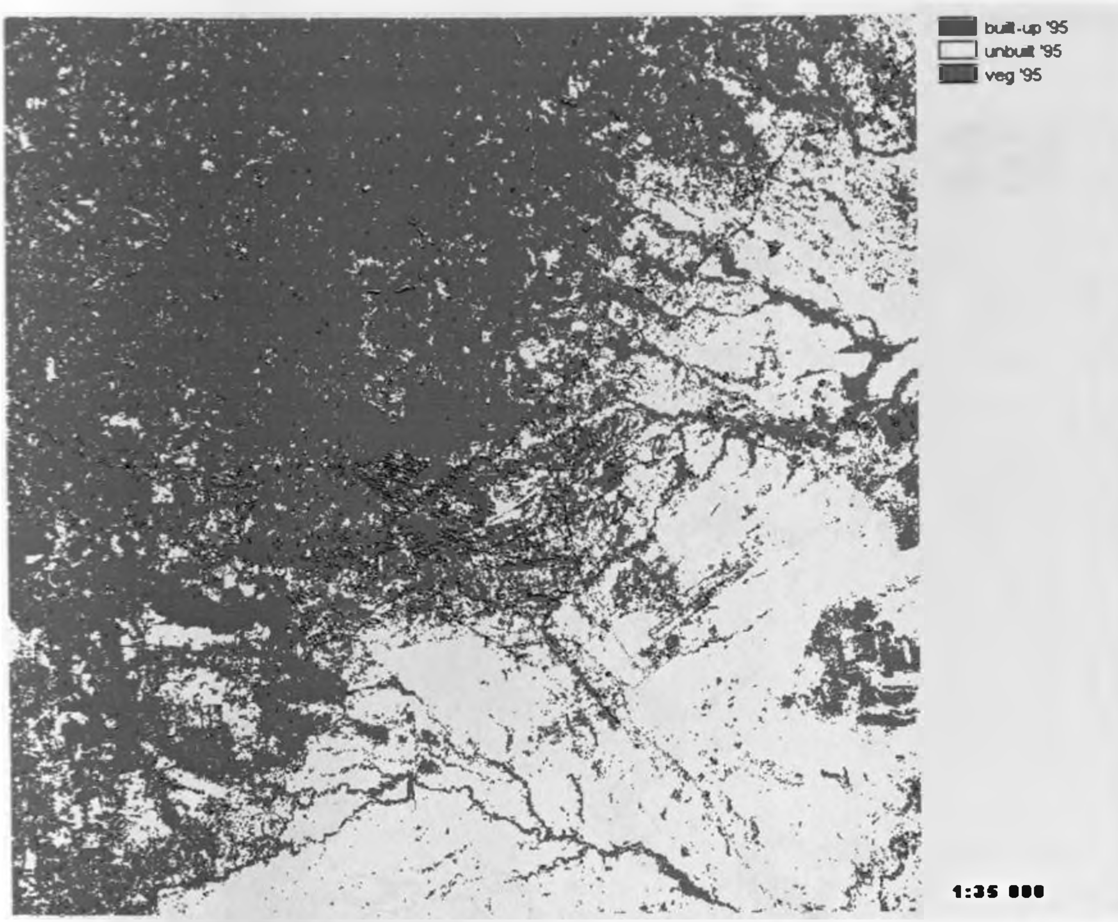

Figure 4.1 (a): Final 1995 cartographic land cover/ land use map

Map grids were added to the images to aid in the navigation and detailed interpretation, and for the study of the animation by the users. The grids were based on the same mapping coordinate system (UTM) used for georeferencing the parent Landsat images. The Grid interval used is 10,000 metres in both X- and Y- grid directions. The three categories of land cover/land use were built-up areas shown in red colour, unbuilt (bare) land shown in yellow colour and vegetated land shown in green colour. The choice of colour was intended to assist in the analysis of the cartographic animation. Since spatial urban growth is characterised mainly by built-up areas, red colour was chosen to represent this category of land use as it makes the features more visible in the animation display. Green colour was used to represent vegetated land category since it is the natural colour for vegetation. The unbuilt land cover/land use category was represented by yellow colour as it enables easier visual identification of the other two land cover categories as well as annotation texts.

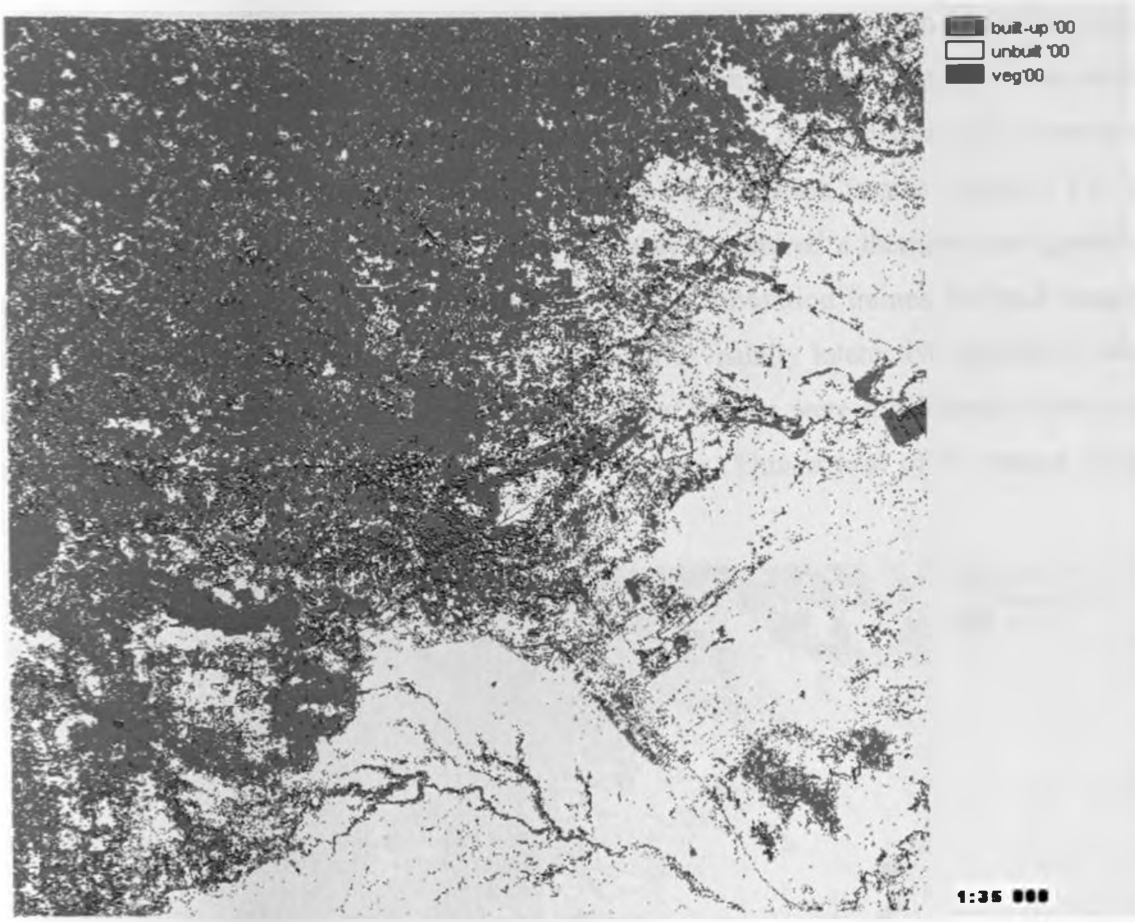

Figure 4.1 (b): Final 2000 cartographic land cover/land use map

Annotations frames were also created representing the year for each thematic image and the legend for the respective land cover/land use category. These annotation frames were generated on copies of respective thematic images for the three epochs. This way, the animation user would be able to track the animation process, year-by-year without interruptions caused by annotation frame breaks. Figures 4.2(a), (b) and (c) show the three annotation images created for the animations. The various cartographic themes are shown in red, yellow and green colours. In addition, the map grid is useful in identification of temporal spatial change pattern during animation display.

The frame dimension was set to 594 x 579 to correspond to the dimensions of the thematic cartographic images. The size of each image was approximately 0.98MB. Since this study was to address the growth of Nairobi for a period of seven years the total number of frames to create the animation was based on the number of years between each two sets of years, i.e. from 1995 to 2000 and from 2000 to 2002 (inclusive). Annotation frames were also considered in the total numbers of animation frames required. For a period of 7 years considered for this study, each year required a thematic cartographic frame for representation. These, in addition to the 3 annotation frames for each image epoch, required a total of 10 frames. However, for a visually interactive animation that does not overload the viewer's memory, 5 copies of frames were considered suitable to represent each year and annotation theme respectively. Thus a total of 50 frames were used to produce the animation.

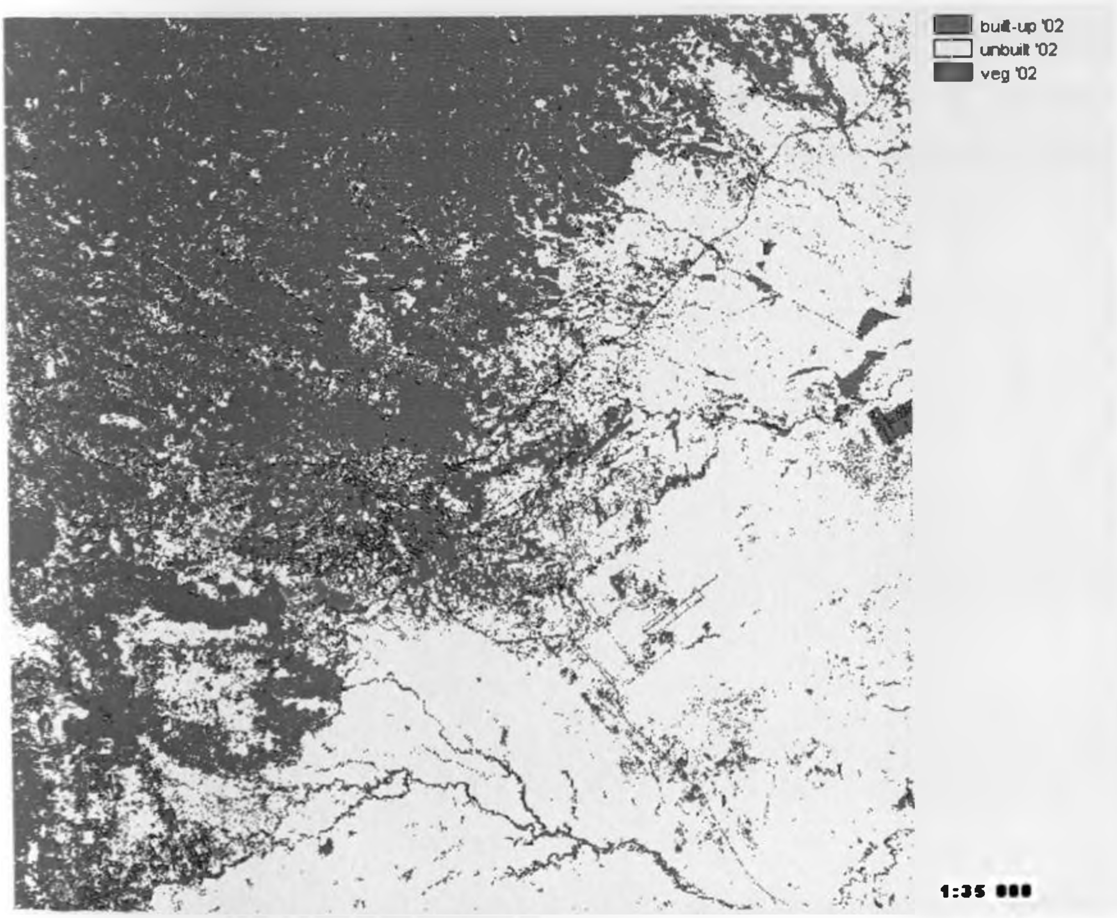

Figure 4.1 (c): Final 2002 cartographic land cover/land use map

A cartographic animation was generated by setting the display speed to 10 frames per second (fps). Therefore, the animation requires 5 seconds to play completely. This implies that 5 seconds are required to visualize Nairobi's growth period of 7 years. In other words 7/5 years per second (yps) is the factor used to visualize the urban growth of Nairobi. The resulting animation can be played in two modes. In the first case, animation parameters can be viewed as the animation plays in Macromedia Flash MX. These include image dimensions, frame rate (animation speed), duration taken and frame number as shown in Figure 4.3. In this animation visualization parameters shown comprise of image dimensions and size, frame rate and duration. Others are bandwidth and animation state (frame number). There are also control parameters on the main viewing computer screen menu. In the second mode, the animation plays, in Macromedia Flash Player 6, occupying the entire screen without animation parameters being shown. However, the screen menu of the computer available is used to control the animation (Figure 4.4). Control operations in both cases include play, rewind, loop, step forward and step backward.

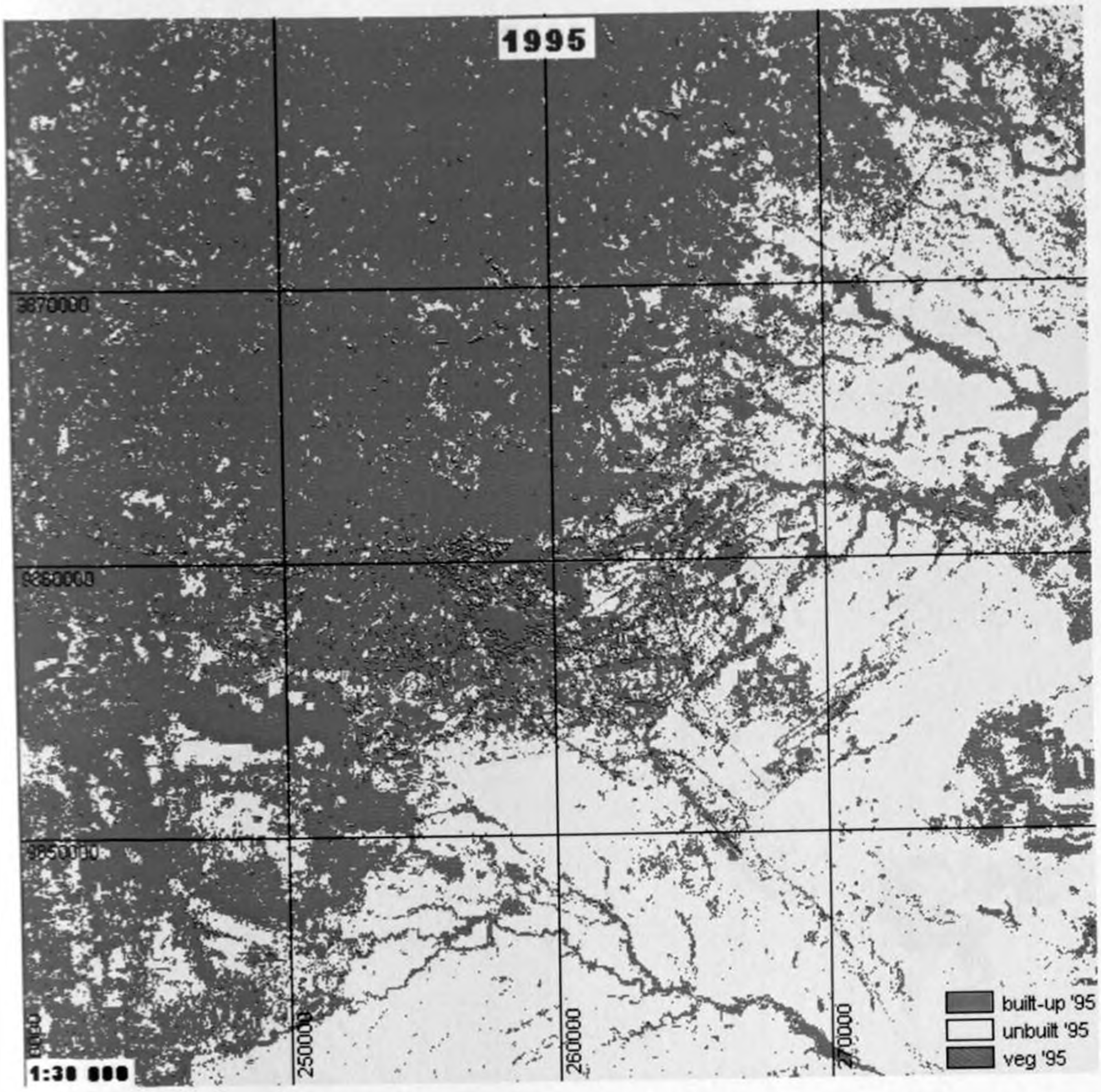

Figure 4.2 (a) 1995 annotation frame for cartographic animation.

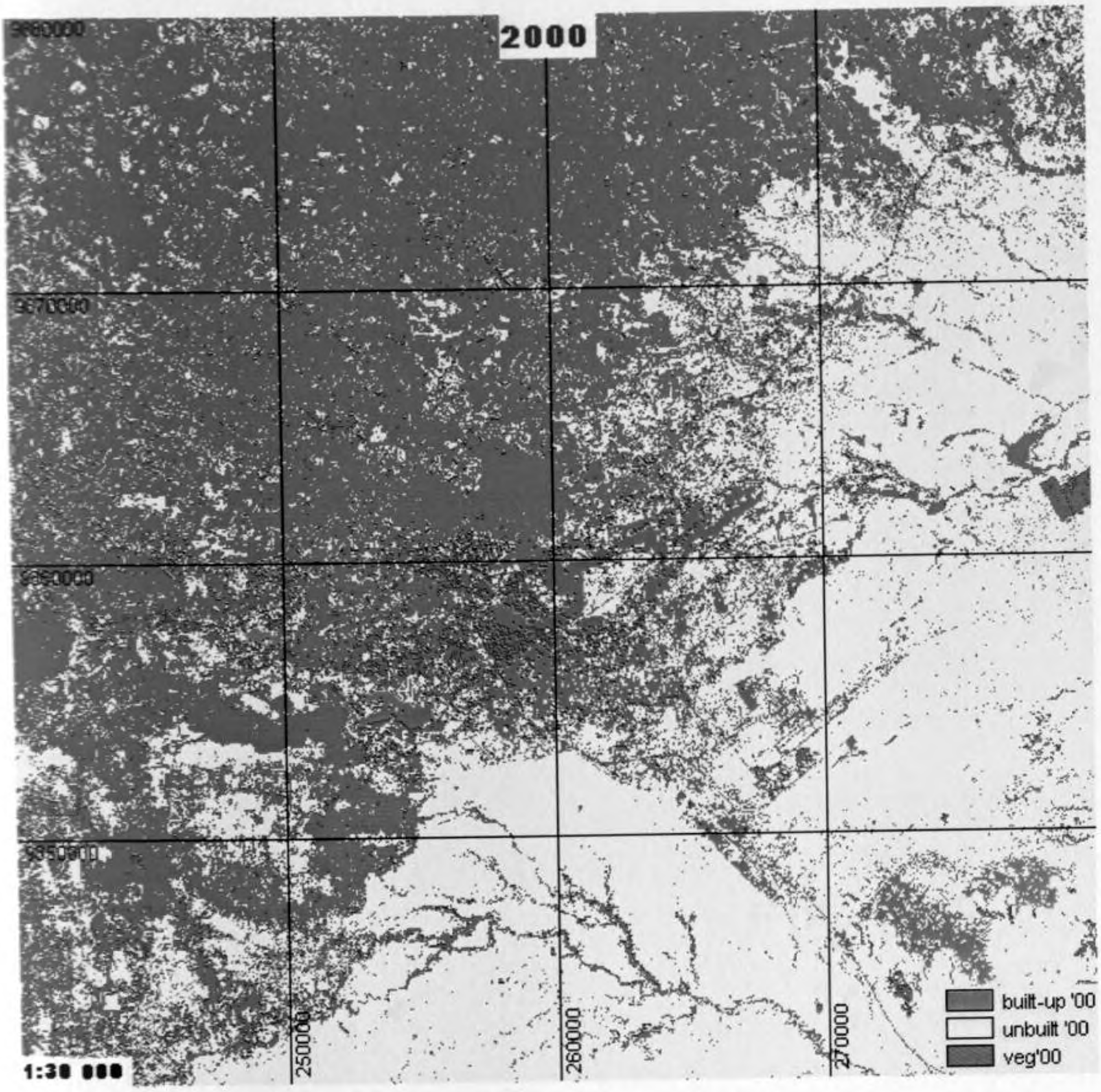

Figure 4.2(b): 2000 annotation frame for cartographic animation.

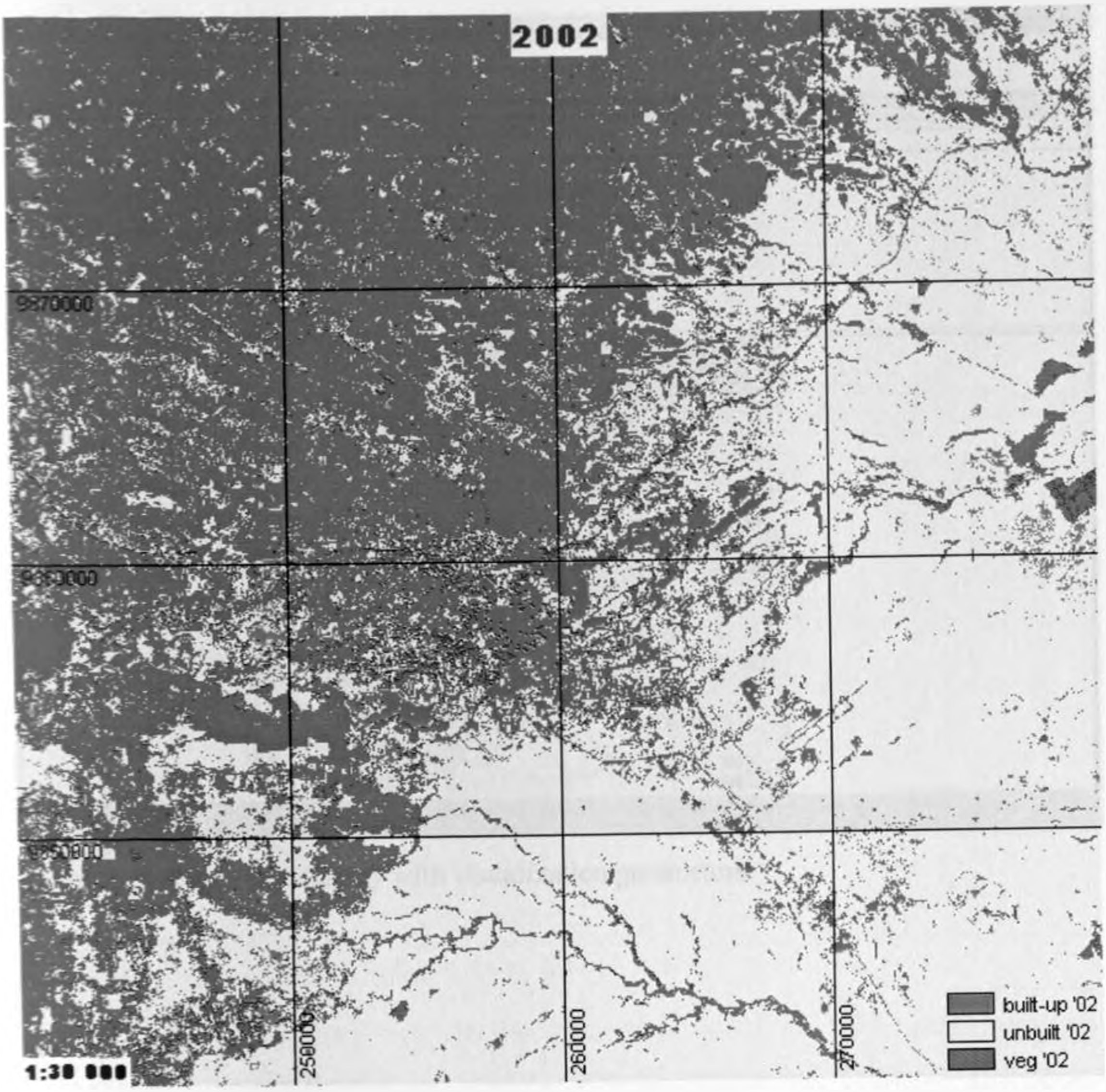

Figure 4.2(c): 2002 annotation frame for cartographic animation

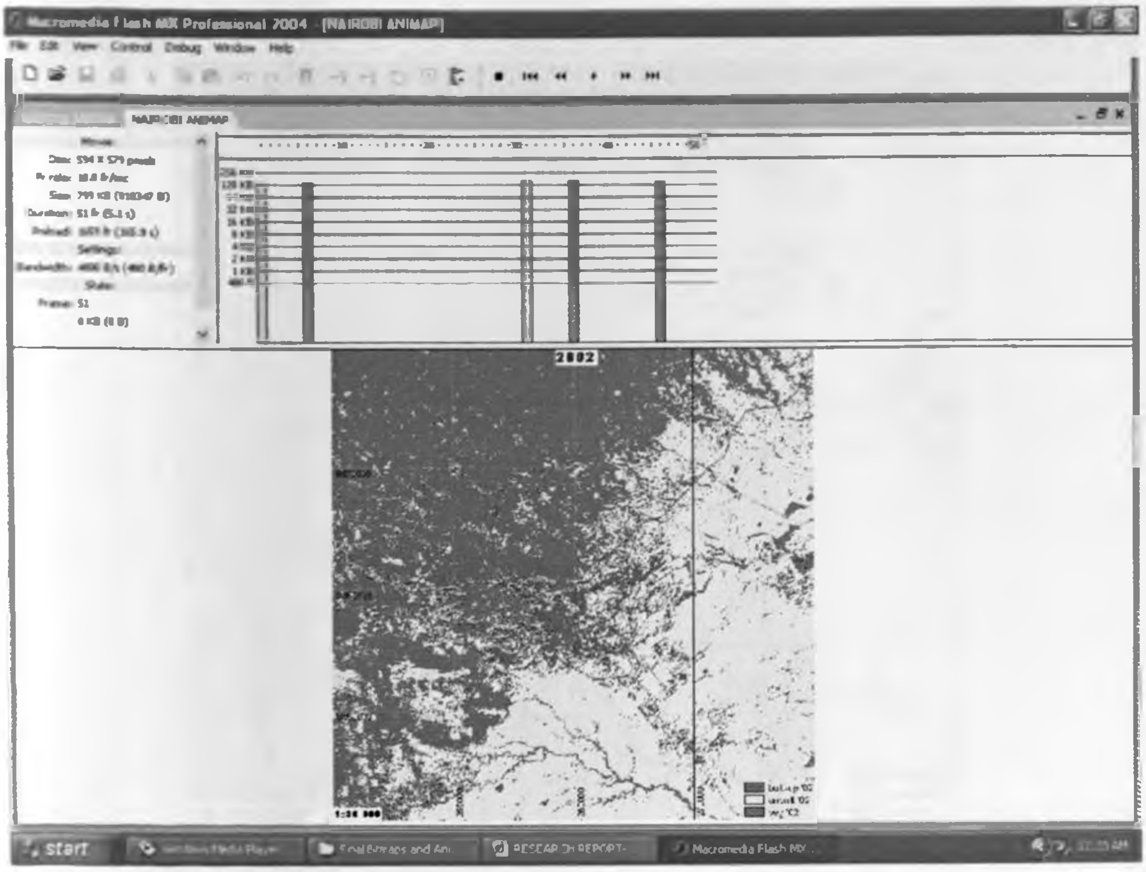

Figure 4.3: Animation display with visualization parameters.

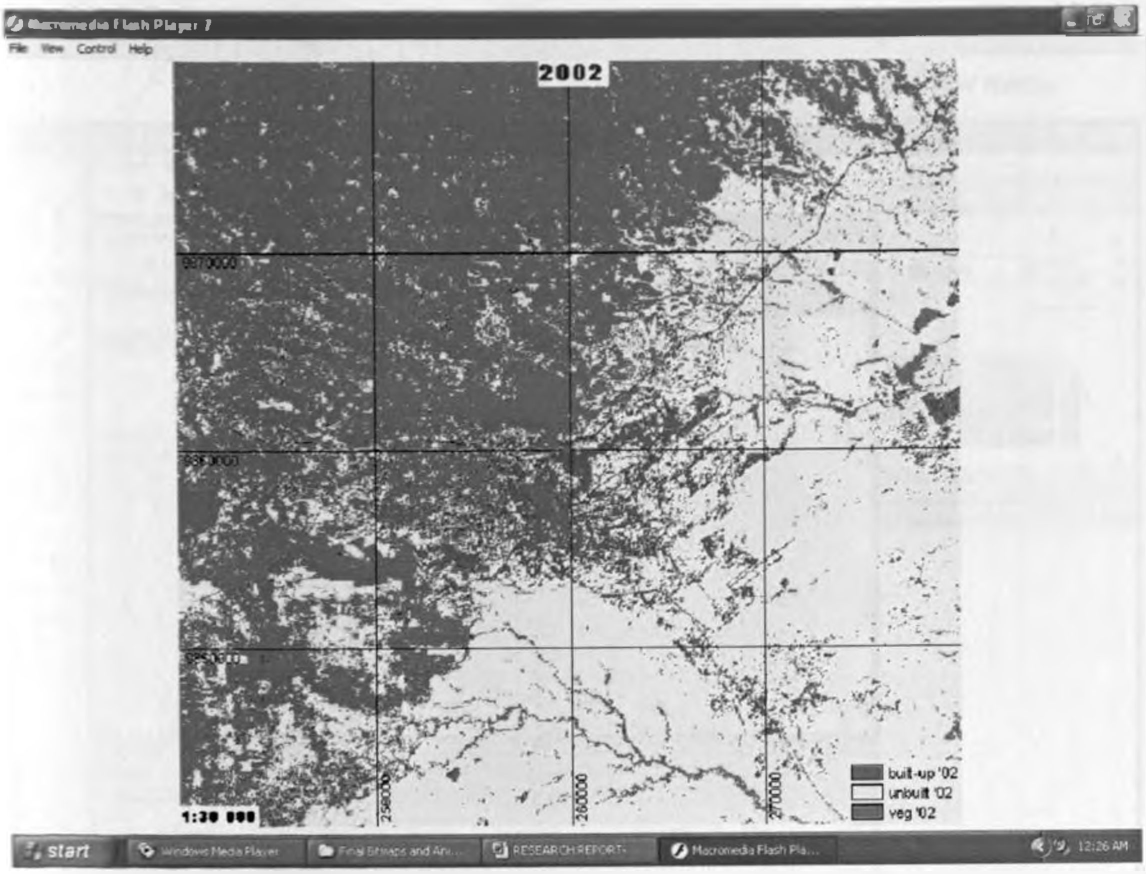

Figure 4.4: Animation display without visualization parameters

4.3 ANIMATION ENVIRONMENT

Macromedia Flash MX allows rapid development of animation by inserting frame-by-frame images. It supports a variety of image data formats including jpeg, gif and bitmap. However, the software does not support Geotiff or Tiff formats, in which many Landsat images are found. Interactive tools built in Macromedia Flash MX include zoom in, zoom out, pan, full extent, pixel information button, state-wise animation, static images and graph. Other interactive aids in the system include the timeline manager, tools for manipulating an image and movie control features. Figure 4.5 shows the Macromedia Flash MX user interface.

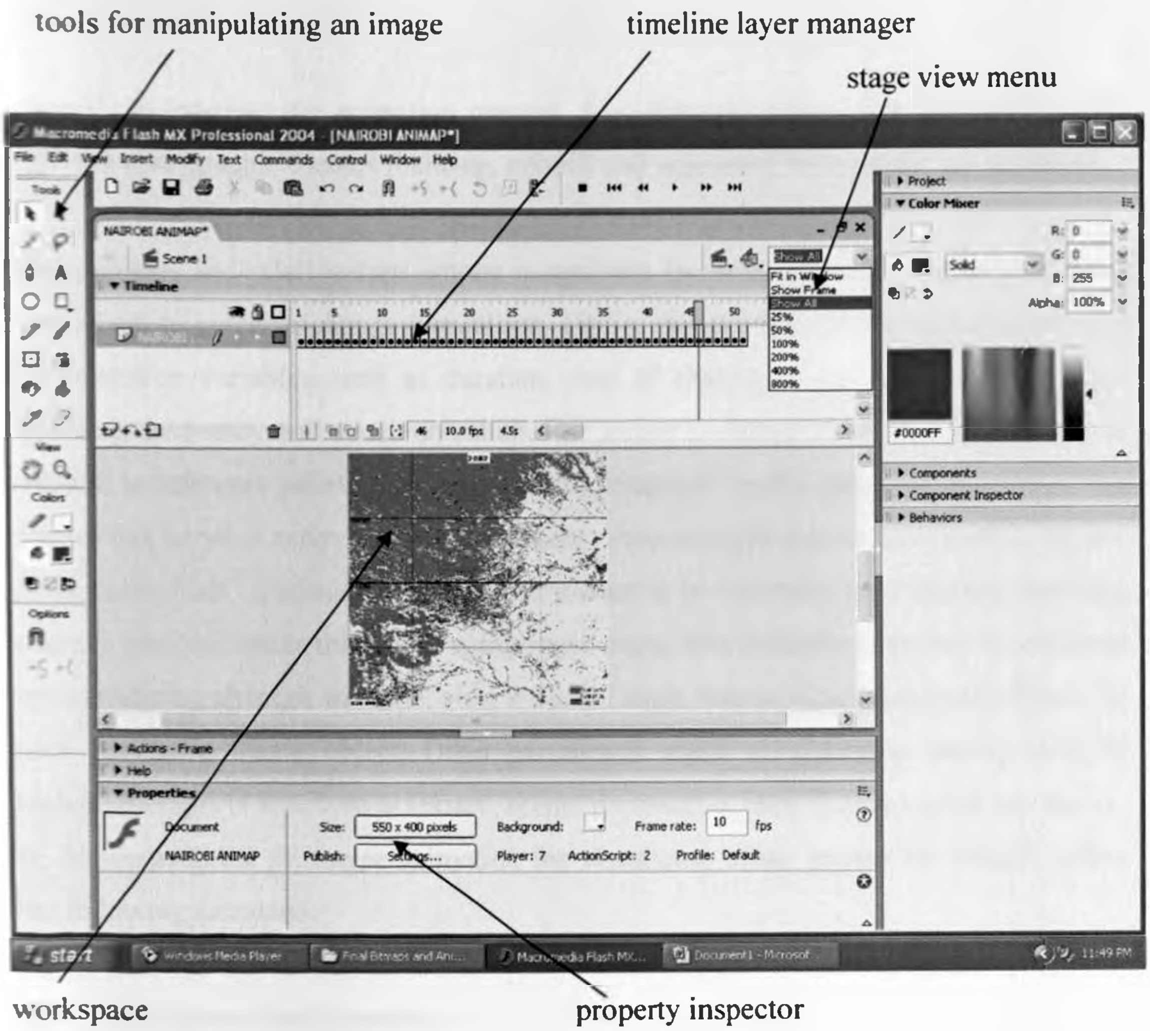

Figure 4.5: User interface for Macromedia Flash MX

4.4 ANALYSIS OF RESULTS

The cartographic animation for Nairobi area offers a valuable tool for visual thinking and communication of information on patterns of land use/land cover categories. It offers an environment to interactively manipulate map parameters such as display speed and also querying (though minimal). The animation frames, through stop, loop and step forward/backward, offers the potential to discern fundamental changes and, hence, prompt visual thinking. Dynamic and spatial elements of urban growth process of Nairobi are represented as more closely as they approximate the real world urban growth process. This is achieved through better choice of animation speed that suits the user's memory capacity to interpret the animation process. Also through cartographic abstraction, only relevant cartographic themes (built-up, unbuilt and vegetated) to the study are animated.

Comparisons and relationships among parameters for urban growth phenomena can be carried out to perceive change (Ormelling, 1995). This is achieved through consideration of animation variables such as duration, rate of change, order, display date (frame number), frequency and synchronization. For instance, change in position is analysed in relation to reference points. The map grid superimposed on the prototype animation map frames can serve as reference guides to enable these comparisons of cartographic themes to be carried out Animation allows information to be communicated quicker, enabling users to perform better than when using static maps. The animation can also be analysed by considering changes in shape, size, location, angle, rate of change and colour hue, for each particular theme object. Other parameters worth consideration during analysis include changes in structure or texture, scene, perspective, shot, (colour) value and theme. In this respect, the prototype animation for visualizing urban growth for Nairobi offers the following functions:

(i) Navigation and Orientation

This is achieved by integrating the external representation (animated map) with the user's internal representations (in the mind). External representations provide memory aids (Zhang and Norman, 1994). Similarly, familiarity with the study area and expertise of the map user (e.g. cartographer or physical planner) can help achieve this function. Landmarks encountered within the external landscape serve as navigational cues and this aids in orientation. For instance, the sewerage works in Dandora area of Nairobi and the Jomo Kenyatta International Airport are conspicuously visible in the 2002 thematic image. Thika Road and Mombasa Road can also be easily identified. The animated map user can therefore, use these features as navigation cues (see Figure 4.6).

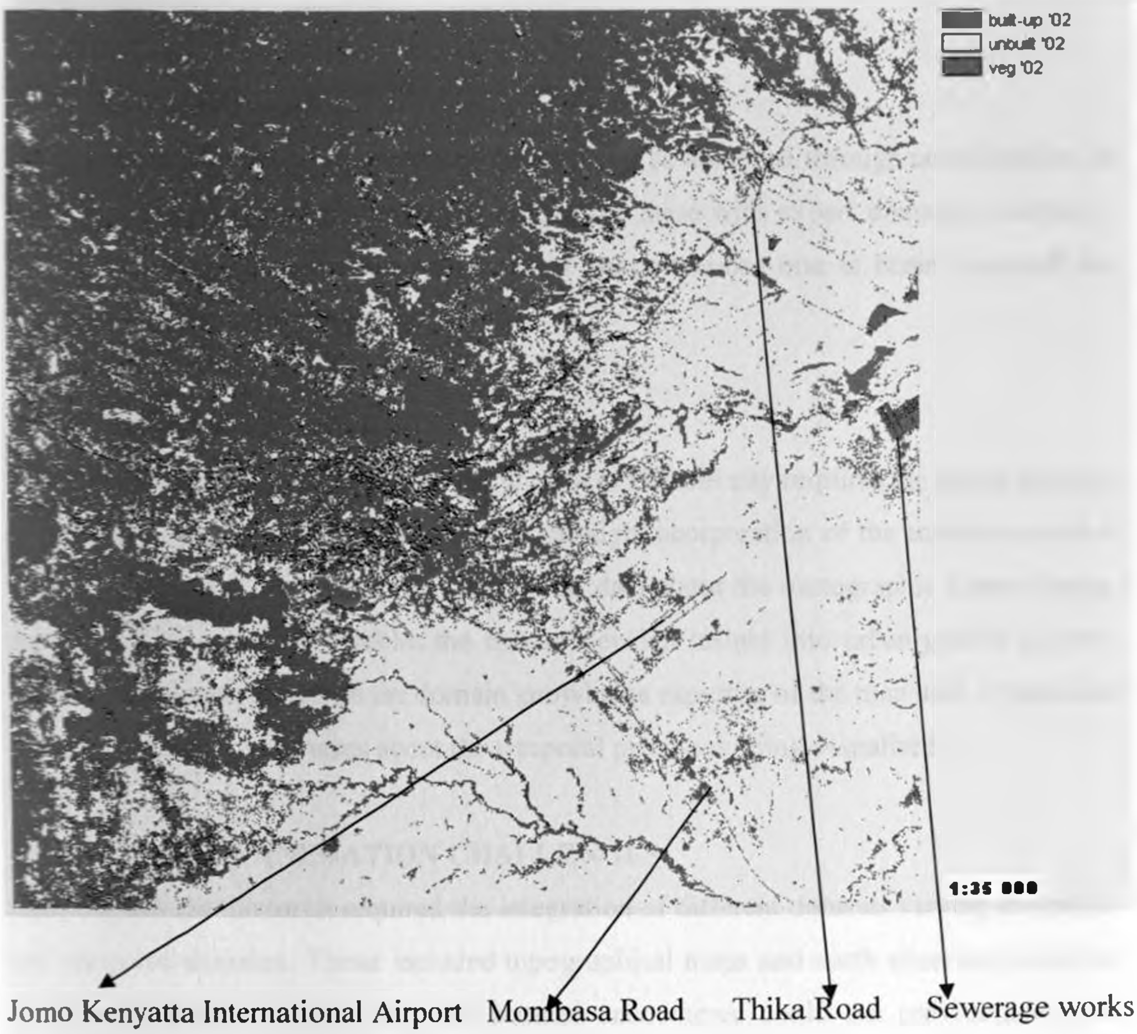

Figure 4.6: Navigation cues for the 2002 thematic image

(ii) Explaining Physical Processes

The map user is able to integrate the relationships between cartographic themes as the animation plays. Stopping the animation for detailed analysis of a particular frame can be helpful in achieving this. In addition, operations such as looping, forward and rewind can aid in achieving this function. For instance, a significant change in vegetated land cover (deforestation) can be identified between the 1995 and 2002 thematic images (see Figures 4.3 (a) and 4.3 (c)). Other physical processes are urbanization and sedimentation.

(iii) Making Forecasts

Making forecasts about the growth of the city can be achieved through consideration of the temporal and spatial patterns, and integrating these with expert domain knowledge. Also, while playing animation sequences of past situations one is better prepared for trends that would not be spotted otherwise.

(iv) Hypothesis Formulation

To formulate new hypotheses about the growth of Nairobi city requires the expert domain of the user. This function can be achieved through incorporation of the animation model with statistical and mathematical computation data about the cartographic themes being animated. The animation enables the user to develop insight into urban growth process for Nairobi. Hence, based on the domain knowledge expertise of the map user, it becomes easier to generate hypotheses about the temporal processes being visualized.

4.5 PROTOTYPE ANIMATION CHALLENGES

Carrying out this research required the integration of different datasets varying in spatial and temporal domains. These included topographical maps and earth observing satellite images. However, many of the data sources encountered could not provide adequate information to generate an efficient cartographic animation for Nairobi. The following problems were encountered during the process.

1. Lack of temporal and spatial data dating back to the beginning of the city that is useful in visualizing Nairobi over the years of its growth.
2. Non-uniformity in spatial coverage and mapping data among topographical map sheets for Nairobi and its environs as used in this research.
3. The low spatial resolution of Landsat remotely sensed images used for this study did not provide adequate information for the land cover/land use category themes during the classification process.
4. Given that Macromedia Flash MX does not support images in tiff format, conversion to bitmap format led to data loss for the already classified cartographic image themes.

Limitations of this prototype animation for the growth of Nairobi are as follows:

i. Bitmap format does not offer good image quality. However, given that a certain degree of abstraction of cartographic themes is required for animated map design, classification accuracy, therefore, does not significantly affect the visualization effect.

ii. There is lack of adequate query functionality. Hence queries at any location of the animation frames cannot be carried out in a dynamic mode.

iii. The system does not support a link to database. This limits the interactive exploratory capabilities offered for the animation.

iv. The prototype animation model does not incorporate other non-spatial factors that influence urban growth planning process e.g. population data, land value, topography, etc.

5. CONCLUSION AND RECOMMENDATIONS

A prototype cartographic animation that visualizes the spatio-temporal growth process of Nairobi is developed from this research. This is done in Macromedia Flash MX. However, this animation environment does not have adequate functionalities to support an efficient interactive exploration process. Only a limited scope for interaction is offered. Three broad cartographic themes are identified for the study area. Cartographic abstraction is necessary to avoid memory overload to the user with a large number of cartographic data themes. Abstraction enables the animation user to track and interpret the cartographic content in the animation efficiently as it plays.

5.1 CONCLUSION

In this research, the objectives as outlined in chapter one of the report have been realized. First and foremost, an outline of the theoretical perspective of representation as it relates to temporal geospatial data and its visualization has been given. This research has also identified examples of tools and systems together with their functionality to support visual data exploration. Success studies of applications of cartographic visualization (animation) to urban growth phenomena have been outlined. The final product of this thesis research is a prototype cartographic animation that visualizes the growth of Nairobi city between the years 1995 and 2002.

Considering the rate at which Nairobi city is expanding and the enormous research attention being given to this process in both academic and professional contexts, no previous attempt in visualizing the spatio-temporal growth of the city using visually exploratory tools has been made. This research, therefore, presents a richer contribution to planning efforts for the growth of the city. The main conclusions of this thesis research comprise of the following:

(i) There is a need for a cognitive approach to planning by generating cognitive models that are compatible with computational approaches. The adoption of cartographic visual exploratory tool design should be based, not only on data characteristics and user tasks, but also on the acquired understanding of the cognitive pathways.

(ii) The research has identified the adoption of visual approaches such as cartographic data exploration and satellite image interpretation. The cartographic animation developed enables the map user to visually explore spatial data for Nairobi area. The processing of satellite Landsat images for the area of study demonstrates that satellite image interpretation can be a vital input to urban growth studies.

(iii) The study presents a cartographic animation model of the urban growth process of Nairobi city that presents more opportunities for developing insight and hypothesis formulation. This approach can similarly be applied to other geospatial phenomena besides urban growth.

The animation environment used has little scope for interaction and subsequently exploration. However, it offers an opportunity to study the urban growth process while giving the user control over the running of the animation. The user can change the display speed of the animation, loop or focus on an individual frame in the animation. This enables the viewer to address analysis tasks at hand. The prototype cartographic animation, therefore, presents an invaluable contribution to cartographic research and its application to planning for urban growth.

5.2 RECOMMENDATIONS

The prototype cartographic animation presents a rich resource for addressing the complex temporal urban growth process for Nairobi. An attempt has been made to incorporate all necessary functionalities in the design for efficient use. However, certain issues still remain unresolved as to its efficiency for optimal use by researchers and urban policy makers addressing this temporal geospatial process. Emerging issues concern the level of interactivity and exploration, developing an all-inclusive analysis criteria and the scope for improvement and adoption of the prototype animation. The following recommendations are, therefore, necessary for the achievement of the desired output from the animation.

(i) The design of the cartographic animation should incorporate a link to a database through dynamically linked maps to improve interactivity and exploration. Simple view animation may not be effective for identification and quantification of complex changes. Thus, combining linked graphics and animation can provide a better exploratory animation environment. Also, addition of a provision for multiple views can improve analysis operations such as change detection and change measurement of complex spatio-temporal phenomena.

(ii) Incorporation of state-wise animations (animation within animation) would also be suitable design requirement for viewing local changes, particularly where the animation is covering a large area. Therefore, an interface can be created to enable animations created in Flash to open multiple views e.g. VB Interface.

(iii) Other multimedia functionalities such as sound, narration, tactile and haptic variables, as well as interactive and temporal legends can be included in the design to improve its exploratory capability.

(iv) The prototype should be analysed in conjunction with statistical data for the same temporal cartographic datasets and themes for the growth of Nairobi.

(v) Studies of usability assessment should be carried out on the prototype animation to improve its design parameters and functions, validate its value and, therefore, help disseminate the research findings to the public for adoption and use for their intended applications.

(vi) Plug-ins can be developed to customize the animation. More advanced forms of animation can be accomplished through the web using a variety of specialised plug-ins that display files stored in a proprietary format. Examples of plug-ins to customize cartographic animations include Macromedia Shockwave that allows the display of a Macromedia Director file through a web page, Java applets for supporting interactive animation and which can be downloaded and executed on the client computer, and JavaScript, a programming language that can be used to control graphic elements on the web page (Peterson, 1999). Others include VRML plug-ins, that is, design content creation languages for 3D interactive cartography and interactive web mapping and advertising.

The cost of producing maps can be quantified in terms of production and distribution. In this respect, printing, warehousing and associated expenses affect the cost of producing and distributing paper maps. On the other hand, the Internet has reduced considerably the cost of distribution, especially animated maps. Animated maps are distributed through computer networks. However, while animated maps are distributed freely over the Internet, costs associated with their use have risen sharply, that is, computers and computer software that are needed to make animated maps usable. This makes the maps usable only to a few people, with computer systems, software, network connection and appropriate expertise.

Physical planners are potential users of the product of this research study. Their views on the use of this map animation, though varied, converge to the fact that the cartographic animation is a good pointer to the direction of changes taking place in the various attributes/cartographic themes for the urban growth process being animated. However, it does not offer an explanation for the trends. Additional effort will, therefore, be required to uncover the reasons for those changes.

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APPENDICES

APPENDIX I: TOPOGRAPHIC MAPS USED FOR THE RESEARCH

MAP SHEET No.	SHEET NAME	SCALE	PUBLICATION	GRID MAPPING SYSTEM	MAP PROJECTION	SPHEROID	DATUM
148/2	Kiambu	1:50000	1997	UTM (ZONE 37S)	UTM	Clarke 1880 (Modified)	New (1960) Arc
149/1	Thika	1:50000	1997	UTM (ZONE 37S)	UTM	Clarke 1880 (Modified)	New (1960) Arc
149/3	Mua Hills	1:50000	1997	UTM (ZONE 37S)	UTM	Clarke 1880 (Modified)	New (1960) Arc
148/4	Nairobi	1:50000	1997	UTM (ZONE 37S)	UTM	Clarke 1880 (Modified)	New (1960) Arc
148/1	Limuru	1:50000	1976	UTM (ZONE 37S)	UTM	Clarke 1880 (Modified)	New (1960) Arc
SK 58	Nairobi & Environments	1:100000	1978	UTM (ZONE 37S)	UTM	Clarke 1880 (Modified)	New (1960) Arc

SOURCE: SURVEY OF KENYA

APPENDIX II: GPS FIELD COORDINATE OBSERVATIONS

Point Number	Eastings (M)	Northings (M)	Location	Class Description
1	278435	9861860	Ruai	Built-up
2	260165	9861547	Karura	Vegetated
3	247219	9860219	Ngong Road	Vegetated
4	269142	9852633	Embakasi	Built-up
5	258193	9857568	City Centre	Built-up
6	270280	9848370	Mlolongo	Unbuilt
7	273464	9872421	Kenyatta University	Unbuilt

INSTRUMENT: GARMIN SportTrex GPS RECEIVER (UTM ZONE 37S/ARC DATUM (1960) NEW)

APPENDIX III: 1995 PCA VARIANCE-COVARIANCE MATRIX

VAR/COVAR	band_1c_hes	band_2c_hes	band_3c_hes	band_4c_hes	band_5c_hes	band_7c_hes
band_1c_hes	5350.25	5111.15	5064.42	-26.37	4224.63	4618.53
band_2c_hes	5111.15	5415.11	5151.26	531.02	4405.93	4647.96
band_3c_hes	5064.42	5151.26	5424.86	-48.82	4681.41	5055.18
band_4c_hes	-26.37	531.02	-48.82	5460.79	1171.85	-394.89
band_5c_hes	4224.63	4405.93	4681.41	1171.85	5438.86	4874.20
band_7c_hes	4618.53	4647.96	5055.18	-394.89	4874.20	5434.61

COR MATRX	band_1c_hes	band_2c_hes	band_3c_hes	band_4c_hes	band_5c_hes	band_7c_hes
band_1c_hes	1.000000	0.949573	0.940044	-0.004878	0.783154	0.856510
band_2c_hes	0.949573	1.000000	0.950419	0.097652	0.811858	0.856791
band_3c_hes	0.940044	0.950419	1.000000	-0.008970	0.861843	0.931017
band_4c_hes	-0.004878	0.097652	-0.008970	1.000000	0.215026	-0.072487
band_5c_hes	0.783154	0.811858	0.861843	0.215026	1.000000	0.896532
band_7c_hes	0.856510	0.856791	0.931017	-0.072487	0.896532	1.000000

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6
% var.	75.54	17.65	4.59	0.83	0.74	0.65
eigenval.	24569.62	5740.22	1493.11	269.65	241.83	210.05
eigvec.1	0.451532	-0.086893	-0.426836	-0.040780	0.707344	-0.323080
eigvec.2	0.456598	0.016298	-0.440941	-0.020430	-0.702870	-0.319970
eigvec.3	0.455225	-0.030668	-0.143463	-0.188344	0.000000	0.857773
eigvec.4	0.020517	0.971095	-0.106588	0.192913	0.075090	0.048363
eigvec.5	0.423760	0.185347	0.642183	-0.564402	0.000000	-0.234788
eigvec.6	0.447677	-0.117747	0.423132	0.778897	0.000000	0.000000

LOADING	C 1	C 2	C 3	C 4	C 5	C 6
band_1c_hes	0.967611	-0.090005	-0.225487	-0.009155	0.150383	-0.064015
band_2c_hes	0.972589	0.016781	-0.231538	-0.004559	-0.148534	-0.063018
band_3c_hes	0.968792	-0.031547	-0.075265	-0.041991	0.000000	0.168787
band_4c_hes	0.043520	0.995631	-0.055735	0.042868	0.015802	0.009485

band_5c_hes	0.900668	0.190413	0.336474	-0.125672	0.000000	-0.046140
band_7c_hes	0.951874	-0.121012	0.221788	0.173499	0.000000	0.000000

APPENDIX IV: 2000 PCA VARIANCE-COVARIANCE MATRIX

VAR/COVARp168r061_7t20000221_z37_n1c_hesp168r061_7t20000221_z37_n2c_hesp168r061_7t20000221_z37_n3c_hesp168r061_7t20000221_z37_n4c_hesp168r061_7t20000221_z37_n5c_hesp168r061_7t20000221_z37_n7c_hes

p168r061_7t20000221_z37_n1c_hes	5405.83	5228.36	5104.91	78.48	4149.04	4629.30
p168r061_7t20000221_z37_n2c_hes	5228.36	5436.79	5238.54	740.52	4370.35	4702.16
p168r061_7t20000221_z37_n3c_hes	5104.91	5238.54	5461.94	571.64	4750.51	5024.13
p168r061_7t20000221_z37_n4c_hes	78.48	740.52	571.64	5445.00	1446.27	70.51
p168r061_7t20000221_z37_n5c_hes	4149.04	4370.35	4750.51	1446.27	5456.16	4987.55
p168r061_7t20000221_z37_n7c_hes	4629.30	4702.16	5024.13	70.51	4987.55	5475.15

COR

MATRXp168r061_7t20000221_z37_n1c_hesp168r061_7t20000221_z37_n2c_hesp168r061_7t20000221_z37_n3c_hesp168r061_7t20000221_z37_n4c_hesp168r061_7t20000221_z37_n5c_hesp168r061_7t20000221_z37_n7c_hes

p168r061_7t20000221_z37_n1c_hes	1.000000	0.964413	0.939471	0.014465	0.763963	0.850916
p168r061_7t20000221_z37_n2c_hes	0.964413	1.000000	0.961315	0.136103	0.802418	0.861842
p168r061_7t20000221_z37_n3c_hes	0.939471	0.961315	1.000000	0.104821	0.870208	0.918733
p168r061_7t20000221_z37_n4c_hes	0.014465	0.136103	0.104821	1.000000	0.265342	0.012914
p168r061_7t20000221_z37_n5c_hes	0.763963	0.802418	0.870208	0.265342	1.000000	0.912528
p168r061_7t20000221_z37_n7c_hes	0.850916	0.861842	0.918733	0.012914	0.912528	1.000000

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6
% var.	75.93	17.24	5.03	0.76	0.57	0.46
eigenval.	24815.13	5634.40	1644.08	248.69	186.90	151.68

eigvec.1	0.450350	-0.145795	-0.425229	-0.035265	-0.310262	0.705410
eigvec.2	0.459279	-0.025305	-0.444505	-0.012899	-0.309850	-0.703324
eigvec.3	0.454354	-0.020161	-0.123358	-0.194922	0.860200	0.000000
eigvec.4	0.060728	0.967162	-0.144090	0.179726	0.010654	0.087935
eigvec.5	0.420729	0.176969	0.622796	-0.579759	-0.260140	0.000000
eigvec.6	0.446217	-0.104768	0.444680	0.769528	0.000000	0.000000

LOADING	C 1	C 2	C 3	C 4	C 5	C 6
p168r061_7t20000221_z37_n1c_hes	0.964889	-0.148845	-0.234505	-0.007564	-0.057690	0.118161
p168r061_7t20000221_z37_n2c_hes	0.981212	-0.025761	-0.244437	-0.002759	-0.057449	-0.117475
p168r061_7t20000221_z37_n3c_hes	0.968454	-0.020477	-0.067679	-0.041593	0.159122	0.000000
p168r061_7t20000221_z37_n4c_hes	0.129644	0.983839	-0.079176	0.038410	0.001974	0.014677
p168r061_7t20000221_z37_n5c_hes	0.897258	0.179836	0.341872	-0.123776	-0.048147	0.000000
p168r061_7t20000221_z37_n7c_hes	0.949963	-0.106281	0.243675	0.164005	0.000000	0.000000

APPENDIX V: 2002 PCA VARIANCE-COVARIANCE MATRIX

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VAR/COVARp168061_06120020210_b1c_hesp168061_06120020210_b2c_hesp168061_0
6120020210_b3c_hesp168061_06120020210_b4c_hesp168061_06120020210_b5c_hes
p168061_06120020210_b7c_hes
p168061_06120020210_b1c_hes     5376.76     5198.26     5097.83    -1259.48
4039.68    4651.52
p168061_06120020210_b2c_hes     5198.26     5416.91     5220.07     -547.64
4144.54    4693.35
p168061_06120020210_b3c_hes     5097.83     5220.07     5463.45     -832.60
4505.89    5086.69
p168061_06120020210_b4c_hes  -1259.48    -547.64    -832.60    5386.45     -
84.60    -983.06
p168061_06120020210_b5c_hes     4039.68     4144.54     4505.89      -84.60
5456.29    5006.93
p168061_06120020210_b7c_hes     4651.52     4693.35     5086.69     -983.06
5006.93    5464.57
```

```
COR
MATRXp168061_06120020210_b1c_hesp168061_06120020210_b2c_hesp168061_06120
020210_b3c_hesp168061_06120020210_b4c_hesp168061_06120020210_b5c_hesp168
061_06120020210_b7c_hes
p168061_06120020210_b1c_hes    1.000000    0.963213    0.940571  -0.234035
0.745826   0.858138
p168061_06120020210_b2c_hes    0.963213    1.000000    0.959548  -0.101384
0.762346   0.862639
p168061_06120020210_b3c_hes    0.940571    0.959548    1.000000  -0.153480
0.825275   0.930945
p168061_06120020210_b4c_hes  -0.234035  -0.101384  -0.153480   1.000000 -
0.015606  -0.181196
p168061_06120020210_b5c_hes    0.745826    0.762346    0.825275  -0.015606
1.000000   0.916949
p168061_06120020210_b7c_hes    0.858138    0.862639    0.930945  -0.181196
0.916949   1.000000
```

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6
% var.	75.67	16.64	5.74	0.77	0.72	0.46
eigenval.	24641.07	5420.11	1867.78	249.84	235.95	149.68

eigvec.1	0.460320	-0.063729	-0.398054	-0.080758	-0.348977	0.705189
eigvec.2	0.446747	0.069243	-0.417164	-0.064835	-0.352034	-0.702471
eigvec.3	0.454322	0.057624	-0.196229	-0.166028	0.850999	0.000000
eigvec.4	-0.112187	0.973376	-0.128380	0.118627	-0.012477	0.096141
eigvec.5	0.405279	0.200904	0.695796	-0.530398	-0.173008	0.000000
eigvec.6	0.453076	0.000000	0.358340	0.816281	0.000000	0.000000

LOADING	C 1	C 2	C 3	C 4	C 5	C 6
p168061_06120020210_b1c_hes	0.985437	-0.063985	-0.234609	-0.017408	-0.073104	0.117658
p168061_06120020210_b2c_hes	0.952830	0.069263	-0.244959	-0.013924	-0.073471	-0.116770
p168061_06120020210_b3c_hes	0.964851	0.057395	-0.114734	-0.035504	0.176849	0.000000
p168061_06120020210_b4c_hes	-0.239950	0.976413	-0.075598	0.025548	-0.002611	0.016026
p168061_06120020210_b5c_hes	0.861262	0.200237	0.407096	-0.113496	-0.035977	0.000000
p168061_06120020210_b7c_hes	0.962106	0.000000	0.209498	0.174537	0.000000	0.000000

APPENDIX VI: ERROR MATRIX FOR 1995 IMAGE CLASSIFICATION

Error Matrix Analysis of UNSUPERVISED NAIROBI 1995 (columns : truth) against 1995 NAIROBI FINAL CLASSIFICATION (rows : mapped)

	1	2	3	4	5	
1	201	8328	57	576	55483	0.9976
2	520589	175576	12745	2	5763	0.7714
3	58464	283496	377491	310258	36743	0.6466
Total	579254	467400	390293	310836	97989	
ErrorO	0.9997	0.6244	0.0328	1.0000	1.0000	

	6	Total	ErrorC
1	19899	84544	0.9976
2	53227	767902	0.7714
3	1774	1068226	0.6466
Total	74900	1920672	
ErrorO	1.0000		0.7119

ErrorO = Errors of Omission (expressed as proportions)
ErrorC = Errors of Commission (expressed as proportions)

90% Confidence Interval = +/- 0.0005 (0.7114 - 0.7125)
95% Confidence Interval = +/- 0.0006 (0.7113 - 0.7126)
99% Confidence Interval = +/- 0.0008 (0.7111 - 0.7128)

KAPPA INDEX OF AGREEMENT (KIA)

Using 1995 NAIROBI FINAL CLASSIFICATION as the reference image ...

Category	KIA
1	-0.4284
2	-0.0194
3	0.1885

UNSUPERVISED NAIROBI 1995

Category	KIA
1	-0.0457
2	-0.0403
3	0.9261
4	0.0000
5	0.0000
6	0.0000

Overall Kappa = 0.0830

APPENDIX VII: ERROR MATRIX FOR 2000 IMAGE CLASSIFICATION

Error Matrix Analysis of UNSUPERVISED NAIROBI 2000 (columns : truth) against 2000 NAIROBI FINAL CLASSIFICATION (rows : mapped)

	1	2	3	4	5	
1 |	447	23	65927	41	0	0.9975
2 |	4589	396766	136147	260819	40594	0.5365
3 |	402521	2741	178853	11987	192805	0.7971
Total |	407557	399530	380927	272847	233399	
ErrorO |	0.9989	0.0069	0.5305	1.0000	1.0000	

	6	7	Total	ErrorC
1 |	36253	79143 |	181834	0.9975
2 |	151	16990 |	856056	0.5365
3 |	91695	812 |	881414	0.7971
Total |	128099	96945 |	1919304	
ErrorO |	1.0000	1.0000 |		0.6999

ErrorO = Errors of Omission (expressed as proportions)
ErrorC = Errors of Commission (expressed as proportions)

90% Confidence Interval = +/- 0.0005 (0.6993 - 0.7004)
95% Confidence Interval = +/- 0.0006 (0.6992 - 0.7005)
99% Confidence Interval = +/- 0.0009 (0.6990 - 0.7007)

KAPPA INDEX OF AGREEMENT (KIA)

Using 2000 NAIROBI FINAL CLASSIFICATION as the reference image ...

Category	KIA
1	-0.2665
2	0.3224
3	0.0055

UNSUPERVISED NAIROBI 2000

Category	KIA
1	-0.1034
2	0.9875
3	0.0190
4	0.0000
5	0.0000
6	0.0000
7	0.0000

Overall Kappa = 0.1207

APPENDIX VIII: ERROR MATRIX FOR 2002 IMAGE CLASSIFICATION

Error Matrix Analysis of UNSUPERVISED NAIROBI 2002 (columns : truth) against 2002 NAIROBI FINAL CLASSIFICATION (rows : mapped)

	1	2	3	4	5	
1	306	15971	16970	40	0	0.9979
2	10095	293964	281013	302281	51395	0.6899
3	379816	20799	27389	0	200620	0.9667
Total	390217	330734	325372	302321	252015	
ErrorO	0.9992	0.1112	0.9158	1.0000	1.0000	

	6	7	Total	ErrorC
1	16513	98121	147921	0.9979
2	0	9116	947864	0.6899
3	194535	360	823519	0.9667
Total	211048	107597	1919304	
ErrorO	1.0000	1.0000		0.8324

ErrorO = Errors of Omission (expressed as proportions)
ErrorC = Errors of Commission (expressed as proportions)

90% Confidence Interval = +/- 0.0004 (0.8320 - 0.8329)
95% Confidence Interval = +/- 0.0005 (0.8319 - 0.8329)
99% Confidence Interval = +/- 0.0007 (0.8317 - 0.8331)

KAPPA INDEX OF AGREEMENT (KIA)

Using 2002 NAIROBI FINAL CLASSIFICATION as the reference image ...

Category	KIA
1	-0.2526
2	0.1665
3	-0.1641

UNSUPERVISED NAIROBI 2002

Category	KIA
1	-0.0827
2	0.7803
3	-0.6041
4	0.0000
5	0.0000
6	0.0000
7	0.0000

Overall Kappa = -0.0072