UNIVERSITY OF NAIROBI

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DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

DEVELOPING A CADASTRAL DATA MODEL FOR PART OF MACHAKOS TOWN, KENYA

BY

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A project report submitted in partial fulfillment of the requirements for the Degree of Master of Science in Geographic Information Systems, in the Department of Geospatial and Space Technology of the University of Nairobi.

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DECLARATION / APPROVAL

Declaration:

I, Edna Kitonga hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other institution of higher learning.

Edna Kitonga ………………… Date: ………………………...

Approval by the University Supervisors

This project has been submitted for examination with my approval as University Supervisor.

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ABSTRACT

Kenya lacks an efficient and effective land administration system. The land administration system in Kenya has been described as bureaucratic, expensive, undemocratic and prone to abuse. One of the major causes of these drawbacks in the land administration in Kenya is the continued use of the traditional and analogue cadastral system. The cadastral system is characterized by low spatial coverage, varying degree of accuracy and is guided by a complex legal framework which has led to multiple registration systems, fixed and general boundaries, UTM and Cassini Soldner coordinate systems, customary, private and public tenure, amongst others. Most importantly the country lacks a formalized cadastral data model from which the development of LIMS at various levels can be based.

The Government of Kenya is in the process of developing a land information system to enhance sustainable land administration at the national level as well as the county level. In the process of introduction of the devolved system in Kenya from a centralized system through the implementation of the constitution of Kenya, 2010, there is need to introduce a component of land administration system that will require some form of standardization.

Though there have been efforts by the government of Kenya to automate the system for efficient and effective land administration, these efforts have been partially successful since there is still lack of a national Land Administration Domain Model (LADM). The focus has been on development of a Land Administration Domain Model (LADM) with little emphasis on the cadastral data model which is a unit of the LADM hence the need for development of a cadastral data model.

The research project focused on integrating/implementing the concepts and fundamental principles of land administration domain model (LADM) into the formal Kenyan Cadastre by focusing on cadastral data modelling. It presents the possibilities and opportunities for testing LADM in Kenya. During the study it showed that it is possible to extend the LADM standard tool by modeling the cadastral data .At the end of the study, it was noted that designing of a cadastral database for Machakos town based on the developed cadastral data model will contribute towards the development of a National Standard LADM that will ensure interoperability between the county and national land Information Management system.

DEDICATION

This project is dedicated to the Almighty God, to my husband, my son Jabali and my daughter Keilah, and to my family members who have been of great help throughout my academic journey.

ACKNOWLEDGEMENT

I wish to express my sincere thanks to many people who contributed towards the completion of this project. Foremost, I want to thank the Almighty God for his guidance, strength and provision during the study period, without him it would not have been possible.

I also wish to thank my supervisor Dr. David Siriba who guided me through to the completion of this project. I would also like to express my sincere gratitude to my friends Emily Wanja and Mercy Rienye who encouraged and supported me through the academic period.

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ABBREVIATIONS

CCDM	Core Cadastral Data Model
ERD	Entity Relationship Diagram
DBMS	Database Management Systems
FIG	International Federation of Surveyors
FR	Folio Register
GCP	Ground Control Points
ISO	International Organization for Standardization
LADM	Land Administration Domain Model
LIMS	Land Information Management System
LIS	Land Information System
NLIM	National Land Information Management System
OODBMS	Object-Oriented Database Management Systems
OGC	Open Geospatial Consortium
ORDBMS	Object Relational Database Management Systems
PWD	Public Work Department
RDMS	Relational Database Management Systems
RIM	Registry Index Map
RRR	RIGHTS Responsibility Restriction
UTM	Universal Transverse Mercator

CHAPTER ONE

1.1 INTRODUCTION

1.2 Background

In Kenya, as the population surges past the 48 million mark, the demand for accurate and up-to-date geospatial information at the national and county level will increase immensely. The Government will need to develop a series of linked requirements in order to effectively control economic development at all levels of the economy. It will require a well-established institutional framework at the centre and a decentralized decision-making capacity at the local levels, basically a distributed and modern cadastral model (Wayumba, 2013).

There is a paradigm shift in land tenure at the wider global land community and it is acknowledged that individual land titling independently may not deliver security of tenure to the masses of people in the developing world. It is widely acknowledged that the land titling process is too slow. Presently, in the developing world, about 30 percent of land is governed by some form of land registration/recordation system (Deininger, 2003).

With the current rate, it will take hundreds of years to be able to realise security of tenure is through a continuum of land rights that allows people to get onto the tenure rights ladder nevertheless , the continuum of land rights approach, if implemented at scale, will need the introduction of new forms of land recordation(Osewe, 2008).

Technological progress, social change, globalization and the increasing interconnectivity of business relations with their legal and environmental consequences put a strain on the traditional cadastral system. In present time, cadastral systems are moving towards digital Cadastre and modelling. Many countries are now developing cadastral models for their economies. Cadastre 2014 emphasises that future Cadastre will depend on modelling rather than cadastral paper maps. In this regard, there has been a concerted effort among the cadastral experts to come up with a new cadastral model. A most prominent initiative has been taken up by Christian Lemmen Et *al*, (2012) that brought statement No.3 on data modelling onto the global stage with the development of the ISO Certified Land Administration Domain Model (LADM).

This research project aims at describing an innovative and affordable land recording system that would enhance recording of formal land rights and tenure, and operate within a management framework with the community. The project aims at incorporating Land Administration Domain Model in order to model land record land rights. This will be achieved by identifying the datasets from the Kenya Cadastre which represent the three packages of the LADM (Party, Spatial Unit and rights package). The Party package is represented by the property ownership class and its attributes; the spatial unit package is represented by the land parcel class and its attributes, while the RRR package is represented by the encumbrances, restrictions and responsibilities in the Kenya cadastral system (Lemmen, 2012).

Fulfilment of these will require access to adequate and reliable geospatial information for the implementing of economic policies at all levels of operation. The realization of these noble objectives calls for a unified approach to map and registries. To this extent, the LADM (built under Cadastre 2014) and Cadastre 2034 recognized the integrated approach to land development as an important attribute to realizing the goals of sustainable development in the 21st century.

1.3 Statement of the Problem

Kenya lacks an efficient, effective and a transparent land administration system. The land administration system in Kenya is described as bureaucratic, expensive, undemocratic and prone to abuse (Siriba and Mwenda, 2013). One of the major causes of these drawbacks in the land administration in Kenya is the continued use of the traditional and analogue cadastral system. The Kenyan cadastral system is characterized by an incomplete spatial coverage, varying degree of accuracy and is guided by a complex legal framework which has led to multiple approaches overseeing registration (torrens and deeds), boundary (fixed and general), coordinate (UTM and Cassini-Soldner), tenure (customary, private and public), amongst others. Most importantly the country lacks a formalized cadastral data model from which the development of LIMS at various levels can be based.

It is however broadly acknowledged that the Kenyan Cadastral system should be improved and upgraded, and a new system established to promote the manipulation and provision of data to both the internal and external users / customers in an efficient way. Though there have been efforts by the government of Kenya to automate the system for efficient and effective land administration, these efforts have been partially successful since there is lack of a formalized cadastral data model.

The focus has been on development of a Land Administration Domain Model (LADM) leaving behind the cadastral data model which is a unit of the LADM.

The LADM provides an abstract, conceptual schema with three basic packages: parties (such as people and organizations), administrative rights, responsibilities and restrictions (such as property rights) and spatial units (such as parcels, buildings and networks), with the latter having one sub package: surveying and spatial representation. (Lemmen, 2012). The need for a uniform reference system is necessary to facilitate the maintenance of a common system of land referencing which ensures seamless exchange of geospatial information internationally.

Development of a cadastral database for part of Machakos town based on a profile cadastral data model will contribute towards the development of Standard National LADM that will guarantee interoperability between the county and National Land Information System.

1.4 Objectives

The overall objective of this study was to design and develop a cadastral data model for part of Machakos town in Machakos County.

The specific objectives of the study were to:

i) To review the efforts on development of the National Land Information System in Kenya and Machakos in particular.

ii) Design and create a cadastral data model

iii) Develop the cadastral database for Machakos town based on the developed cadastral data model

1.5 Research Matrix

Table 1-1: Research matrix

Objective	Research question	Methodology	Data and Materials	Results/Output
1. To review the efforts on development of NLIS in Kenya and in Machakos in particular.	-What efforts have been made to develop a NLIS in Kenya?	-Literature review of existing reports.	Journals, Task force report	Report of all NLIS efforts
2. Design and create a cadastral data model	What are the appropriate entities and attributes for the cadastral data model for Kenya?	Conceptual and logical modelling -	LADM Microsoft visual	-Cadastral Data Model
3. Develop the cadastral database for Machakos town	What are the required data elements in the database? What is the appropriate process of developing a database?	Database Development	GIS Software	- a prototype cadastral data model for part of Machakos town

1.6 Justification and Relevance

In order to modernize the Kenya cadastre to international standards it is necessary that the disparate systems in the country are harmonized into one reference frame that can be adopted nationally for seamless transfer and access of spatial information. Lack of a shared set of concepts and terminology is a major problem in the cadastral domain (Nyandimo, 2006). The LADM has however provided the necessary benchmark for development of a modern Cadastral system in Kenya.

The introduction of the devolved system in Kenya from a centralized system to the devolved county system has introduced a component of land administration system that will require some form of standardization. Kenya, like many African countries, still lacks a modern cadastral data model, a fact that has given rise to several problems in the land administration. The existing cadastral system only contains information related to land dimensional measurements and is largely oriented towards internal tax collection. In view of the challenges stated above, it is evident that the cadastral system in Kenya needs to be modernised in order to provide a digital base for smooth data exchange and access. (Wayumba, 2013)

The Kenyan situation is such that there is no modern cadastral model that has been developed or tested to take care of the disparate cadastral registration systems that exist in the country. This study therefore intends to address the issue of a standard cadastral model that would encompass both the National and County Governments based on the LADM as a Benchmark.

Without a modern cadastre it will be a challenge to solve issues like poverty reduction and economic recovery strategy for wealth and employment creation. For several decades the traditional cadastral systems were reliable, had well defined processes and well-organized security of private land ownership, however due to technology advancement, new human land relationships, and globalization the system is strained.

In Williamson *et al*, (2010) he has pointed out how the system has become cumbersome and fraught with delays in searches since it is not spatially enabled. Additionally, it is an inefficient and time-consuming system with complicated planning, zoning and overall management of land. According to (Christiaan, Van Oosterom, & Williamson) they really encourage the conversion of analogue cadastral maps and land registers to digital format. When digitizing the cadastral maps more attention is required in order to maintain data consistency and enhance accessibility.

LADM comes in handy to reduce these weaknesses. As a recommended international standard in the Land Administration field, the LADM addresses the major conditions of cadastral registration globally. Therefore, application of LADM in this formal tenure is of great importance in enhancing international standardization (Lemmen, 2012).

1.7 Scope of work

The scope of this research is described as following; it is based on developing a cadastral model based on the Land Administration Domain Model (LADM) concept in a formal tenure set up to integrate both the formal registry and the spatial element of the formal cadastre in part of Machakos County. Land tenure security and Modelling is considered to be a principal objective of land tenure management in this formal settlement.

The study will confine itself to the development of a cadastral model for part of Machakos Town. Machakos town is quite big and therefore due to the time limit for the study 40 parcels of land will be used as study area. The issue of data security will not be addressed in this study since the model is just a prototype. The cadastral model is presented in one formal estate only. Real data from the 40 parcels has been loaded for testing and validating. The area has a well laid out scheme of precise cadastral survey (formal tenure) which has been checked and authenticated by the Director of Survey. The scheme has both spatial and non-spatial attributes which were found valuable for the development of the model, and the site is close to the City of Nairobi hence access for field visits and measurements are feasible.

1.8 Organisation of the project report

The project report is organised into five chapters. Chapter one introduces the subject, presents the problem statement, objectives, research matrix, justification and relevance and finally the scope of the study. Chapter two gives a review of the literature on the subject matter. Chapter three presents the methods and the technology used in the study to achieve the objectives. Chapter four presents the study results and their analysis. In chapter five conclusions of the study and recommendations are presented.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The necessity of a digital Cadastre has been and is a major interest of the United Nations since its establishment. In the year 1972, the UN assembled a group of professionals to analyse the challenges of cadastral surveying in the developing nations and contemplate installing a continual committee to be reviewing the advancements in this field (UN-FIG, 1996). More engagements towards these reforms were exhibited in the Agenda 21 (UN FIG, 1998) and the Habitat II Global Plan of Action. During the sessions, it was acknowledged that effective and efficient cadastral systems are major drivers for economic development, social stability and environmental management in developed and developing countries.

Presently, it is apparent that western countries have migrated from the conventional Cadastre to digital multi-purpose Cadastre. A multi-purpose Cadastre incorporates information on resources, land use planning, land value and land titles and both the individual and indigenous rights into one geospatial database for efficient utilization (Zevenbergen, 2002).Land registries in majority of these countries were upgraded to accommodate the coded building information (in both 2D and 3D) and utilities, and their LIS are web-based.

Nyandimo, (2006) indicates that in Africa, the old traditional cadastral systems are still in use by several countries whereby most of the cadastral processes are manual based and their operations are in paper format. Whilst these systems were suitable for the agrarian societies, the 21st century economies need the modern Cadastre to successfully achieve the goals of sustainable development. The isolated methods that supported particular purposes are not sustainable

2.2 Land Information System

The Land Information System (LIS) has been defined by the International Federation of Surveyors (FIG) as a tool for legal, administrative and economic decision-making and an aid for planning and development. A land information system consists, on one hand, of a database containing spatially referenced land-related data for a defined area and, on the other, of procedures and techniques for the systematic collection, updating, processing and distribution of the data. The base of a land information system is a uniform spatial referencing system, which also simplifies the linking of data within the system with other land-related data (UNECE, 1996).

The Land Information system uses land parcels as the basic building block. A map based Land Information System may possibly have information on land rights and restrictions, precise delineation of boundaries, land value, land taxes land use, information on building situated on the land parcel, population data; administrative data and environmental data .Property data can also be linked to land data such as utilities data for example water, electricity, telecommunications, sewage, gas and emergency services. Climate, topography vegetation, geological, soil, wildlife, hydrology, geophysical and transport data among others can also be linked to the land information depending on the nature of the Land Information System. Figure 2-1 gives a general concept of a Land Information System.

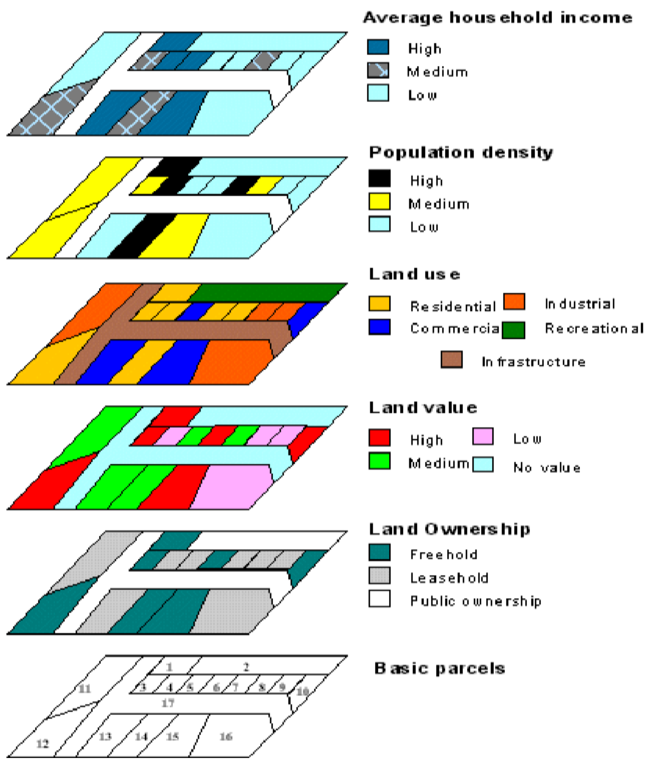


Figure 2-1: The concept of LIS ***(Source: Dale and McLaughlin, 1988)***

In local government an LIS could include the property appraisers maps ,maps on which approved subdivisions are compiled ,utility maps ,right of way maps and zoning maps .It could also include all of the tabular records associated with the maps: the property assessment files ,deeds, subdivision review applications and approved plans ,inventories of pipes manholes details ,maintenance records ,buildings permits, zoning violations and other code enforcement records. At the planning level, LIS might incorporate road networks-existing, planned, funded-and related data on capacity and volume. It could include land use, land cover, projected or planned land uses, soils, environmentally sensitive areas, socio-economic data, and redevelopment areas. In short, a land Information system is what a government or unit wants it to be and/or do and become what they want it to become. (Federal Geodetic Control Committee, 1989).

A land Information System contains different components which are very useful in developing, updating and implementing the system. A typical Land Information has Cadastre as a primary component. A Cadastre is typically a parcel based, and up-to-date land information system comprising a record of interests in land (e.g. rights, restrictions and responsibilities). It generally includes a geometric description of land parcels (cadastral data) related to other records describing the nature of the interests, the ownership or control of those interests, and many times the value of the parcel and its improvements (attribute data). It may be established for fiscal purposes (e.g. valuation and equitable taxation), legal purposes (conveyance), to aid in the management of land and land use (e.g. for planning and other administrative purposes), and enables sustainable development and environmental protection. Parcels are described using a unique Identification Number (IN) for each of them and relates the parcel to attribute information (Enemark, 2001).

Geodetic reference framework is also an important component of LIS, it consists of permanently monumented stations whose locations are accurately measured and mathematically described relative to a common datum. For a LIS the framework provides an accurate and efficient means to describe the location of land features and their relationship to one another and makes it possible to interpret, analyse and disseminate compatible land information. An adequate geodetic reference framework ensures sufficient spatial accuracy for linking the different types of data that comprise a LIS. In Kenya the local geodetic reference frame work used is the Universal Transverse Mercator arc 1960.

A LIS is maintained by a unit of government responsible for tracking land ownership and control. In Kenya the custodian of LIS is the Ministry of Land Housing and Urban Development. Other components of a LIS include hardware, softwares, procedures and human resources. Hardware involved may include Workstations-(various configurations standalone, networked, server based), Plotters-(Pen, electrostatic, laser, thermal, film writers), Digitizers-(digitizing tables/tablets, onscreen/heads-up digitizing), Scanners-(optical…) and Printers. There are different land management Softwares used in development, updating and maintenance of the LIS e.g. ArcGIS, Microsoft office. Technical personnel required in the development and running of the system may include Leader/Manager, GIS Analyst, System Administrator, Database Administrator, Programmer, Processor, and Digitizer/Cartographer among others.

2.3 Efforts on development of LIMS in Kenya

Kenya has had deficiencies in land administration since independence. There have been initiatives to address reforms in the land sector for the past several years which included formulation of policies and implementation framework for Land Reform Support Programme in 2006.The LRSP documented the road map to development of the LIMS. In the year 2007 through the Rapid Results Initiative programme the government identified various data capture activities which are listed in the work plan of each department for fast tracking.

Despite the land reform initiative there was lack of a clear and defined land policy to govern the management and administration of land which led to social, economic, political and environmental problems. In order to address these problems the government embarked on a journey to formulate a National Land Policy which was done through a wide consultation with all the stakeholders both in public and private sector The policy was implemented in three years (2009-2012) and its vision is 'to guide the country towards efficient, sustainable and equitable use of land for prosperity and posterity".

The National Land Policy pointed out the need for the provision of core datasets for the National Spatial Data Infrastructure (NSDI) for the whole country. It indicated the need to establish a comprehensive computer-based land information management system which is user friendly, accessible and transparent. It also pointed out the need to have national guidelines on land information to govern issues such as data security, standards, pricing and dissemination of Land information.

In 2009 the government entered into an agreement with the Swedish authority for survey and mapping as part of the land reform programme and implementation of the NLIMS. This was to implement the "Project for Improving Land Administration in Kenya (PILAK). The project proposed to improve the processes, procedures and the working environment at the ministry of Lands and physical Planning. This was done through safeguarding land paper records, development of business and information technology systems, updating the geodetic network and development of a land rent collection system. The project also aimed at converting titles from the Government Land Act (GLA), Registration of Titles Act (RTA) and Land Titles Act (LTA) to the Registered Land Act (RLA). The project did not accomplish its mandate.

The National Land Policy vested the mandate to develop the NLIMS to NLC prior to the implementation of the Land Act in 2012 which transferred the responsibility to the Ministry of Lands and Physical Planning. The NLC was in the initial stage of the development of the NLIM however it went ahead and developed a Public Land Information Management System (PLIMS) which is complete currently and awaits integration with the parcel data from Survey of Kenya for it to be operational. The Survey of public land by survey of Kenya is ongoing and soon it will be complete.

The Ministry of Lands and physical planning is the key player in attainment of vision 2030.Land reforms were recognized as the basis upon which economic, social and political pillars of Vision 2030 are anchored. Vision 2030 envisions that land reforms is about the change or replacement of existing institutional arrangements governing land ownership and its use in order to enhance land management (Wayumba, 2013).

The government of Kenya so far has achieved some of the objectives of the vision 2030 by approving new Laws and regulations governing land administration. These include the Constitution of Kenya(2010), National Land Policy(2009), National Land Commission, Land Act(2012), Land Registration Act(2012),Community Land Act(2016) ,Survey Act(Cap 299) , Sectional Property bill (2018), Access to Information Act (2016) and Registration of Documents Act (CAP285 among others.

The land reforms are focused on enhancing access to land and guaranteeing better use of the natural resources. The Ministry acknowledges that the change anticipated under Vision 2030 should be based on secure policies and legal-institutional framework .The Ministry's Strategic Plan (2008-2012) and its performance contract (2010/2011) already pointed out that to ensure effective and efficient service delivery to the public; current methods and techniques of handling and managing land information require re-designing. It additionally cited that re-designing should be inclusive of Business Process Re-Engineering, and it focused on four bench-marking activities in achieving these goals. These activities included reviewing and documenting the current land processes, procedures and practices; redesigning methods and techniques of land administration; recommending the quick impact projects; and implementation of a National Land Information System. (Ministry of Lands and physical planning, 2011).

The ministry, in an effort to implement the NLIMS, in 2013 rolled out a digitization programme to digitise all the land records. This marked the commencement of digitization of 57 land registries which had been keeping manual records since 1895.The ministry has so far been able to digitise 16 of the land registries, Nairobi and central registries being the first to be completed The digitisation program has led to what could be termed as the initial implementation of the NLIMS.

The ministry of lands and physical planning in the year 2016 appointed a taskforce to come up with recommendations on how to set up NLIMS. The task force recommended the following for; (i) A stable policy and legal framework (ii) A data model to support the NLIMS (iii) Distinct interoperable sub-systems i.e. Cadastre, Valuation, Physical Planning, Land Adjudication & Settlement, Land Administration and Land Registry (iv) Review of current legal framework (v) Adequate infrastructure (software, hardware, human resource) (vi) System Rollout (pilot project) (vii) Financing of the System (viii) Country wide mapping and geo-referencing

Despite the above efforts by the ministry of lands and physical planning, Kenya still lacks a digital NLIS. Land administration operates on a manual system which has exhibited the following weaknesses; Poor land records management, a Non-integrated approach (lack of collaboration between various spatial information stakeholders), opaque to current advances in technology (slow adoption to new technology), inefficient system administration (centralised and bureaucratic) and low cadastral coverage among others.

The spatial aspect which is a major component of the NLIS has not been given much attention. The spatial data is still in analogue form, the cadastral coverage is still low at 20% as 80% is on general boundaries. The system is far from being modernised as most of the above recommendations by the task force have not been rolled out.

At the county level and especially in Machakos County the efforts on development of NLIS are very minimal. The system is manual based though the registry records have been digitised. The spatial data is analogue and the cadastral coverage is very low.

2.4 The need for a Standardized Model

The inception of the LADM was prompted by Cadastre 2014.Which gave a conceptual perception about Land Administration modeling (Kaufmann & Steudler, 1998). The modeling method to link non-technical data consumers and software program analysts in land management is a concept in this Cadastre 2014. One of the critical visions on Cadastre is Cadastre 2014 and Cadastre 2034(Kaufmann, 2014a). One of the primary goals of the Cadastre 2014 was to enhance the details on legal status of land and then reinforce the security of tenure. Cadastre 2014 and Cadastre 2034 are new approaches in the cadastral field. The vision of Cadastre 2014 is described by six statements and six principles of Cadastre future.

One of the Cadastre 2014 statements described the function of data modeling. The position of the LADM and Cadastre 2014 with regard to data modeling is comparable with contract and implementation. Cadastre 2014 establishes modeling concepts briefly, and needs to be implemented into an actual model as LADM did. The LADM also further and outlined the Cadastre model. According to (Kaufmann, 2004b), the difference between LADM and Cadastre 2014 wide. Additionally, he concludes that in every step of LADM development, it's proved, that more components of Cadastre 2014 are incorporated

Another feature of Cadastre 2014 is the legal independence which was the main component to realize Cadastre 2014 .Legal independence concept is aimed at localizing a particular layer with respect to certain law or regulation. The Cadastre 2014 supported the informal and customary rights, occupation rights and indigenous rights (Kaufmann, 2014a). The areas in which these rights are more effective is familiar. However, they are applicable to other legal rights such as private property rights, public rights and restrictions, and for the utilisation of natural resources.

Therefore, Cadastre 2014 if fully implemented will show overlapping rights and will regulate land transactions. Additionally it will monitor and improve any uncertain situations in land administration (Kaufmann, 2014a). This will be achieved by describing any single layers for any particular land object governed by the same law. This particular aspect is modeled as a restriction class in LADM.

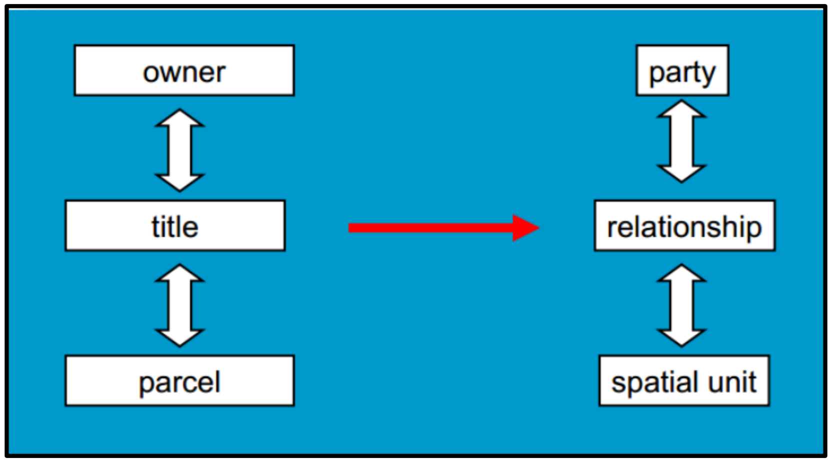


Figure 2-2: LADM Rights Concept ***(Source: Kaufmann, 2004a)***

Today, some countries have implemented Cadastre 2014 vision and geared toward Cadastre 2034 and some are far from achieving the vision. A standardized model is necessary for many countries in realizing the vision of Cadastre 2014 and also enhancing people's welfare through security of tenure.

According to (Soltanieh, 2008) land administration systems are evolving from a focus on core functions of regulating land and property development, land use controls, land taxation and disputes to a focus on an integrated land management system designed to support sustainable development. Enemark, (2001) points out that management of social, environmental and economic interests in land is necessary for sustainable development. However, land administration subsystems use diverse services and functions in management of land interests (Figure 2-3).

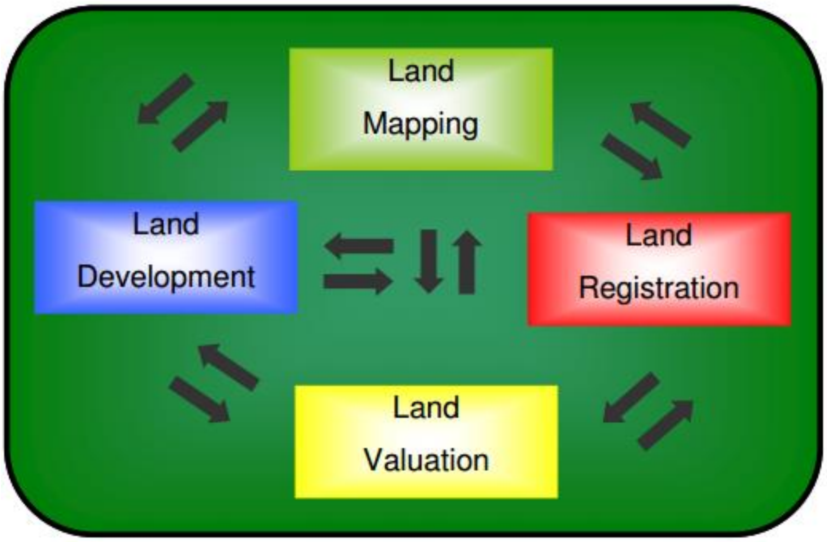


Figure 2-3: Relationship among Land Administration subsystems ***(Source; Soltanieh, 2008)***

For instance, the land registry subsystem emphasizes on the management of private rights, restrictions and with the economic functions of land. The land tax office needs the change of property use in addition to owner updates for calculation of revenue and tax.

2.5 The Land Administration Domain Model

Land administration domain model (LADM) is an ISO standard (ISO 19152) which was initiated by the FIG (International Federation of Surveyors). The objectives of the standard are to facilitate data exchange and the implementation of land registration systems in developing countries. The standard is an abstract conceptual model whose principle is that a Party (physical or legal person) has RRR (Rights, Responsibilities, and Restrictions on a Spatial Unit. The LADM consists of basically three packages which are; the party, the legal/administrative, and the spatial unit packages, and surveying and representation which are sub packages of the spatial unit package. The three packages are implemented in four main classes; LA_Party, LA_RRR, LA_BAunit, and LA_SpatialUnit) (Kuria et al, 2016) as shown in Figure 2-4.

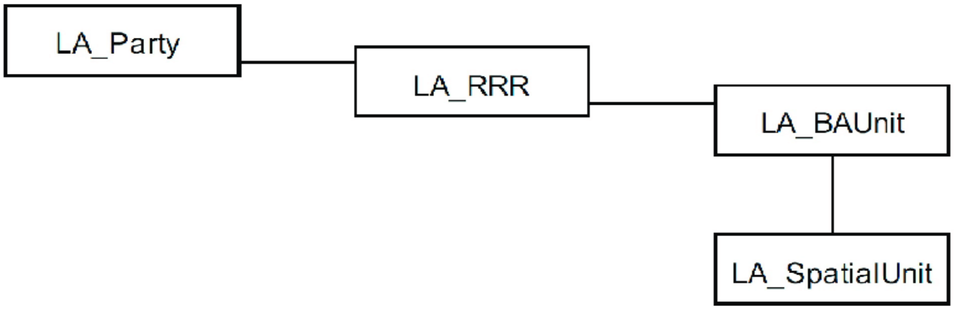


Figure 2-4: The LADM packages *(Source Kuria et al 2016)*

The main class of the party package of LADM is class LA Party (Siriba and Mwenda, 2013) with a specialisation LA_GroupParty. A Party could be a person or organisation that plays a role in a rights transaction. An organization can be a church community, company, a municipality or the state. A 'group party' may be several numbers of parties forming a distinct entity. A 'party member' is a party registered and identified as a constituent of a group party. This allows documentation of information to membership (holding shares in rights) (Christiaan Lemmen, 2015)

The administrative package comprises two basic classes: Class LA_RRR and Class LA_BAUnit (Basic Administrative Unit). The LA_RRR class has three subclasses which are LA_Right, LA_Restriction and LA_Responsibility. A right is a moral or legal entitlement to have or do something, Examples are: customary, ownership, tenancy, possession, or informal rights. Restrictions are limitations from doing something they can be formal or non-formal. Responsibility is a moral obligation to do something.

The LA_BAUnit is an administrative entity and it may consist of none or more spatial units (parcels) against which one or more precise and homogeneous rights (e.g. an ownership right or a land use right), responsibilities or restrictions are related to the entire entity as included in the land administration system (Christiaan, 2015). BAUnits are necessary in registration of the 'basic property units' and comprises various parcels (spatial units) that belong to a particular party governed by the same right. An administrative unit must be governed by an homogenous right (Siriba and Mwenda, 2013)

A spatial unit may be represented as a point (or multiple points), a line (or multi line) representing a one area (or multiple areas) of land (or water) or, more specifically, a single volume of space (or multiple volumes of space).A parcel can represent a spatial unit which may be combined into two forms: The sub spatial units (or sub-parcels) or the spatial unit group. Sub spatial unit is a combination of a spatial unit into its parts while the spatial unit group is a number of spatial units which may be regarded as an entity for example a settlement scheme or a municipality. (Siriba and Mwenda, 2013)

The Spatial Unit class in Kenya, is associated with the different types of cadastral maps (.RIM, PID, FR) which are used for registration of land. The parcels of land are plotted in cadastral maps and are identified with the block number, the registration section and the county where the parcel is. This information is recorded on every cadastral map. Spatial units are classified into two special categories: The building unit and the utility network categories.The building unit is a component of building and is considered as a legal space, which does not necessarily fall into the physical space of a building.

The utility network describes the topology of a utility. It may be associated with information about its legal, recorded or informal space and can be adopted as a basic administrative unit. A utility network also does not necessarily coincide with the physical space of a utility network rather it concerns the legal space. These unique categories of the spatial unit are attributable to the Kenyan cadastre in terms of sectional properties and easements respectively. In order to register properties as sectional properties, reference is made to the cadastral plan where the land parcel having the building lies. Likewise, any easement registered with respect to a particular parcel of land, is plotted on the cadastral plans showing the affected land parcels (Siriba and Mwenda, 2013).

The spatial units are identified and represented by the surveying and the representation sub package. Surveying involves the identifying and acquiring points of the boundaries of the spatial units. Boundary is a set that describes the extent of the spatial unit. Spatial units are represented as points, polygons or polyhedral surfaces.

Documents that describe the spatial representation of a single or several spatial units are known as spatial sources. These documents may be final or all the related documents to survey of the spatial unit for example a satellite imagery or even a field sketch showing the boundaries of the spatial unit. In Kenya these documents are described in different names, the survey plans and the Registry index Map. The most geometrically accurate are the survey plans which describe the boundaries of the parcels using lines plotted from corner point coordinates measured from the field. The registry Index Map describes the parcel boundaries using lines plotted from approximate measurements from the field while for the sectional properties the building and floor plans are plotted as line.

2.6 Cadastral 2014 Model

The inception of LADM is set off by Cadastre 2014 which gave a conceptual idea concerning Land Administration modeling (Kaufmann & Steudler, 1998). The main concept in Cadaster 2014 in terms of data modeling is to link the non-technical end-users and software analysts in land management. One of the main aims of the Cadastre 2014 was to enhance information on legal state of land and to reinforce security of tenure. Cadastre 2014 and Cadastre 2034 are new approaches to cadastral domain.

The vision of Cadastre 2014 is described by six statements and six principles of future Cadastre.In one of the Cadastre 2014 statements mentions the role of data modeling. The role of Cadastre 2014 and the LADM in terms of data modeling is comparable to a contract and implementation. Cadastre 2014 presents modeling concepts in a theoretical view, and should be executed into a real model as the LADM did. LADM further described the Cadastre model. According to (Kaufmann, 2004b) the difference between LADM and Cadastre 2014 is not wide. He further concluded that the development of the LADM shows that in every step more elements of Cadastre 2014 are incorporated. A course along the direction of Cadastre 2014 can be adopted.

Further aspect of Cadastre 2014 concerning its principles is the legal independence which was the major component in realizing Cadastre 2014 (Kaufmann & Steudler, 1998). Legal independence principle is designed to localize a particular layer with regards to certain law/regulation. The Cadastre 2014 supported the informal and customary rights, occupation rights and indigenous rights through local independent concepts (Kaufmann, 2014a). Those rights and the areas where they are effective is well known. Nonetheless, they can overlap to another legal land object, such as private property rights, public rights and restrictions, and concession for the exploitation of natural resources.

Therefore, Cadastre 2014 aspect will indicate overlapping rights and assist in formalizing the situation, regulating the transactions, monitoring and improving the ambiguous situation (Kaufmann, 2014a). Cadastre 2014 achieves this condition by specifying an individual layer for each land object under the same law. This concept is modeled as a restriction class in LADM. For instance, the legal right that is linked to a particular land can be restricted by customary right or public law. Today, some countries have implemented Cadastre 2014 vision and some are still having troubles in realizing the vision. A standardized model can help the countries to achieve the Cadastre 2014 vision, and eventually enhance people welfare through tenure security. DE Soto, (2000) outlines the positive effect of an operational cadastral system in a stable formal property system.

The Cadastre 2014 guidelines provide a good starting point for modeling, however it is a general, or conceptual set of guidelines, which need to be refined into a more specific model. This is the aim of the CCDM. Possibly one might compare the two levels with the conceptual and the implementation level of specification within the Open Geospatial Consortium (OGC). The conceptual level has the primary knowledge, though this can be implemented in several different manners, which can all claim to be compliant (but the systems would not support automated interoperability). The CCDM moves ahead and gives specification on the implementation level of the model, meaning that different systems holding fast to the core cadastral model will be interoperable. (Kaufmann, 2004b). Note that in Cadastre 2014 the legal land object (instead of only the parcel) is in the centre. This kind of approach necessitates throwing overboard some conventional practices as the parcel-only-centric approach thinking in land objects is the future in modern cadastral systems. One of the important characteristics of Cadastre 2014 is that the same land objects are arranged in independent layers. This is translated in different independent object classes, such as parcel, building, and other register object (legal area of easements, utility infrastructure, specific land use or protection, etc.). All these classes of immovable have one common characteristic, they are sort of related to persons via (all kinds of) rights (restriction and responsibilities).

The six statements of the Cadastre 2014 (Kaufmann and Steudler, 1998) presents the future of the cadastral systems. The six statements have great influence on the development of the land administration systems and are recommended for their evaluation. The six statements includes:

i. The Cadastre 2014 will show the complete legal situation of land, including public rights and restrictions.
ii. The Separation between maps and registers will be abolished.
iii. Cadastral mapping will be dead! Long live modelling.

iv. Paper and pencil-Cadastre will have gone.
v. Cadastre 2014 will be highly privatized. Public and private sectors are working closely together.
vi. Cadastre 2014 will be cost recovering.

2.7 The Cadastral Systems in Kenya

According to Zevenbergen, (2002) the cadastral system defines and records the location and extent of property rights, restrictions and responsibilities. It comprises a geometric description of land and real property boundaries related to other records outlining the nature of the interests, the ownership or control of those interests, and generally the value of the parcel and its improvements. The Kenyan cadastral system was established in 1903 when a land survey section was established in the then Public Works Department (PWD). The objective of establishing the land survey section was primarily to cater for the alienation of land for the Uganda Railway and white European settlements in the Kenya Highlands. In 1906 the section was elevated to the status of a fully-fledged, autonomous, department and established as the Department of Surveys and placed under the Director of Surveys. While the intention and purpose for which the cadastral section and cadastral surveys were met given the minimal pressure and use of land and land related activities at the time, it has now become evident that there is more demand on cadastral activities given the rise in population and developments in technology.

As a result of these surveys, a huge amount of cadastral data has been generated over the last 100 years. Although the cadastral system has served the country well since its establishment in 1903, and has been a major source of economic and infrastructure development, its current status indicates that it is outdated and can no longer cope effectively with the demands of a modern economy (Wayumba, 2013).

The cadastral system is characterized by several problems, including an incomplete spatial coverage, and the varying degree of accuracy of its form (Siriba et al, 2011).The system also has a complex legal framework dating back to the colonial era, which has resulted in multiple approaches overseeing registration (torrens and deeds), boundary (fixed and general), coordinate (UTM and Cassini-Soldner), tenure (customary, private and public), amongst others. Crucially, the country lacks a formalised cadastral data model from which the development of LIMS at various levels can be based (Siriba and Mwenda, 2013).If the country has to attain its vision of industrialization by the year 2030 as pledged by the Government, there will be a need to modernize the current cadastral system in order to provide a framework upon which the industrialization can be anchored.

In Africa, Kenya is possibly the leading example of a country which has made an effort to establish a European type cadastral system for its land registration programmes. This was accomplished through a systematic adjudication of existing traditional land rights in the African Reserves. Since the adoption of the land adjudication programme by the Government in 1956, several land parcels have been registered and about 60% of the country has been brought under registration (Wayumba, 2013). The cadastral system in Kenya has influenced agricultural production in a region where many economies are stagnant. Osterberg, (2001) observed that early establishment of this cadastral framework and the adoption of open market economy have propelled the level of economic development of the country far beyond countries of similar status but which lack such a well-established Cadastre.

Table 2-1: Cadastral process in Kenya

1. A Surveyor carries out the precise cadastral surveys which comprises; field data capture, compilation and submission to the Director of Surveys for checking and authentication 2. Director of Survey authorizes numbering and cross referencing of survey records 3. Cross Referencing of Records 4. Preliminary checking 5. Final checking 6. Authentication of survey records 7. Preparation of Deed Plans and Registry Index Maps 8. Submission of Deed Plans or Registry Index Maps to the Commissioner of Lands for Title Registration

2.8 Approaches that people have used on cadastral data modeling.

In the past years several studies have been done on cadastral modeling by different researchers in the world and Kenya in particular. Wayumba (2013) did a study on evaluation of the cadastral system in Kenya and a strategy for its modernization. In his study he reviewed the Kenyan cadastral system and he highlighted its strengths and weaknesses. He designed a model for the cadastral system whereby he recommended that the hybrid of Object-Relational database management system is more preferred for the development of GIS-based cadastral databases other than the typical Relational or Object-Oriented models independently. He also highlighted that the use of smiths normalization method and functional dependency diagrams automatically produce well normalised tables which can be queried successfully.

In 2013 (Siriba and Mwenda) did a study on Kenya's Profile of the Land Administration Domain Model and they documented Kenya's cadastral processes and mapped them to the LADM standard. Their study set a stage for creating a profile of the LADM standard for Kenya however the study did not emphasise on the cadastral data model. This study has borrowed so much from their study specifically on understanding the spatial unit package in the Kenyan context.

The year 2016 (Kuria et al) mapped the LADM to the Kenyan data and the approach used in their study is as shown in Table 2-2. Their study was exemplary however their model could be improved.

Table 2-2: Mapping of LADM to Kenyan land data

LADM classes	**Kenya LIMS Classes**	**Description**
LA_Party	Owners	Records information about legal owners of a particular parcel of land and also special ownership, for example group ownership, non-person or institutional ownership.
	Parcel	Has information about parcels of land.
	Administration Class	stores information on counties
LA_Spatial Unit	Spatial Unit.	This records various types of spatial entities that can be referenced in the system
	Registration Class	Stores information about the registration section .Every land parcel belongs to a particular registration section.
LA_RRR	Rights	stores information about peoples entitlement to land
	Restrictions	It stores information on encumbrances on land.
	Responsibilities	This stores information on owners' obligations in land with respect to its use, the environment and the state.

Landuse	Land Use	Stores information on Land use zones
Valuation	Valuation Land	Information about Valuation of parcels of land
extTransaction	Transaction	Captures all the information on land transactions which are as a result of change of owner, rights and administration unit of a parcel.
extApplication	Application	Records all applications lodged by land owners to the land administrators
extStaff	Staff	Information about employees who are key players in land transactions is stored in this class

Recently (Mwange) did a study on development of a subject domain (SD) model of Kenya's cadastral data model, and aligned it with the country's legal framework. The SD model for Kenya's cadastral system was based on Unified Modelling Language (UML) and it was based on fixed and georeferenced boundaries disregarding the general boundaries. The study also derived a mapping between the developed SD model and the LADM and it's shown in Table 2-3.

Table 2-3: Mapping LADM

SD Model	**LADM Model**	**Package**
Person	Party	Party
Group	GroupParty	Party
GroupMember	PartyMember	Party
Interest	RRR	Administrative
PropertyGroup	BAUnit	Administrative
Property	SpatialUnit	Spatial Unit
SubProperty	SubSpatialUnit	Spatial Unit
SectionalProperty	LegalSpaceBuildingUnit	Spatial Unit
Utility	LegalSpaceNEtwork	Spatial Unit
CadastralMap	SpatialSource	Surveying
CadastralSurvey		Surveying

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Area of Study

The study area for the project is part of Machakos town which is in Machakos County. Machakos town is a major rural centre, and also a satellite town due to its proximity to Nairobi. It stretches from latitudes 0º 45' South to 1º 31' South and longitudes 36° 45' to 37° 45 East. Machakos town is one of the fastest growing towns in Kenya since the implementation of the constitution of Kenya 2010 through devolution. This is influenced by several major infrastructure projects happening within the county among them being the upcoming Konza techno and new industries among others. The project area was chosen due to various reasons; availability of data, the project site has a well laid out scheme of precise cadastral survey which has been checked and authenticated by the Director of Survey, and its proximity to the City of Nairobi hence easy access for field visits.

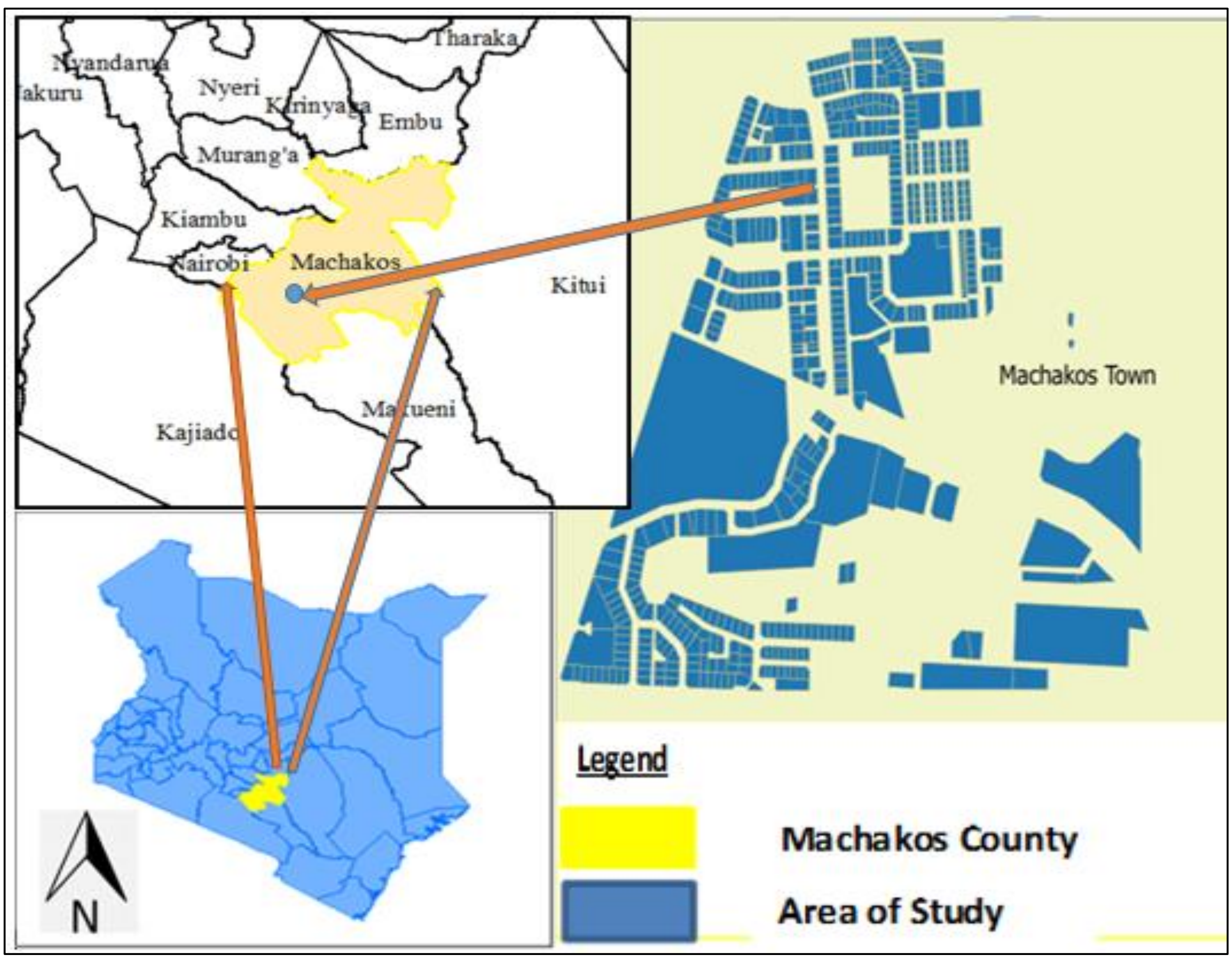


Figure 3-1: Area of study

3.2 Designing of the cadastral data model

The design of the cadastral data model was based on a three level architecture which consists of three sections;

- External modelling (user needs assessment)
- Conceptual/Logical modelling
- Physical modelling

The reasons for adopting the three-level Architecture are ; each user has access to the same data but views the data differently, any changes by the user do not affect the other users, no direct interaction with the physical database storage system by the users ,the Database Administrator (DBA) can be able to change the database storage structure without affecting the users views , the internal structures of the database are not affected by changes in the physical aspects of the storage ,the DBA can change the global structure of the database without affecting any user.

3.2.1 External Modelling

External modelling also referred to as 'user needs assessment' represents the way users perceive data in the database. The external level consists of a number of different external views of the database. Each user's view is an external model. External Modelling was designed after carrying out user needs assessments in different organisations including the ministry of lands and physical planning and Teleposta pension Scheme (who own land in the study area), professionals and members of the public, who interact with the spatial data. This was done through administration of questionnaires and oral interviews. The end result of external data modelling is the user needs assessment. report.

3.2.2 Conceptual Modelling

Conceptual modeling involves combination of all the external models into an E-R diagram. The following tasks were carried out interactively:

(i) Identification entity types;

(ii) Identification of attributes;

(iii) Identification of relationship types;

(iv) Assigning of keys;

(v) Drawing of Entity–Relationship diagram;

An entity type could represent a collection of people, places, things, events or concepts. In this study the entity types were defined during the user needs assessment. The following entity types were identified; spatial unit, spatial unit group, survey class, reference system class, map class, boundary class and boundary beacon class. Entity types just have data.

An entity type may have one or more data attributes that uniquely identifies individual occurrences of an entity type. For example, the spatial unit entity has attributes such as spatial unit ID and area. Different attributes for different entity types were identified as shown in Table 3-1.

Table 3-1: Entities and their attributes

S/No	**ENTITY**	**ATTRIBUTES**
1	Spatial unit (Parcel)	Parcel_ID, Area
2	Spatial unit group	Registration section, Registration type ,Year of registration
3	Cadastral survey class	Survey ID ,Comps No, File reference No, field book number ,Instrument, survey date ,Status ,locality ,authority
4	Reference system class	Coordinate system ,datum ,description ,projection ,
5	Map class	Map type ,Map number ,Map Scale
6	Boundary class	Boundary ID, Boundary type, Beacon ID
7	Boundary beacon class	Beacon ID ,Beacon type ,date set ,xcoordinate ,Ycoordinate ,Hcoordinate ,Vertical datum ,horizontal datum

In the real-world entities have relationships with other entities. For example, a parcel has an owner, a parcel has an area etc. An entity can be related to one or to many entities one entity can be defined to which all other entities are related, allowing an indirect relationship to exist between all entities. Different entity relationships were identified and are shown in figure 3.2

An entity type may have one or more possible candidate keys, one of which is selected to be a primary key. A primary key must be unique for the entity in question. Primary keys were identified for each entity type for example; parcel_ID was assigned to be the primary key in the spatial unit class. An E-R diagram was then modeled from the identified entities, attributes and relationships this is shown in Figure 3-2.

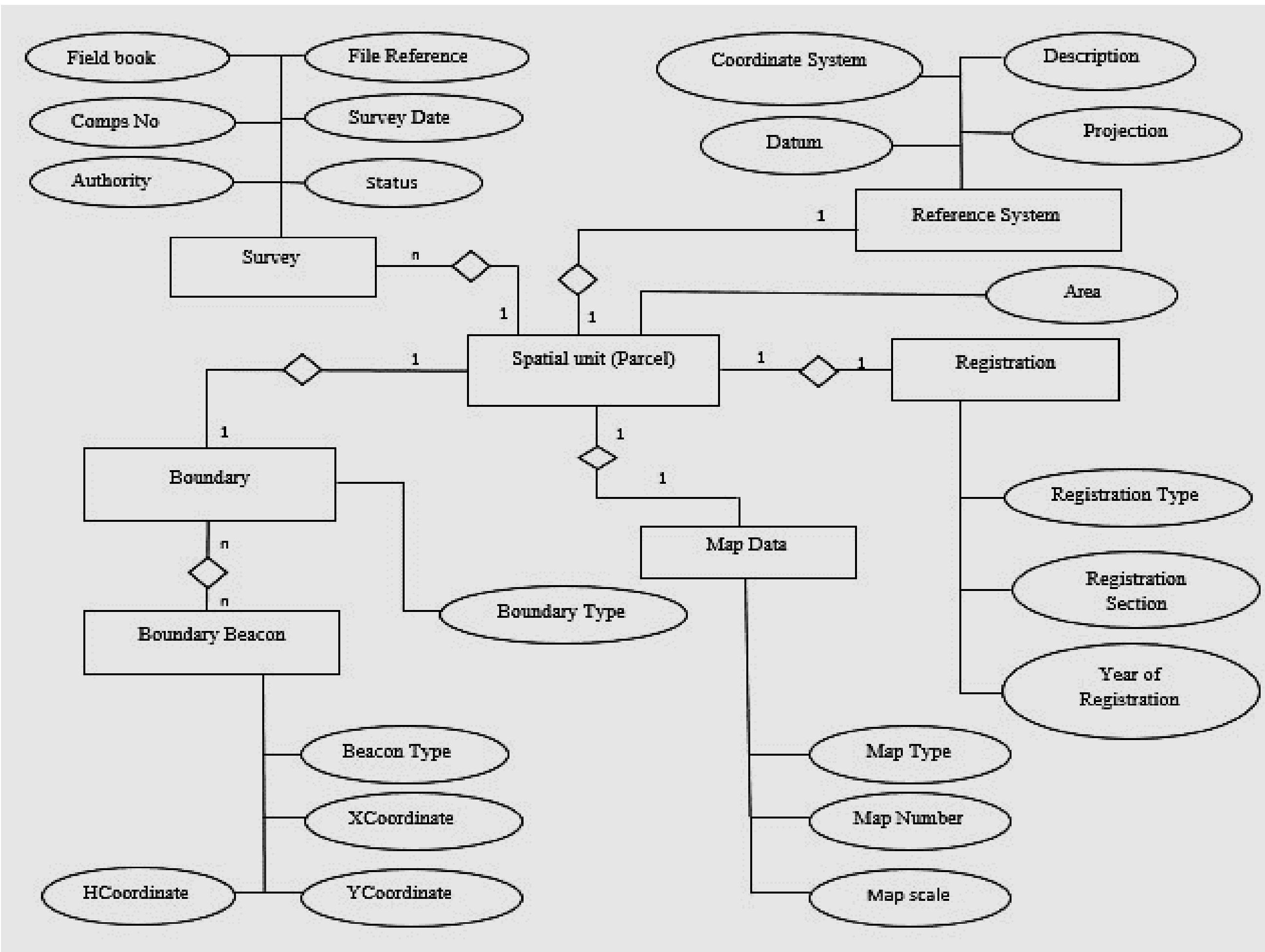


Figure 3-2: E-R Diagram

3.2.3 Logical Modelling

Under the logical modelling, the conceptual schemer is translated into the data model of a particular type of a Database Management Systems (DBMS). The DBMS is a software application designed to organize the efficient and effective storage of, and access to, data. DBMS can be classified according to the way they store and manipulate data. Currently, there are three main types of DBMS available to GIS users. These are the Relational Database Management Model (RDBMS), Object-Oriented Database Model (OODBMS) and a hybrid of the Object-Relational Model (ORDBMS). Logical modeling involves designing and normalization of the relational tables according to the entities, attributes and relations identified from the conceptual modeling.

3.2.4 Designing of Ms Access Relational Tables

From the entity relationship diagram, the following tables were created and populated in Ms Access. The Tables were named as spatial unit group, map class, cadastral survey class, reference system class, boundary class and boundary beacon class. Tables 3-2, 3-3, 3-4, 3-5 and 3-6 shows the relevant attributes and selected data types.

Table 3-2: Spatial unit Group Class

Parcel_İD	Registration Type	Registration section	Year of Registration

Table 3-3: Reference system class

Parcel_ID	Reference_ID	Coordınate System	Datum	description	projection

Table 3-4: Map class

Parcel_ID	Map_Type	Map_No

Table 3-5: Boundary Class

Parcel _ID	Boundary ID	Boundary type	Beacon ID

Table 3-6: Boundary Beacon Class

Beacon ID	Beacon type	Xcoordinate	Ycoordinate	Hcoordinate	Horizontal Datum	Vertical Datum

3.3 Data sources, tools and software

3.3.1 Data sources

The data used for the study was acquired from different sources as shown in Table 3-7.

Table 3-7: Data and data sources

Data	**Source**	**Characteristics**	**Purpose**
Registry Index Map (Machakos municipality Block 2)	Survey of Kenya, Ruaraka	Raster format Scale 1:2500	Creation of a cadastral base map
Topographic Map	Survey of Kenya, Ruaraka	Raster format	Georeferencing
FR	Survey of Kenya, Ruaraka	Raster format	Used for extraction of attribute data

Table 3-8: Summary of hardwares used

Item No	**Hardware**
1	LENOVO Laptop (Intel core 7 duo processor 2.3 GHz, 8GB RAM memory,)
2	Master Excel Scanner
3	Printer (Canon IPF8300S)
4	Handheld GPS

Table 3-9: Summary of Softwares used

Software	Purpose
ArcGIS 10.5	Georeferencing and digitization of the RIM, Querying of the database
Draw.io	Designing of the data model
Microsoft Access	Development of the database
Microsoft Word	Report typing and editing

3.3.2 Data Preparation

This involves data evaluation, scanning, geo-referencing and digitization in order to convert the data into a digital form that is compatible with the system.

3.3.3 Data Evaluation

The collected data was evaluated for anomaly, validity and consistency before further processing was done. The parcel numbers were checked manually and those that were not visible on the analogue plan were verified and rectified. Roads, streets and lanes names were also verified on the ground and with the use of Google maps.

3.3.4 Data Scanning

The acquired RIM and FR were in analogue format and in order to convert them to digital format they had to be scanned. Scanning is a data capture process by which data is digitized in the raster format using a scanner. The scanner senses the binary grey tones or colour values of the analogue data and outputs them as a series of pixels in parallel scan lines. The plans were scanned with master excel scanner and saved as an image file in jpeg format. The scanned RIM of Machakos town is shown in Figure 3-3

Figure 3-3: A scanned FR map

3.3.5 Coordinate Transformation

The cadastral plans for the study area acquired from the Survey of Kenya were in Cassini-Soldner projection and were transformed to UTM (arc 1960 datum) coordinate system for use with the GIS system which operates in UTM projection. In order to determine the four transformation parameters used to convert Cassini coordinates to UTM coordinates, transformation equations were used. The four parameters are ;Two translations in N and E ,a uniform scale factor and a rotation angle .The conversion requires use of four corresponding points both in Cassini and UTM coordinates. The four points used were corner points of the topographical map sheet 149_3 and were acquired from Survey of Kenya. The transformation equations are:

E= aX-bY+Tx

N= bX+aY+Ty

Where E and N are the Eastings and Northings UTM coordinates respectively, whereas X and Y are the Cassini coordinates of the corresponding point, a and b are constants, Tx is translation along the x-axis and Ty is translation along the y-axis. The corner points used are provided in the Table 3-10.

Table 3-10: Transformation Corner points

	Cassini Soldner coordinates		UTM coordinates	
Point_ID	**(Y)**	**(X)**	**UTM(E)**	**UTM(N)**
1	72731.1	-508499.9	299,727.10	9,845,195.00
2	90986.2	-508501.7	305,292.10	9,845,199.20
3	90984	-526638.2	305,296.90	9,839,670.60
4	72729.5	-526636.5	299,732.10	9,839,666.20

The following parameters were derived using the least square adjustment method and were used to transform the Cassini coordinates into the local UTM coordinates.

The parameters were then used to derive UTM coordinates of the parcels of the area of study.

a=	0.304841658	b=	0.00028332180
Tx=	277411.7744	Ty=	10000186.1727

Table 3-11: Grid Coordinates for RIM

Points	Cassini (Y) (ft)	Cassini (X) (ft)	UTM (N) (m)	UTM (E) (m)
1	-550,000.00	96,000.00	9,832,550.23	306,832.17
2	-550,000.00	100,000.00	9,832,551.29	308,051.53
3	-553,000.00	100,000.00	9,831,636.77	308,052.33
4	-553,000.00	96,000.00	9,831,635.70	306,832.97

Table 3-12: Transformed boundary Coordinates for FR (538_591)

Points	Cassini (Y)	Cassini (X)	UTM (N)	UTM (E)
NK2	-168,626.76	29,488.61	307,060.87	9,831,563.53
NK1	-168,689.16	29,670.14	307,242.48	9,831,501.28
H30	-168,778.86	29,650.81	307,223.23	9,831,411.55
H30	-168,790.27	29,665.95	307,238.38	9,831,400.15
P2	-168,649.48	29,473.57	307,045.85	9,831,540.80
P9	-168,718.47	29,555.79	307,128.14	9,831,471.87
P12	-168,774.82	29,553.46	307,125.86	9,831,415.51

3.3.6 Geo-referencing

The scanned RIM and FR were not referenced and therefore the need for Georeferencing in order to have the true ground position of the features once digitized. Georeferencing simply involves selecting a pixel on the raster image and specifying what coordinate it represents on the ground by use of known ground control points (GCPs). This registration must be accurate for proper representation of features as well as overlapping other layers. This is ensured by maintaining the RMS error to the minimum. Four Ground Control Points (GCPs) were used in a four-parameter transformation that takes care of rotation, scale and all translations in X and Y direction. The four GCP used were obtained from the survey plans

The scanned raster image was added to Arc-Map and four corner points were identified on the scanned plans and their coordinates noted. These were the first intersections of the Northings and Eastings on the four corners of the plans and served as the GCPs (Ground Control Points). The four identified GCP were input subsequently in the GCP entry for georeferencing and the projection was specified. The fully Geo-referenced plans were saved and added to the Arc Map for manipulation.

3.3.7 Digitization

The acquired spatial data was in analogue form, hence the need for digitisation to convert the raster image to vector data. This is for the purpose of computer compatibility and data manipulation. The Scanned image was loaded to ArcMap and different shapefiles were created for different features. Projected Coordinate System, Arc_1960_UTM_Zone_37S was used during digitisation. Different spatial entities were used for digitisation, and this was based on the features on the plan and the scale in which the data was to be presented. Polylines were used to represent features that are linear in nature, for example roads and administrative boundaries. Polygons represented a closed set of lines and were used to define features such as parcels. Points were used to define beacons. The features on the scanned raster image were digitised by tracing them hence creating a vector copy of the features.

3.3.8 Creation of a Geodatabase

A Geodatabase is a collection of geographic datasets of various types held in a common file system folder. A geodatabase contains three primary dataset types:

- Feature classes
- Raster datasets
- Tables

A personal Geodatabase was created in Arccatalog through connection to a MSC project folder in Drive C. The Geodatabase was named cadastral data model and in it a feature dataset called project was created. In the project feature dataset parcels, selected plots and roads feature classes were created the shapefiles that had been created in the digitisation process were then imported into Cadastral Data model Geodatabase.

3.3.9 Data Editing

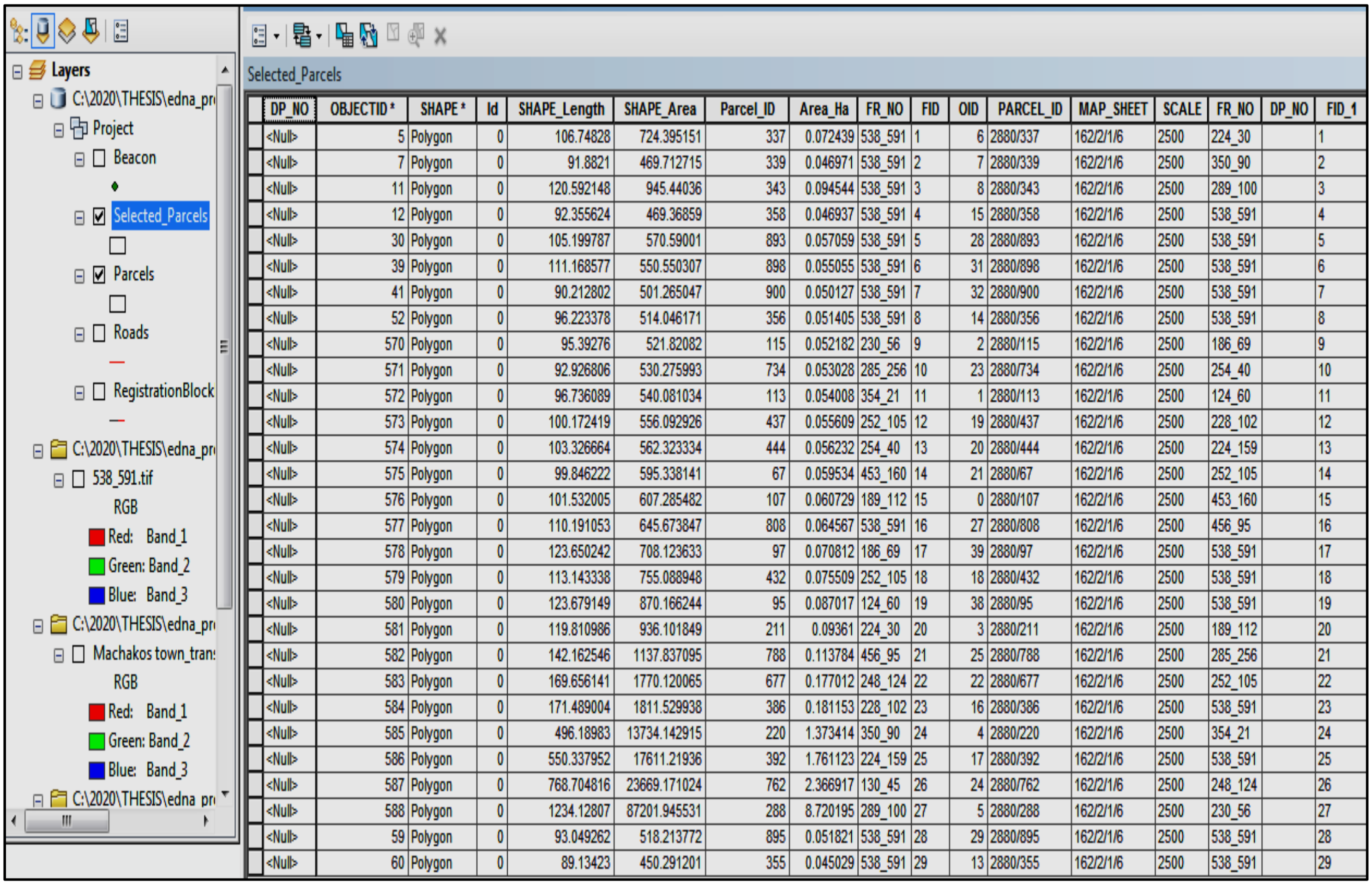
The digitization process always introduces some errors which include gaps, silvers disclosure, overshoots and undershoots. The following tasks were performed to edit the data:

- Error correction
- Entering missing data
- Building topology

3.3.10 Linking of the MS Access tables to the ArcGIS

ArcMap 10.5 does not allow a direct link with Ms Access tables therefore the attribute tables were exported as database files which are permissible to ArcMap environment, and then added to Arcmap. In ArcMap there are two ways to link data stored in tables with the spatial features: joins and relates. When you join two tables, you append the attributes from one table to another using a common field in both. When relating tables, you define the relationship between the two tables also based on a common field, but you don't append the attributes of one table to the other; rather, you are able to access the related data when necessary. The added tables were linked to the parcel data through creation of a join for each attribute table; this was done through the use of Object_ID which is a common field in all the tables and also in the parcel data. Figure 3-4 shows how the joins were made.

Figure 3-4: Shows joining of the tables



DP_NO	OBJECTID *	SHAPE *	Id	SHAPE_Length	SHAPE_Area	Parcel_ID	Area_Ha	FR_NO	FID	OID	PARCEL_ID	MAP_SHEET	SCALE	FR_NO	DP_NO	FID_1
<Null>	5	Polygon	0	106.74828	724.395151	337	0.072439	538_591	1	6	2880/337	162/2/1/6	2500	224_30		1
<Null>	7	Polygon	0	91.8821	469.712715	339	0.046971	538_591	2	7	2880/339	162/2/1/6	2500	350_90		2
<Null>	11	Polygon	0	120.592148	945.44036	343	0.094544	538_591	3	8	2880/343	162/2/1/6	2500	289_100		3
<Null>	12	Polygon	0	92.355624	469.36859	358	0.046937	538_591	4	15	2880/358	162/2/1/6	2500	538_591		4
<Null>	30	Polygon	0	105.199787	570.59001	893	0.057059	538_591	5	28	2880/893	162/2/1/6	2500	538_591		5
<Null>	39	Polygon	0	111.168577	550.550307	898	0.055055	538_591	6	31	2880/898	162/2/1/6	2500	538_591		6
<Null>	41	Polygon	0	90.212802	501.265047	900	0.050127	538_591	7	32	2880/900	162/2/1/6	2500	538_591		7
<Null>	52	Polygon	0	96.223378	514.046171	356	0.051405	538_591	8	14	2880/356	162/2/1/6	2500	538_591		8
<Null>	570	Polygon	0	95.39276	521.82082	115	0.052182	230_56	9	2	2880/115	162/2/1/6	2500	186_69		9
<Null>	571	Polygon	0	92.926806	530.275993	734	0.053028	285_256	10	23	2880/734	162/2/1/6	2500	254_40		10
<Null>	572	Polygon	0	96.736089	540.081034	113	0.054008	354_21	11	1	2880/113	162/2/1/6	2500	124_60		11
<Null>	573	Polygon	0	100.172419	556.092926	437	0.055609	252_105	12	19	2880/437	162/2/1/6	2500	228_102		12
<Null>	574	Polygon	0	103.326664	562.323334	444	0.056232	254_40	13	20	2880/444	162/2/1/6	2500	224_159		13
<Null>	575	Polygon	0	99.846222	595.338141	67	0.059534	453_160	14	21	2880/67	162/2/1/6	2500	252_105		14
<Null>	576	Polygon	0	101.532005	607.285482	107	0.060729	189_112	15	0	2880/107	162/2/1/6	2500	453_160		15
<Null>	577	Polygon	0	110.191053	645.673847	808	0.064567	538_591	16	27	2880/808	162/2/1/6	2500	456_95		16
<Null>	578	Polygon	0	123.650242	708.123633	97	0.070812	186_69	17	39	2880/97	162/2/1/6	2500	538_591		17
<Null>	579	Polygon	0	113.143338	755.088948	432	0.075509	252_105	18	18	2880/432	162/2/1/6	2500	538_591		18
<Null>	580	Polygon	0	123.679149	870.166244	95	0.087017	124_60	19	38	2880/95	162/2/1/6	2500	538_591		19
<Null>	581	Polygon	0	119.810986	936.101849	211	0.09361	224_30	20	3	2880/211	162/2/1/6	2500	189_112		20
<Null>	582	Polygon	0	142.162546	1137.837095	788	0.113784	456_95	21	25	2880/788	162/2/1/6	2500	285_256		21
<Null>	583	Polygon	0	169.656141	1770.120065	677	0.177012	248_124	22	22	2880/677	162/2/1/6	2500	252_105		22
<Null>	584	Polygon	0	171.489004	1811.529938	386	0.181153	228_102	23	16	2880/386	162/2/1/6	2500	538_591		23
<Null>	585	Polygon	0	496.18983	13734.142915	220	1.373414	350_90	24	4	2880/220	162/2/1/6	2500	354_21		24
<Null>	586	Polygon	0	550.337952	17611.21936	392	1.761123	224_159	25	17	2880/392	162/2/1/6	2500	538_591		25
<Null>	587	Polygon	0	768.704816	23669.171024	762	2.366917	130_45	26	24	2880/762	162/2/1/6	2500	248_124		26
<Null>	588	Polygon	0	1234.12807	87201.945531	288	8.720195	289_100	27	5	2880/288	162/2/1/6	2500	230_56		27
<Null>	59	Polygon	0	93.049262	518.213772	895	0.051821	538_591	28	29	2880/895	162/2/1/6	2500	538_591		28
<Null>	60	Polygon	0	89.13423	450.291201	355	0.045029	538_591	29	13	2880/355	162/2/1/6	2500	538_591		29

Figure 3-5: Attribute table after joining the selected plots and reference table

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the discussion of results based on the specific objectives of this project. The discussion is divided into the three main areas; Results from the review of the efforts on development of NLIS in Kenya, designing and creation of the cadastral data model and development of the cadastral database for Machakos town based on the developed cadastral data model.

4.2 Results on the review of efforts on development of NLIS in Kenya

The Ministry of Lands and Physical Planning has previously maintained a manual system of land records management. Initial efforts towards computerization were disparate and driven by each of the departments within the Ministry. After formulation of the National Land Policy, there was a push for a comprehensive and coordinated approach towards establishing a modern LIMS. This was to provide the core datasets for a National Spatial Data Infrastructure (NSDI) for the country.

The following are the previous efforts by the Ministry of lands and Physical Planning in development of a NLIMS;

i. The launch of the Land Reform support Programme, 2006.
ii. The launch of the Rapid Results Initiative programme, 2007.
iii. Launch of the Project for Improving Land Administration in Kenya (PILAK), 2009.
iv. Formulation of the National Land Policy, 2009.
v. Promulgation of the Constitution of Kenya, 2010.
vi. Enactment of laws and regulations governing land administration in Kenya, which include the National Land Commission, Land Act(2012), Land Registration Act(2012),Community Land Act(2016) ,Survey Act(Cap 299) , Sectional Property bill (2018), Access to Information Act (2016) and Registration of Documents Act (CAP285 among others.
vii. The development of Public Land Information System

In the fulfilment of the Big 4 Agenda and attainment of Kenya's Vision 2030 the Ministry of Lands and Physical planning also launched the digitization of land records to come up with a digital

LIMS. This marked the commencement of digitization of 57 land registries which had been keeping manual records since 1895.The ministry has so far been able to digitise 16 of the land registries, Nairobi and central registries being the first to be completed The digitisation program has led to what could be termed as the initial implementation of the NLIS.

The ministry of lands and physical planning in the year 2016 appointed a taskforce to come up with recommendations on how to set up NLIMS. The task force came up with the following recommendations;

(i) A stable policy and legal framework
(ii) A data model to support the NLIMS
(iii) Distinct interoperable sub-systems i.e. Cadastre, Valuation, Physical Planning, Land Adjudication & Settlement, Land Administration and Land Registry.
(iv) Review of current legal framework
(v) Adequate infrastructure (software, hardware, human resource)
(vi) System Rollout (pilot project)
(vii) Financing of the System
(viii) Country wide mapping and geo-referencing

Despite the above efforts by the ministry of lands and physical planning, Kenya still lacks a digital NLIS. Land administration operates on a manual system which has exhibited the following weaknesses; Poor land records management, a Non-integrated approach (lack of collaboration between various spatial information stakeholders), opaque to current advances in technology (slow adoption to new technology), inefficient system administration (centralised and bureaucratic) and low cadastral coverage among others.

The spatial aspect which is a major component of the NLIS has not been given much attention. The spatial data is still in analogue form, the cadastral coverage is still low at 20% as 80% is on general boundaries. The system is far from being modernised as most of the above recommendations by the task force have not been rolled out.

At the county level and especially in Machakos County the efforts on development of NLIS are very minimal. The system is manual based though the registry records have been digitised. The spatial data is analogue and the cadastral coverage is very low.

4.3 Results of designing and creation of a cadastral data model

4.3.1 Distribution of Respondents

As indicated in the external modelling, the mains groups that were used as respondents were the departments in the Ministry of Lands and physical planning, members of Teleposta Sacco, Lawyers, Valuers and Surveyors, and members of the public who frequently use the cadastral data. In total, fifty (50) questionnaires were administered but feedback was received from only 45 interviewees who were distributed as follows; Government officials 25%, members of public37%, and professionals 38%. Figure 4-1 shows the distribution in a pie chart.

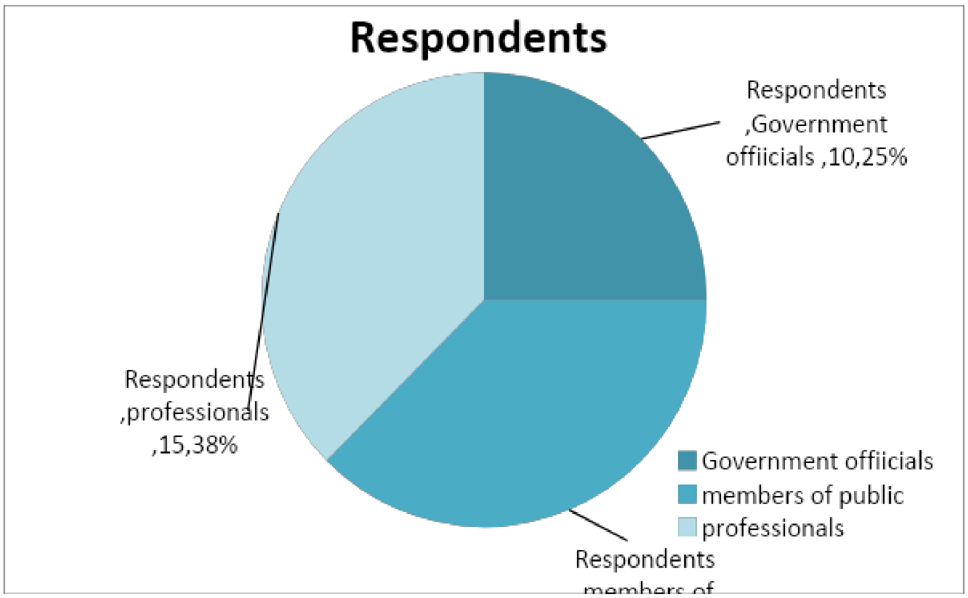


Figure 4-1: Distribution of respondents

4.3.2 Requirements of the respondents

Out of the respondents interviewed different groups had different requirements and the results are shown in Table 4-1.

Table 4-1: Respondents Requirement

Requirements	Number of respondents	Percentage %
Acreage	15	37
Cadastral plans	10	20
Locality	12	25
Projection	8	18
Total	**45**	**100**

4.3.3 Preferences of members of the public

Out of the total number of members of the public interviewed, 53%were more concerned with knowing the acreage, 20% were interested in knowing the cadastral plan number (FR No) and 27% were interested in the locality of the parcel. The analysis is shown in Table 4-2.

Table 4-2:Ppreferences of members of public

Category	**Respondents**	**Percentage**
Acreage	8	53%
Cadastral plan number	3	20%
locality	4	27%
Total	**15**	**100%**

4.3.4 Preferences of professionals

Surveyors were interested in knowing the locality, boundary beacons, the coordinate system, and acreage and survey plan number. Valuers were interested in knowing the acreage, survey plans number and locality. Data to be included in the database was informed by the views of the users interviewed who frequently interact with cadastral data.

4.3.5 Conceptual and logical modelling

After analysing the users' views, different entities, their attributes and their relationships were determined. The entities were assigned primary keys and an E-R diagram was drawn. The relational tables according to the entities, attributes and relations identified from the conceptual modelling were designed and normalised.

Table 4-3: Cadastral Survey Class

Parcel_ ID	Survey ID	Comps No	File Reference No	Field book No	Instrument	Survey date	Status	authority

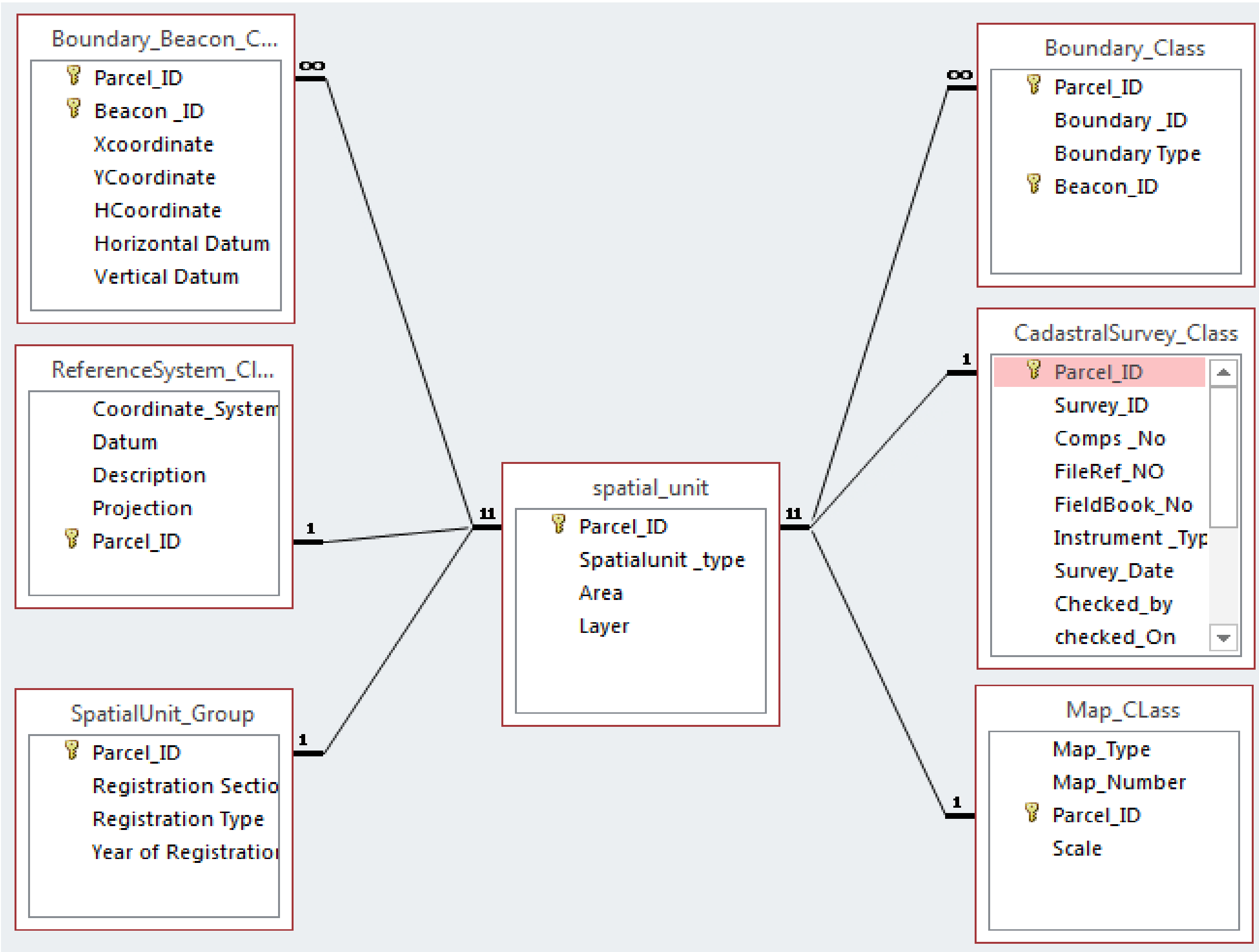


Figure 4-2: Relationships as created in MS Access

4.3.6 Physical Modelling

In this study, the designed cadastral model was implemented in part of Machakos town. The designed tables were populated with data and linked to the spatial data through join in Arcmap 10.5 where the database could be queried. The populated Cadastral Survey table is shown in Figure 4-3.

PARCEL_ID	COMPS__NO	FILEREF_NO	FIELDBOOK	SURVEY_DAT	CHECKED_BY	CHECKED_ON	VERIFIED_B	VERIFIED_	APPROVED_B	APPROVED_O	LOCALITY
2880/107	65040	CT50/30/45	W.C	11/06/1993	P. Omollo	17/06/2020	M.Akinyi	17/06/2020	D.Njeru	15/09/2020	Machakos Municipality
2880/113	40452	CT50/30/43	W.C	27/11/2012	E.Maina	15/09/2020	P.wanyama	15/09/2020	P.wanyama	19/01/2020	Machakos Municipality
2880/115	35271	CT50/32/45	W.C	19/11/2003	C.Odhiambo	19/01/2020	E.Kitonga	19/01/2020	E.Kitonga	26/10/2018	Machakos Municipality
2880/211	15268	CT51/30/46	W.C	01/01/2020	D.Wangui	26/10/2018	F.Ngugi	26/10/2018	F.Ngugi	13/01/2020	Machakos Municipality
2880/220	65045	CT52/31/42	W.C	17/06/2020	P.wanyama	13/01/2020	W.Kiongo	13/01/2020	W.Kiongo	01/01/2019	Machakos Municipality
2880/288	65034	CT50/30/47	W.C	15/09/2020	E.Kitonga	01/01/2019	G.Musyoka	01/01/2019	G.Musyoka	12/07/2016	Machakos Municipality
2880/337	55030	CT50/30/42	W.C	19/01/2020	F.Ngugi	12/07/2016	F.Obwoma	12/07/2016	F.Obwoma	17/04/2000	Machakos Municipality
2880/339	23076	CT50/30/35	W.C	26/10/2018	W.Kiongo	17/04/2000	T.Mutua	17/04/2000	T.Mutua	17/06/2020	Machakos Municipality
2880/343	45098	CT50/31/35	W.C	13/01/2020	G.Musyoka	08/05/1985	J.Wambua	17/06/2020	J.Wambua	15/09/2020	Machakos Municipality
2880/346	12509	CT50/30/36	W.C	01/01/2019	F.Obwoma	24/02/2012	S.Wasua	15/09/2020	S.Wasua	19/01/2020	Machakos Municipality
2880/348	12409	CT50/25/35	W.C	12/07/2016	T.Mutua	24/11/2013	P. Omollo	19/01/2020	P. Omollo	26/10/2018	Machakos Municipality
2880/350	65430	CT50/28/35	W.C	17/04/2000	J.Wambua	11/06/1993	E.Maina	26/10/2018	P.wanyama	13/01/2020	Machakos Municipality
2880/352	45670	CT50/27/35	W.C	08/05/1985	P. Omollo	27/11/2012	C.Odhiambo	13/01/2020	E.Kitonga	01/01/2019	Machakos Municipality
2880/355	78900	CT50/28/22	W.C	24/02/2012	E.Maina	19/11/2003	D.Wangui	01/01/2019	F.Ngugi	12/07/2016	Machakos Municipality
2880/356	98760	CT50/18/22	W.C	24/11/2013	C.Odhiambo	01/01/2020	P.wanyama	12/07/2016	W.Kiongo	17/04/2000	Machakos Municipality
2880/358	12340	CT50/13/22	W.C	11/06/1993	D.Wangui	17/06/2020	E.Kitonga	17/04/2000	G.Musyoka	17/06/2020	Machakos Municipality
2880/386	34560	CT50/13/20	W.C	27/11/2012	P.wanyama	15/09/2020	F.Ngugi	17/06/2020	F.Obwoma	15/09/2020	Machakos Municipality
2880/392	45671	CT50/14/22	W.C	19/11/2003	E.Kitonga	19/01/2020	W.Kiongo	15/09/2020	T.Mutua	19/01/2020	Machakos Municipality
2880/432	57903	CT50/15/22	W.C	01/01/2020	F.Ngugi	26/10/2018	G.Musyoka	19/01/2020	J.Wambua	26/10/2018	Machakos Municipality
2880/437	34023	CT50/40/22	W.C	17/06/2020	W.Kiongo	13/01/2020	F.Obwoma	26/10/2018	S.Wasua	13/01/2020	Machakos Municipality
2880/444	12670	CT50/22/22	W.C	15/09/2020	G.Musyoka	01/01/2019	T.Mutua	13/01/2020	P. Omollo	01/01/2019	Machakos Municipality
2880/67	32670	CT50/22/28	W.C	19/01/2020	F.Obwoma	13/01/2020	J.Wambua	01/01/2019	E.Maina	12/07/2016	Machakos Municipality
2880/677	49230	CT50/22/30	W.C	26/10/2018	T.Mutua	01/01/2019	S.Wasua	12/07/2016	C.Odhiambo	17/04/2000	Machakos Municipality
2880/734	75240	CT50/22/31	W.C	13/01/2020	J.Wambua	12/07/2016	P. Omollo	17/04/2000	D.Wangui	15/09/2020	Machakos Municipality

Figure 4-3: A populated Cadastral survey class table

The cadastral survey class table stores data related to cadastral survey. The file reference number is given once a surveyor submits his/her cadastral work to the director of surveys for approval this can be used in the cadastral database for tracking the progress of the approval or for retrieval of data of a particular parcel. The survey date is also indicated in the table and it's useful especially when finding out when a particular parcel was registered or when the RIM was amended .The date of checking and also the checking officer of the computation file of a particular survey are also shown and they are equally important in the database since it will be easier to find out the status of a particular parcel of land.

4.4 Results of development of the cadastral database

4.4.1 Cadastral Map

A Cadastral map for Machakos Town was created and is shown in Figure 4-4.

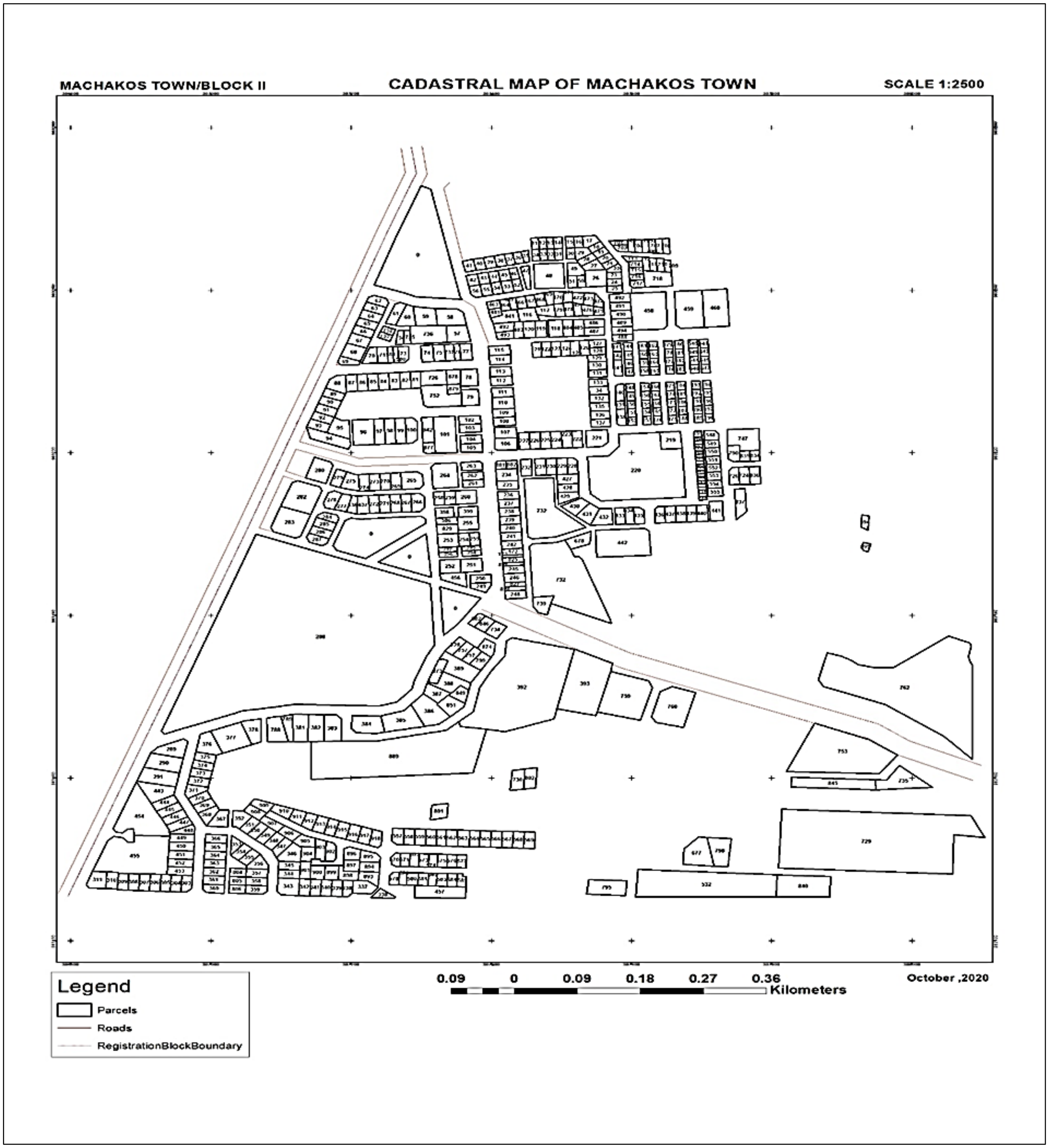


Figure 4-4: A Cadastral map for Machakos Town

4.5 Querying of the database

To test the database some queries were done with SQL statements and the results of querying the parcels within a FR number are shown in Figure 4-5. The SQLstatement for the above query as follows:

Select: <Parcel_ID>

From: <Selected_parcels>

Where: <FR_No =538_591>

Figure 4-5: Parcels within FR No538_591

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study sought to design and develop a cadastral data model for part of Machakos town in Machakos County. The main concern of the study was, despite the efforts the government has put in developing a Land Information Management System Kenya still lacks a cadastral data model which is a key component of LIMS. It is expected that the results of this study will act as a reference point for development of a National cadastral data model.

5.2 Conclusions

In view of the results of this study the following conclusions have been drawn:

- The efforts on development of the NLIMS have not been exhaustive, all components of the NLIMS have not been factored in. The efforts have been biased, focusing on the land records and ignoring the spatial component which is a key player in the development of NLIMS. This has contributed to the lack of a National Land Information Management System in Kenya.
- The LADM provides a good starting point to cadastral data modelling and development of a National land information management system. Though the cadastral data model based on the LADM is not conclusive since it only supports the fixed boundaries and doesn't accommodate the general boundaries hence the need for its modification.
- The cadastral data model provided a point of reference in development of a cadastral database for Machakos town. The database enhances elimination of data redundancy and ensures data integrity and accuracy: This is because the same piece of data was not stored in more than one place.

5.3 Recommendations

Although good results have been obtained in this study, the following recommendations have been identified.

(i) The efforts to develop a NLIMS should be exhaustive, incorporating all the components of the LIMS.

(ii) Development of Cadastral data models which accommodates both the fixed and general boundaries for all the county governments and which in turn should influence development of a national cadastral data model.

(iii) The Mapping of the spatial unit Group in the Kenyan Cadastre since this has not been fully described in previous studies

(iv) Georeferencing of all the boundaries countrywide as this will improve accuracy and enhance the development of a national cadastral data model.

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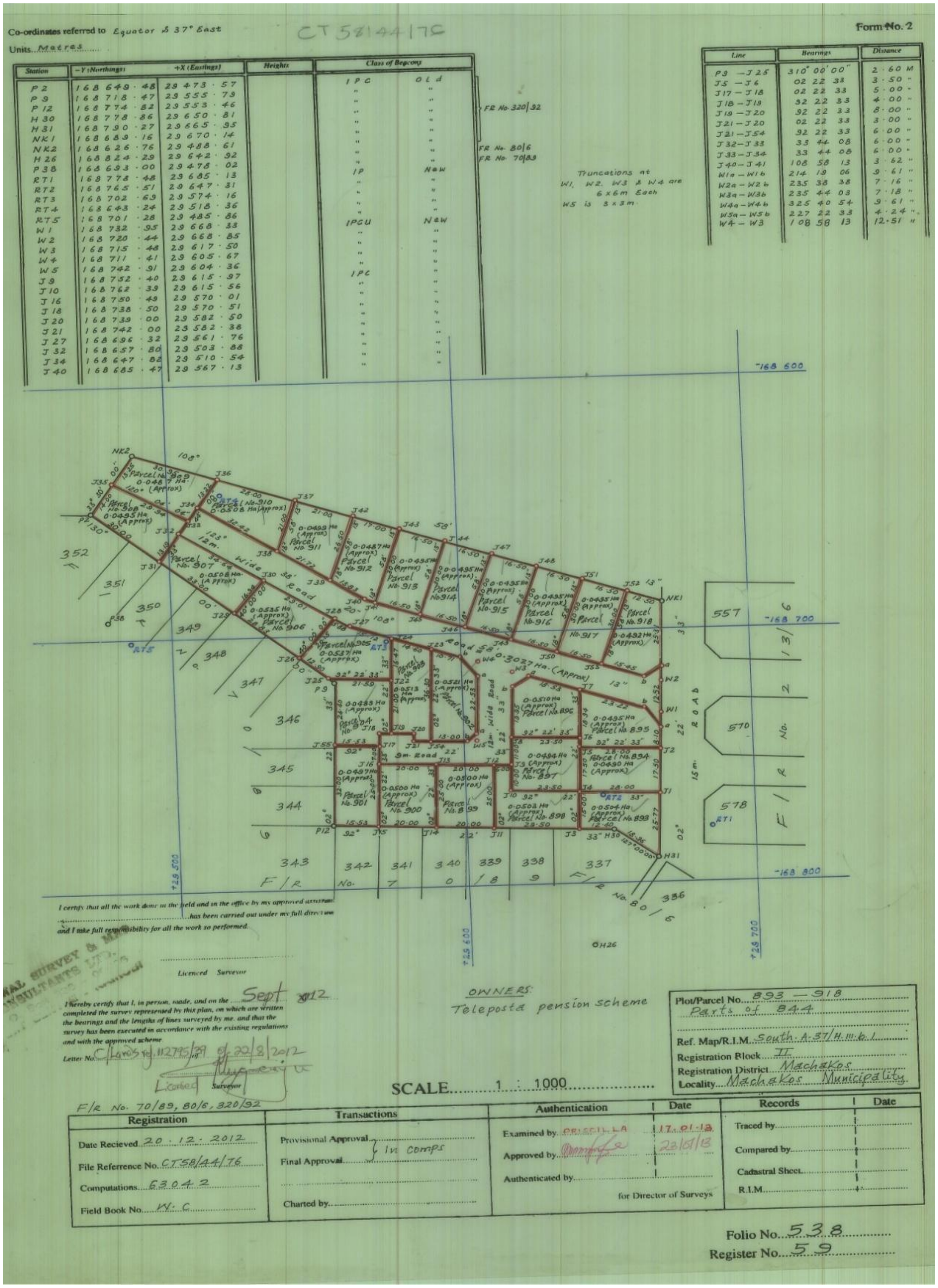
APPENDICES

Appendix 1.1 Scanned RIM for Machakos municipality Block 2

Appendix 1.2 Scanned FRNo 539/591



Appendix 1.3 Boundary class table

Parcel_ID	Boundary Type	Beacon_ID
2880/211	Fixed	B2
2880/905	Fixed	B23
2880/895	Fixed	B28
2880/913	Fixed	C12
2880/915	Fixed	C23
2880/346	Fixed	C23
2880/918	Fixed	C24
2880/95	Fixed	C28
2880/97	Fixed	C9
2880/909	Fixed	D10
2880/808	Fixed	D15
2880/339	Fixed	D2
2880/392	Fixed	D23
2880/900	Fixed	D29
2880/343	Fixed	D4
2880/893	Fixed	D9
2880/356	Fixed	F34
2880/762	Fixed	G5
2880/788	Fixed	H23
2880/107	Fixed	J1
2880/898	Fixed	J13
2880/896	Fixed	J17
2880/358	Fixed	J2
2880/386	Fixed	J4
2880/806	Fixed	J6
2880/220	Fixed	K12
2880/355	Fixed	K20
2880/432	Fixed	M1
2880/437	Fixed	M3
2880/444	Fixed	M5
2880/115	Fixed	N12
2880/677	Fixed	N20
2880/67	Fixed	N23
2880/113	Fixed	P15
2880/350	Fixed	P28
2880/352	Fixed	P29
2880/348	Fixed	P30
2880/288	Fixed	S1
2880/337	Fixed	S2
2880/734	Fixed	W78

Appendix 1.4 Map class table

Parcel_ID	Map_Sheet	Scale	FR_No
2880/107	162/2/1/6	2500	453_160
2880/113	162/2/1/6	2500	124_60
2880/115	162/2/1/6	2500	186_69

2880/211	162/2/1/6	2500	189_112
2880/220	162/2/1/6	2500	354_21
2880/288	162/2/1/6	2500	230_56
2880/337	162/2/1/6	2500	224_30
2880/339	162/2/1/6	2500	350_90
2880/343	162/2/1/6	2500	289_100
2880/346	162/2/1/6	2500	538_591
2880/348	162/2/1/6	2500	538_591
2880/350	162/2/1/6	2500	538_591
2880/352	162/2/1/6	2500	538_591
2880/355	162/2/1/6	2500	538_591
2880/356	162/2/1/6	2500	538_591
2880/358	162/2/1/6	2500	538_591
2880/386	162/2/1/6	2500	538_591
2880/392	162/2/1/6	2500	538_591
2880/432	162/2/1/6	2500	538_591
2880/437	162/2/1/6	2500	228_102
2880/444	162/2/1/6	2500	224_159
2880/67	162/2/1/6	2500	252_105
2880/677	162/2/1/6	2500	252_105
2880/734	162/2/1/6	2500	254_40
2880/762	162/2/1/6	2500	248_124
2880/788	162/2/1/6	2500	285_256
2880/806	162/2/1/6	2500	130_45
2880/808	162/2/1/6	2500	456_95
2880/893	162/2/1/6	2500	538_591
2880/895	162/2/1/6	2500	538_591
2880/896	162/2/1/6	2500	538_591
2880/898	162/2/1/6	2500	538_591
2880/900	162/2/1/6	2500	538_591
2880/905	162/2/1/6	2500	538_591
2880/909	162/2/1/6	2500	538_591
2880/913	162/2/1/6	2500	538_591
2880/915	162/2/1/6	2500	538_591
2880/918	162/2/1/6	2500	538_591
2880/95	162/2/1/6	2500	538_591
2880/97	162/2/1/6	2500	538_591

Appendix 1.5 ReferenceSystem_Class table

Parcel_ID	Coordinate System	Datum	Description	Projection
2880/107	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/113	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/115	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/211	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/220	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/288	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/337	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/339	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/343	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator

2880/346	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/348	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/350	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/352	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/355	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/356	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/358	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/386	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/392	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/432	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/437	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/444	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/67	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/677	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/734	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/762	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/788	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/806	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/808	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/893	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/895	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/896	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/898	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/900	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/905	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/909	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/913	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/915	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/918	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/95	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator
2880/97	Projected	Arc 1960	UTM ZONE 37S	Transverse_Mercator

Appendix 1.6 SpatialUnit_Group class table

Parcel_ID	Registration Section	Registration Type	Year of Registration
2880/107	Machakos Central	Machakos/misakwani	2013
2880/113	Machakos Central	Machakos/misakwani	2000
2880/115	Machakos central	Machakos/misakwani	2011
2880/211	Machakos central	Machakos/misakwani	1992
2880/220	Machakos Central	Machakos/misakwani	2014
2880/288	Machakos Central	Machakos/misakwani	1994
2880/337	Machakos central	Machakos/misakwani	1995
2880/339	Machakos Central	Machakos/misakwani	1999
2880/343	Machakos Central	Machakos/misakwani	2013
2880/346	Machakos Central	Machakos/misakwani	2000
2880/348	Machakos central	Machakos/misakwani	2011
2880/350	Machakos Central	Machakos/misakwani	2012
2880/352	Machakos central	Machakos/misakwani	1990
2880/355	Machakos Central	Machakos/misakwani	1996
2880/356	Machakos central	Machakos/misakwani	1998

2880/358	Machakos Central	Machakos/misakwani	1993
2880/386	Machakos central	Machakos/misakwani	1992
2880/392	Machakos central	Machakos/misakwani	1994
2880/432	Machakos Central	Machakos/misakwani	1995
2880/437	Machakos Central	Machakos/misakwani	1999
2880/444	Machakos central	Machakos/misakwani	2013
2880/67	Machakos Central	Machakos/misakwani	1994
2880/677	Machakos Central	Machakos/misakwani	2000
2880/734	Machakos Central	Machakos/misakwani	2011
2880/762	Machakos Central	Machakos/misakwani	2012
2880/788	Machakos central	Machakos/misakwani	1990
2880/806	Machakos Central	Machakos/misakwani	1996
2880/808	Machakos Central	Machakos/misakwani	1998
2880/893	Machakos central	Machakos/misakwani	1993
2880/895	Machakos Central	Machakos/misakwani	1992
2880/896	Machakos Central	Machakos/misakwani	2014
2880/898	Machakos central	Machakos/misakwani	1994
2880/900	Machakos Central	Machakos/misakwani	2012
2880/905	Machakos Central	Machakos/misakwani	1990
2880/909	Machakos central	Machakos/misakwani	1996
2880/913	Machakos Central	Machakos/misakwani	1995
2880/915	Machakos Central	Machakos/misakwani	1998
2880/918	Machakos Central	Machakos/misakwani	1993
2880/95	Machakos Central	Machakos/misakwani	1995
2880/97	Machakos central	Machakos/misakwani	1999

Appendix 1.7 Spatial unit class table

Parcel_ID	Area_Ha
2880/107	0.06
2880/113	0.05
2880/115	0.05
2880/211	0.09
2880/220	0.09
2880/288	0.05
2880/337	0.04
2880/339	0.06
2880/343	0.05
2880/346	0.05
2880/348	0.05
2880/350	0.18
2880/352	1.76
2880/355	0.08
2880/356	0.06
2880/358	0.06
2880/386	0.18

2880/392	0.05
2880/432	2.37
2880/437	0.11
2880/444	0.04
2880/67	0.06
2880/677	0.06
2880/734	0.06
2880/762	0.05
2880/788	0.05
2880/806	0.06
2880/808	0.05
2880/893	0.05
2880/895	0.05
2880/896	0.05
2880/898	0.05
2880/900	0.09
2880/905	1.37
2880/909	8.72
2880/913	0.05
2880/915	0.07
2880/918	0.05
2880/95	0.09
2880/97	0.07