ACCURACY ASSESSMENT OF PRELIMINARY INDEX DIAGRAMS (PIDs) FROM HIGH RESOLUTION ORTHOIMAGE

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DECLARATION

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

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DEDICATION

This thesis is dedicated to all my family members and friends, especially my wife; Margaret Mwende Ondulo who has been very patient and supportive.

I thank them all for their support, encouragement and patience in all the years of my study.

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ABSTRACT

Land tenure reforms and modernization to conform to current land management and development demands remain a challenge facing developing countries today. Promotion of land titling is the starting point to achieve this target. Land titling exercise relies on some form of description and/or rough sketches known as cadastral maps. In Kenya, various types of cadastral maps have been used for land administration; the most famous being Registry Index Maps (RIMs). This is due to their ease of production by simple surveying techniques and air survey methods. RIMs produced from unrectified photographs referred to as Preliminary Index Diagrams (PIDs) were initially intended as a temporary measure to speed up land registration in the rural areas pending preparation of more accurate documents, are still in use today. This has resulted in unreliable and lack of up to-date survey information relating to property boundaries in the majority of rural parts of Kenya.

In this context, the study investigated a new system that would facilitate quick production of reliable, accurate and up to-date cadastral maps for land administration. Earlier studies recommended the use of high spatial resolution satellite imagery such as QuickBird amongst many others. The study investigated the potential use of high spatial resolution QuickBird satellite imagery data for cadastral surveying. Three types of data were integrated to provide the database; namely QuickBird orthoimage, aerial digital orthophoto and measurements of parcels from RIMs. The evaluation was made by statistically comparing parcel areas from the official PID Area List, orthophoto and QuickBird satellite orthoimage.

Double tailed t-statistics was used to assess for any difference in areas. The results at 99% confidence interval ($p = 0.01$) indicated that there was no significant difference between parcel areas from orthophoto and satellite orthoimage while there was significant difference between PID and orthophoto areas. Good results were obtained for large and medium parcels with an average area difference of 0.3% and 1.0% respectively and 2.6% for small parcels. However, with regard to the minimum requirements for a Land Registry Index Map to be of sufficient accuracy to perform its core functions of parcel identification, boundary relocation, mutation surveys and area computation, it can be reasonably concluded that PIDs from QuickBird orthoimage at a scale of 1:5000 met these requirements. Therefore, the study has demonstrated that high spatial resolution QuickBird satellite imagery data can be used as an input for indirect land surveying methodology.

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1 INTRODUCTION

1.1 Introduction

This chapter gives a brief introduction to the topic and the motivation for the research. It states the problem that this thesis intends to tackle, and the aims and scope of the research.

1.2 Study Background

The importance of land in an agricultural economy needs no emphasis. It constitutes the primary form of wealth and source of political power (Konyimbih, 2001). Kenya is an agricultural economy hence land is its economic mainstay. It has therefore been a government policy to: (i) improve the quality of life through increased agricultural productivity in rural areas, (ii) transfer land ownership through an orderly land transfer programme and (iii) create security of tenure through an accelerated programme of land consolidation, adjudication and registration (UN-HABITAT, 2001).

The government strategy on land policy in Kenya aims to achieve optimum utilization and equitable distribution of land for the country's rapidly increasing population. This strategy was pursued with programmes aimed at transforming customary land tenure to individual tenure system. The process was influenced and shaped by various land reform strategies since colonial times and has continued to engage successive governments in Kenya to the present day.

1.3 Historical Background

The history of land tenure system in Kenya is not a direct development from customary to statutory tenure. It is intertwined with the European settlement in Kenya towards the end of the 19th century and early Arab settlement at the East Coast of Africa (Onalo, 1986). Indeed the *Periplus of the Erythraean Sea*[1] and Ptolemy's Geography of 140 A.D. (Chittick, 1974) indicates that as early as the First Millennium A.D, the East Coast of Africa already had important urban centres such as Rapta at the mouth of River Ruvuma in Tanzania. From 632 A.D., the area became a major destination for the Indian Ocean trade.

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[1] Periplus of the Erythraean Sea was a historical document prepared by Greek merchant living in Egypt around the 1st Millennium A.D. It detailed all the towns in the East Coast of Africa and was the most reliable account of the region before the before the 10th Century A.D.

Towards the end of the 19th Century, the British were facing major political challenge from other European powers towards the control of East Africa. Once the Suez Canal was opened in 1869, Uganda assumed an important dimension in international political diplomacy. The country that controlled Uganda (the source of the Nile) also controlled the Anglo Egyptian Sudan and the Suez Canal. Controlling the Canal was important as it was the shortest route to India where the British already had considerable investments.

Additionally, the British were not comfortable with the Indian Ocean trade which had existed since the 7th Century A.D. and were keen to scuttle its operations as it competed with their interests in India and the far East (Okoth-Ogendo, 1991). Thus in September 1888, Queen Victoria granted a charter to the Bombay-based Imperial British East African Company (IBEACo) to operate and administer the East African Territory from the Coast inland. Sir William MacKinnon was appointed the administrator of the Company (Patel, 1997). The IBEACo soon became bankrupt due to lack of physical infrastructure and provincial administration.

When Kenya was formally declared East African Protectorate on the 15th June 1895, all the operations and assets of the IBEACo (including interests in land) were handed over to the new administration. Through this arrangement, the colonial government could deal with land in this area and the new protectorate by virtue of administrative agreements entered into in 1895 between the IBEACo and the British government, and the 1888 concessionary agreement between the IBEACo and the Sultan of Zanzibar (Okoth-Ogendo, 1991).

The protectorate status did not confer any land ownership rights over the protectorate as the British Laws of 1833 had emphasized that the protectorate status would merely give the imperial power political jurisdiction over the territory but not the right to acquire land. The only way to overcome the impasse was to extend the powers of Indian Land Acquisition Act[2] to cover land in the interior of Kenya in 1897 although there was no juridical basis for this extension (Okoth-Ogendo, 1991).

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[2] Indian Land Acquisition Act is a legal Act in India which allows the Government of India to acquire any land in the country for public use after paying some compensation in lieu of loses occurred to land owner.

Subsequently, the British Foreign Jurisdiction Act[3] of 1890 and the East African Land Regulation[4] of 1887 were revised and incorporated as the East African (Lands) Order[5] in Council (1899). This formed the basis for the enactment of the Crown Lands Ordinance of 1902 to provide a basis for the alienation of indigenous land for the Crown. Through this ordinance, African land was alienated without compensation or provision of alternative land for re-settlement, and soon Africans became tenants of the crown in their own country.

Some of the noted deficiencies of the Crown Lands Ordinance (CLO) were that, it had no registration component and it could not grant leases beyond 99 years. It therefore became necessary to revise the CLO to cater for these deficiencies. The revision gave rise to the Land Titles Act (LTA) and Government Lands Act, cap 280 of 1915.

These Acts were used to register private claims and to adjudicate land at the coastal region respectively. The adjudication was carried out through the use of simple chain and compass surveys. The boundaries were marked using wooden pegs or cairns of stones and a certificate of ownership was issued as the registration document. Any unclaimed land reverted to the Government for fresh alienation under Government Land Act cap 280, of 1915.

Registration of Documents Act (RDA) intended to create a register of documents and LTA defined the land policy and legislations till 1915. The first major legislation and policy review occurred in 1915 when Crown Lands Ordinance was revised and Government Lands Act (GLA, Cap 280) was enacted to cater for further alienation of Government land for the First World War Soldiers. This Act replaced the alienation aspect of the CLO of 1902 and the registration aspects of RDA (1901) and LTA (1908).

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[3] An Act that gave Her Majesty the Queen of England to exercise jurisdiction in foreign country.
[4] In East Africa, the first right to land parcels in private occupation were recorded by certificates of occupancy for a period of 21 yrs under the East African Land Regulation.
[5] An order empowering the colonial government to sell land and buyers to obtain freehold but subject to developing the land.

Under this arrangement, the Commissioner of Lands could grant the Ex-Soldiers leases for agricultural land for a period of 999 years free of any purchase price and subject only to an annual rent of 10 cents of a rupee per acre. (Okoth-Ogendo, 1991). It made further and better provisions for regulating the leasing and disposition of government lands and for other purposes. Most of the leases for agricultural land were excised from the land occupied by the indigenous people without their consent and soon there developed major conflicts between the Government and the local communities.

The GLA also brought with it a fairly advanced system of registration of deeds and provision for accurate survey and deed plans. It was through GLA that the British Government created and implemented its policy of European settlement and racial segregation in the 'white highlands' (Maini, 1966). However, the Act still required documents and historical data for purposes of registration, which was found to be cumbersome especially for accurate surveys. A new Act, the Registered Titles Act (RTA Cap 281 of 1919), was therefore enacted to provide for title registration.

The purpose of RTA was to introduce a form of title registration to the alienated land based on the Torrens system of title. The registration of title system was pioneered by Sir Robert Torrens in Australia. It provided for transfer of land through registration of titles, only thus no historical documents were needed to have the land registered. However, there was need for an accurately surveyed plan supported by a deed plan duly authorized by the Director of Surveys. RTA has been used in all urban centres, and other agricultural areas in Kenya up to the present date.

Some of the major shortcomings of RTA were that the Act required very accurate plans executed by a qualified surveyor. The Survey Act (Cap 299) of 1923 (amended in 1951 and 1961) defined the types of surveys and the accuracy standards required for registration of land under RTA. The surveyors were few, thus making it difficult for its application in wide areas especially within the native reserves. It however introduced an efficient system of land registration in terms of security of tenure, simplicity, government indemnity, finality and guarantee of title.

With the RTA in place, the alienated agricultural lands were secured for the white settlers through title registration. The "Native" reserves were also established with fixed ethnic boundaries to cater for particular ethnic communities. This new arrangement disturbed the equilibrium between patterns of African land-use and the availability of land, which the indigenous communities had maintained through a process of shifting cultivation and nomadism.

The establishment of the "native reserves' resulted in land shortage accompanied with insufficiency in food supply. Soon a major discontent among the indigenous communities erupted. The Government also soon realized that the settlers would not enjoy any security in land unless some form of stable property arrangements were provided for these communities. It therefore became necessary to raise the juridical status of the Native Reserves and these developments led to the third review of the cadastral system in Kenya, which involved the creation of the Trust Lands out of the former Native Reserves.

1.3.1 The Trust Lands

The implementation of the colonial policy of European settlement and racial segregation led to loss of valuable land that the African communities had occupied over generations. Consequently, unrest over colonial domination emerged as the Asians also agitated for equal treatment. The extent of insecurity and restlessness created by the provisions of the Government Lands Act of 1915 and the creation of the "Native" reserves first manifested itself in Nairobi 1922 where several Africans were killed as a result, for the agitation against incarceration of their political leaders, who were fighting for their land rights.

It became apparent to the British government that the land occupied by Africans could not remain unregistered forever.This led to the declaration of the Devonshire White Paper[6] in 1923 in which it was emphasized that the interest of the indigenous people of Kenya (including their interest in land) was paramount and should be respected by the foreigners therein (Patel, 1997). As a result of this declaration there was an urgent need to review the land policy and legislations to accommodate "the African land question".

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[6] The Devonshire White paper refers to a document prepared in Britain, to decide on the political interests of the different communities living in Kenya then. According to Sorrenson [1967: 23], the paper upheld the Elgin principle. In 1906, Lord Elgin, Secretary of State in London, had stated that 'As a matter of administrative convenience', grants of land in the Highlands should not be made to Asians or Non-Europeans.

Consequently, three Commissions were set up between 1924 and 1935; the East African Land Commission (1924-1925) popularly known as Ormsby-Gore Commission, the Hilton Young Commission (1927-1929), and the Kenya Land Commission (1930-1934) the Morris Carter Commission. The Ormsby Gore Commission first mooted the idea of creating trust land from the native reserves to check the insecurity and restlessness within the African reserves. Consequently, the native reserves were officially gazette in 1926 The Hilton Young Commission ratified the "dual" policy; to provide separately reserved areas for Europeans (White highlands) and Africans (Native reserves). The Carter Commission recommended the creation of 'Trust Lands' exclusively for the use by Africans with respect to ownership but with the authority of use vested in the local authorities or county councils.

As a result of these land Commissions, the land policy was reviewed and effected through the enactment of Trust Land Act (Cap 288; 1939) to accommodate African interests and thus attain settler political security. It was not until 1950s that the Act was amended to make provision for a system of land consolidation and adjudication of African land rights in the former native reserves.

The implementation of the programme was interrupted by the breakout of the Second World War in 1939 and it was not until 1946 that the scheme was revisited. Meanwhile the government was getting ever more convinced about the need for land tenure reforms that would provide better security to the land occupied by indigenous African people. Consequently, a process of land individualization of title deeds in the African land reserve was considered the best option.

1.3.2 Individualization of Title Deeds in the Native Reserves

Land scarcity in the reserves became a critical economic and political issue leading to revolt which peaked in 1952. It thus became clear that the African land issue could no longer be ignored. The colonial government realized, for the first time, that the security of the white settlers was in jeopardy unless some form of stable property arrangement was provided for the African reserves.

An answer to this problem was found in the Sywnerton[7] plan which proposed the reform of land tenure in the reserves by providing secure individual title and intensifying agricultural production. The plan sought to individualize titles to land in the African reserves and thereby create landed African elite that would participate effectively in intensive, and large-scale, agriculture. It argued that the individualization of title in the reserves would achieve three main purposes: (i) it would enhance proper decision-making in land use and encourage individual initiative, (ii) it would confer exclusive rights of ownership over parcels of land and thereby remove conflicts, and (iii) it would improve agricultural production through the allocation of large economic units of land.

According to Wanjala (2000), the process of land reform in the reserves would take three main phases: adjudication, consolidation, and registration. The first phase would entail the ascertainment of rights or interests in land in the Native reserves in favor of individual claimants; the second phase was to involve the aggregation of various parcels of land into economic units. The final phase was the entry of the adjudicated and consolidated rights into a Land Register and issuance of a title deed. The registration of an individual as a proprietor of land would confer upon the individual an absolute and indefeasible title.

The land consolidation phase was successful in Kiambu, Nyeri, Murang'a, Nyanza and Western Province. The problem however was that at the time, there were neither legal provisions nor technical approaches suitable for the immediate mapping and registration of land in the African reserves. The government soon realized that some form of legal framework had to be developed to support the land consolidation program already in progress (Sorrenson, 1967).

Consequently, the Native Land Tenure rules of 1956 were passed under the Native Lands Trust Ordinance of 1939 to give the programme some legal backing (GoK, 1966). In 1959, the Working Party on the African Land Tenure Reforms recommended the enactment of the Native Lands Registration Ordinance, although its applications had already been adopted in 1957 (GoK, 1966).

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[7] The Sywnerton plan was published by the then Deputy Director of Agriculture in Kenya in 1954 and defined land tenure reforms in the Native reserves.

In 1960, the name of the Native Lands Registration Ordinance was changed to Land Registration (Special Areas) Ordinance. The registration component of this Act was repealed by the Registered Lands Act Cap 300 of 1963. Parts I and II were not altered and became the Land Adjudication Act of 1963 (Onalo, 1986). This adjudication act was used to conduct all the land consolidation programmes between 1965 and 1968 when the new Adjudication Act was passed.

The land consolidation programme in progress in Central Kenya had relied mainly on ground based surveying techniques (step chaining, compass, and plane table) which were too slow to cover the vast African reserves. The government consequently sought for cheaper and faster methods to accomplish the task. In spite of the problems experienced, it was recognized that there was rapid economic and agricultural growth in the areas where land consolidation and registration had taken place. However, the process was thus discontinued and in its place a new process of land adjudication was introduced.

1.3.3 The Land Adjudication Process

The registration of rural lands in Kenya in accordance with RLA was conceptualised as a large scale project to have the lands under African ownership in rural Kenya registered. Ground based survey methods could not be used for reasons discussed in section 1.3.2. The survey techniques adopted were to be kept simple, requiring only the use of the simplest pieces of equipment such as the surveyor's chain. Under this mass land adjudication, the boundaries of parcels were walked and determined by the elders or committee members and the demarcation officer planted the hedges.

Once the boundaries were established, the boundary owners marked them with hedges. In order to produce the maps of the parcel boundaries, air photography of the entire adjudication area was carried out. This would show the parcel boundaries as marked by hedges, and through the direct tracings of such boundaries from the photographs the respective plot boundaries could be shown in map form. It was originally intended that once the boundaries were air visible, new aerial photographs would be acquired at a scale of 1:12 500 to generate more accurate maps. This process for the new acquisition was known as the "re-fly", as proposed by Adams (1969). The process was however later abandoned due to lack of funds and administrative bureaucracy.

From the above discussion, the photographs were simply used without any corrections for errors being applied on them. The photographs were thus simply enlarged five times to a scale of 1:2500 to facilitate the production of representative diagrams of the parcels on transparent paper. The resultant intermediate maps were viewed simply as preliminary diagrams and were consequently referred to as Preliminary Index Diagrams (PID) because the photographs used to produce them were unrectified.

The second phase of the adjudication program to produce Registry Index Maps (RIM) has not been executed in most parts of the country. Thus, the PIDs have remained as an official map amongst other maps such as demarcation map, registry index maps, registry index maps (provisional) used for land registration under RLA. The intended production of parcel boundaries from the rectified photographs after the "re-fly" was to result in Registry Index Maps (RIM). This however was not executed as has been explained and PIDs have remained the official 'map' for registration under RLA.

The use of PIDs for registration in Kenya has served the country well for over 40 years. However due to rapid technological and global changes, it is evident that PIDs can no longer cope with the demands of a modern economy. If the country has to attain its vision of industrialization by the year 2030, there will be a need to modernize the land adjudication system in Kenya in order to provide a reliable spatial data framework upon which the industrialization concept can be anchored.

Land adjudication program in Kenya has had many benefits such as:-

- Establishment of a cadastral system,
- Individualization of title deeds,
- Comprehensive land registration program amongst others.

On the other hand, there are weaknesses that have so far become manifest in the usage of these maps for registration. These weaknesses have posed major challenges that need to be addressed.

1.4 The Challenges of Land Adjudication Process In Kenya

Kenya has a land registration the system that lags behind technologically. The survey standards were compromised in the production of registration maps thus reducing their importance and efficacy as instruments of land registration. As has been indicated, the majority of title registration in Kenya within the rural areas is based on the PIDs. The following challenges have been noted.

i. The process of registration has moved on quite slowly to the extent that although it has been in operation for close to fifty years, hardly 30% of the country has been covered (Aduol, 2006). Large areas of the country remain un-adjudicated due to incomplete land registers, pending adjudication appeals or absence of the land adjudication exercise altogether. This has led to indifference by the intended beneficiaries. In addition, failure to complete the land adjudication program constrains the land administration system owing to the large number of unregistered land transactions resulting into tenure insecurity.

ii. The accuracy in acreage of land registered under RLA is guaranteed only to within an error of 20% or more. However, discrepancies exceeding 50% in parcel areas have been obtained from some of the PID when compared with those obtained from more accurate survey methods (Mulaku, 1995). More checks and balances in the determination of parcel areas and boundary location are required. Amendment of section 32 of the Registered Land Act in 1987 to allow for inclusion of areas of parcels on title deeds (which had hitherto been known as land certificates) signaled a general dissatisfaction with the quality of these maps.

iii. Land proprietors never realized the full potential of their parcels in terms of monetary support from the financial institutions for development. Land registered under RLA and based on PID is advanced only 40% of the property as compared to 90% in the case of titles registered RTA (Mulaku *et. al.*, 1996). This has the potential to lessen the tenure security of primary right holders in a manner that would endanger the trust needed for transactions and mortgaging, which are a prerequisite for desirable long-term investment.

iv. The government does not guarantee the area of parcels as shown on the register only the parcel's existence on the register (Njuki, 2001). This has given rise to boundary disputes that often take longer periods to arbitrate thereby leaving land parcels idle thus uneconomical for long periods.

v. The PIDs have non-uniformity of the scale within particular registry map sheet, unreliable areas and distortion of shapes of parcels since there are no standard specifications for boundary features for general boundaries. Continuous features, such as hedges and fences often mark boundaries, but quite often these features are missing. Though the approximate scale is indicated on PID map sheets, indication of grid lines on the sheets is avoided.

vi. There are also problems associated with the use of these maps for registration, as they never offer secure and valuable land tenure (Ogalo and Wayumba, 2002). Accurate demarcation of boundaries will minimize litigation emanating from indeterminate boundaries, ensure certainty in land ownership, land tenure, land right and facilitate the registration of right in customary land and subsidiary interests and promote valuable development information which will enhance sustainable national development.

In spite of the many observed weaknesses in the system, Kenya still has one of the best land registration systems in the developing world; that is relatively cheap and effective.

1.5 Problem Statement

Maps are used for land registration, but the registration is incomplete if the object cannot be unambiguously identified on the ground. An efficient title registration system is one that has a proper cadastral basis and is reliably georeferenced. It has been universally accepted that the best registration system is the registration of titles. Each parcel is described on a map with well-defined boundaries, accurate cadastral index maps and is given a special entry in a register showing all existing rights in the parcel (Mwenda, 2001; Ariyaratne, 2003).

One major setback in the title registration under RLA in Kenya is the lack of accurate and reliable large-scale maps. In an attempt to produce large-scale maps for title registration, using PID, the accuracy was compromised. To resolve the above challenges, Mwenda (2001) recommended the use of high spatial resolution satellite imagery such as IKONOS and QuickBird. Such imagery are useful sources of information for land management, especially in land adjudication.

At the moment, however there has been no study to assess the suitability of high spatial resolution satellite imagery in Land Adjudication in Kenya. Thus, this study seeks to look at the possibility of using the combination of the modern technologies of remote sensing, digital mapping, and GPS, in the development of a more accurate approach to the establishment of boundaries and georeferencing of parcels in the registration of land parcels under RLA.

The main objective of this study can thus be stated as: **to evaluate the suitability of high spatial resolution satellite imagery for use in the production of PIDs for adjudication survey in Kenya.**

The specific objectives of the study are then

1. To assess the accuracy of PIDs produced from orthorectified satellite imagery
2. To carry out a field study with the high spatial resolution data to assess its suitability for adjudication in Kenya.
3. To establish the potential use of satellite imagery with a spatial resolution of 1m or less as a main source for parcel identification in adjudication surveys.
4. To review the current technological applications in adjudication surveys in Kenya.

1.6 Justification and Relevance

Land is one of the most important resources an individual can own and hence its sensitivity in any developing economy such as Kenya where it retains a focal point in the history of the country. Land was the main platform on which independence was fought for in Kenya. Land has traditionally dictated the pulse of the nationhood and continues to command a pivotal position in the country's social, economic, political and legal relations. Therefore empowerment of rural people through some land reform is central to the livelihoods of the rural poor.

Empowerment of the rural people through accelerated titling of tribal and community lands can significantly improve livelihoods of the rural poor. It has been noted that land titling can now be achieved much more rapidly than in the past by combining indigenous local knowledge of traditional boundaries with use of modern geospatial technologies (low cost Global Positioning System (GPS), computer technology and satellite mapping). The introduction of high-resolution satellite technology presents another opportunity for quick, cheap and accurate mapping and hence a quick solution to current land conflicts in the country today.

Land has been, and continues to be, used as collateral against bank loans, hence the need to ascertain the correct value. Size of land is one of the many determinants of land value. Land in Kenya is registered under fixed and general boundaries. Land under fixed boundaries normally attracts higher loans as compared to general boundary land. In almost every country, a great body of public and private rights and privileges relating to the land has grown over time, usually accompanied by an almost equally complex system of duties and responsibilities.

An accurate large-scale map is the only sound basis for a record of such rights, privileges, duties and responsibilities. No system of registration of rights can be effective and no system of land taxation can be just and efficient without a description which enables the land affected to be identified with certainty on the ground, and no such identification can be regarded as certain without a suitable map to which the description can be referred.

As the population of the world continues to grow and the technical resources available become greater and more varied, so it becomes both more important and more easily possible to plan and organize development of natural resources. But no great work of engineering, no orderly development of agricultural, forest or mineral resources, no schemes for town or country planning can be prepared and executed without maps on large scales and of high accuracy. The research seeks to reduce the disparities between the two registration systems in terms of their accuracy and hence value for money.

1.7 Scope and Limitations of the Study

Various factors limited this study in many ways. PIDs are dependent on visible boundaries hence the boundaries that were not identifiable on the images due to cloud cover; missing edges, etc, could not be considered. Presence of cloud cover in some areas hindered the identification of some parcel boundaries and especially on the satellite image. Bright spots on the photographs also presented a similar challenge. Digital Terrain Model editing could not be done due to lack of stereo glasses.

1.8 Organization of the Report

Chapter one places this study in its wider context, states the aims and objectives and presents the structure of the thesis. The remainder of this thesis consists of five chapters and appendices. Chapter two introduces and discusses the land administration process. Chapter three presents the design of the study and the experiments while chapter four presents the results and discussion of the results. Chapter five gives a general discussion of the results while chapter six presents specific and general conclusions and recommendations based on all the previous chapters. Appendices relate to analytical data tables and figures.

2. LAND ADMINISTRATION PROCESS IN KENYA

2.1 A Review of Land Administration Practices

There has rarely been a period in history when change has been more rapid or far-reaching as it is today. With the burgeoning growth of populations in the Third World, the need to ensure the proper use of land has never been so urgent. The rate of increase in the population is only exceeded by the pace of change that is taking place through technological innovation, which in turn is providing more open access to information. There is a much greater awareness of the magnitude of the land-related problems to be faced and the resources that can in theory be brought to bear on their solution.

Not all human activities have, however, responded rapidly to change. Cadastral systems in particular have been slow to adapt, many being rooted in concepts and practices that are a century or more old and no longer satisfy the needs of present-day society. A cadastral system consists of two parts, the first of which contains a written record or register showing details about each parcel of land such as the name of the owner and the rights or assessed values that relate to the land; it is thus dependent on the juridical system and in particular the land law of the country concerned (UNCHS, 1990).

The second part is cross-referenced to the first and contains a detailed description of the parcel, either in the form of maps or survey measurements that identity each Land parcel. The overall process of recording details about land parcels for the purposes of land ownership is known as land registration (UNCHS, 1990). The origins of the cadastre go back to antiquity although its present form dates from the late eighteenth century.

Within mainland Europe the basis of the modern cadastre was in taxation while in much of the English speaking world the activity known as cadastral surveying has been directed at the protection of property rights. Within developing countries the emphasis in the cadastre has been on land ownership and support for land settlement. In those countries settled by the French, the Napoleonic Code Civil was adopted. The European settlers in South Africa introduced Roman-Dutch law while in much of the British colonial empire, the system of jurisprudence was based on

English Common law and practice. Land was, in general, treated as an estate to be owned in freehold or leasehold; thus many traditional rights in land were ignored (UNCHS, 1990).

In the case of Zambia, land law was based on the English system prior to land reform in England in 1925. The government of Zambian therefore inherited what the English themselves found unworkable. In some countries, such as in Uganda, land rights were granted to the local chiefs as an instrument of land policy. The system of registration of title has been based in part on the practices in Victoria, Australia, from where sections of the Registration of Titles Act were derived. These were however modified to meet local conditions. In other countries, land was alienated for the benefit of settlers or to record government properties. In the latter cases, only limited areas of land were cadastrally surveyed (UNCHS, 1990).

The rights in land that were statutorily recognized depended on the customs and procedures of the colonizing power or on the experiences of the settlers. Throughout much of East and Central Africa, either British legal practice was followed or South African procedures were adopted. The system of deeds registration that until two decades ago was practiced in Malawi was supported by a survey and land registration system that was based on South African methods. These procedures were largely influenced by the South African surveyors who had run the Survey systems in the country (UNCHS, 1990). The system in Malawi now has been modeled on the English approach to title registration, modified in part as a result of the experiences gained in land registration in Kenya in the 1950s and 1960s.

In Kenya, two systems of registration of title to land have been practiced: the Deeds registration system and the Title registration system. The deeds system was based on the South African approach to surveying that was adopted in the early part of last century while the latter was introduced when substantial areas of land that had been settled by expatriates were returned to the indigenous peoples.

The United Republic of Tanzania has remainder of its German occupation while many of the English-speaking countries of Central and Southern Africa have had systems based on South African practice and the registration of deeds. Over the last decades most of these have however been transferred to the Title Registration System. In Botswana, for example, there has been the introduction of certificates of rights of occupancy, though still based on deeds registration.

Throughout the colonial period, relatively little was done to ensure the protection, or even identification, of customary interests in land. For instance, in the Uganda Protectorate, insufficient care was taken in identifying native rights so that the chiefs who had been trustees of the land became full owners of the freehold. This brought about a major change in the social structure of the Buganda community.

Throughout most countries, the general approach to land registration has been directed primarily at the projection of individual property rights, rather than communal rights and has ignored the general concept of land as a resource to be managed. The good uses of the land has in most cases been left to market forces or to attempts at town and country planning that have been divorced from the management of land tenure systems (UNCHS, 1990).

2.1.1 Existing Land Registration Practices

Two major systems for recording rights in land have been established: the deeds registration system in which the documents of transfer are recorded, and title registration in which the land parcel is the focus of the records. In general, French-speaking countries and those under Roman-Dutch law have adopted systems of registration of deeds (Enemark, 2005).

Under most systems of registration of title, the information on the registers is guaranteed by the State so that in the unlikely event of fraud or error, anyone inadvertently suffering from the incorrectness of the information will be compensated. Two apparently different systems of registration of title to land emerged at much the same time in the nineteenth century: the so-called Torrens or Australian system and the English equivalent.

The similarities between the English and the Australian approaches to registration of title to land are much greater than their differences as Simpson (1976) has pointed out. Both systems have worked well within their own environments but both are equally flawed in terms of overall land management and administration. These flaws stem from their origins which were primarily in support of private conveyancing. Both have effectively protected the property rights of government and of registered private individual owners. Many rights and tenures have, however, been ignored, especially the customary rights and traditional procedures followed in those less developed countries that have been persuaded to introduce registration of title to land.

2.1.2 The Benefits of Land Registration

The need to record details of land parcels within a cadastre stems from a need for the better administration of the land. Land after all is the ultimate resource from which almost all wealth comes. Improvements in the management of land are essential for the betterment of both the rural and the urban poor.

In most developing countries, the inadequacy of land information poses serious constraints on what can be done. Without knowledge of who owns the land, development cannot peacefully take place. Consequently, the emphasis in many development programmes is placed on ensuring that rights in land are identified, recognized by the State, and recorded in some suitable form. According to Williamson (1986), the benefits of such land registration include:

- ***Certainty of ownership:*** The compilation of land records will necessitate the formal identification and recognition of the ownership of the land, a process known as adjudication. This should provide certainty not only as to who is the landowner but also what other rights exist in the land.
- ***Security of tenure:*** Through the adjudication process, existing defects in any titles to land can be cured by the judicious use of appropriate powers. In many countries the official record is supported by a State guarantee of the title to the land. Greater security should in turn lead to increased productivity, especially in rural areas where farmers have an incentive to take greater care of the land and to invest their capital and resources in it.
- ***Reduction in land disputes:*** Disputes concerning land and boundaries can give rise to expensive litigation. The settlement of such disputes should be part of the process of adjudication and will not only lead to greater productivity from the land but also reduce the money wasted on litigation and going to court.
- ***Improved conveyancing:*** The costs and delays in transferring property rights can be substantially reduced through the operation of a land-registration system. Duplication of

effort, for instance in the repeated investigation of old titles, can be avoided thus saving on costs.

- ***Stimulation of the land market:*** The introduction of a cheap, secure and effective system for recording and transferring interests in land should improve the operation and efficiency of the land market. It should not only lower transaction costs but should also permit the market to respond effectively to all the needs of users.
- ***Security for credit:*** The land title can be used as security against any loan. Tentative evidence suggests that the combination of a sound title with the ability to raise long-term credit can give rise to substantial increase in productivity from the land.
- ***Monitoring of the land market:*** The cadastral system may be used to monitor and, if necessary, to control land transactions and ownership.
- ***Facilitation of land reform:*** Land redistribution, land consolidation and land assembly for development and re- development can be expedited through the ready availability of information on who currently owns what rights in what land.
- ***Management of State lands:*** The State is often the major landowner in a country. The development of a cadastral system and in particular, the creation of cadastral maps in a systematic manner will benefit the State in the administration of its own land, often giving rise to improved revenue collection from the land which it leases. In addition, the public acquisition of land through compulsory purchase prior to redevelopment can be expedited.
- ***Support for land taxation:*** Many countries have some form of land assessment and derive revenue from charges on the land. Often the cost of improvements in the cadastral systems is offset by greater efficiency in tax collection and the consequential greater amount of tax recovered.
- ***Improvements in physical planning*** The cadastral system may be used to support physical planning in both the urban and rural sectors. Many development programmes have failed or been unnecessarily expensive through a lack of knowledge of existing land rights. The cadastre also provides a basis for restricting certain uses of the land which might, for example, give rise to pollution.
- ***Recording of land-resource information:*** The availability of up-to- date large-scale cadastral plans can lead to the creation of an efficient land information system which services a variety of land- resource-management activities and

- ***Supporting environmental management:*** Cadastral records, in their multipurpose form, can be used as a tool in assessing the impact of development, in helping in the preparation of environmental impact assessments and in monitoring environmental change.

2.2 Land Registration in Kenya

Land issues need to be understood in historical context. This history is often decades or even centuries old, with people laying claim to land on grounds of first settlement, conquest, or market acquisition by distant ancestors. The genesis of the Kenyan cadastre was the establishment of a survey section and the appointment of a Chief Surveyor in 1903 to superintend over the demarcation and survey of plots that had been alienated in Nairobi. Subsequently under the Chief Surveyor four ordinances were then enacted, namely; the Land Titles Ordinance, 1908; the Crown Lands Ordinance 1915 and the Registration of Titles Ordinance, 1919 and the Land Surveyors Ordinance, 1923.

These Ordinances guided the land tenure policies for the next fifty years. The post Second World War saw the individualization of land ownership and mobility in the transfer of land in areas held under customary law by Africans through the process of land consolidation. After independence the land policy was to accelerate land adjudication in trust land areas and to transfer land ownership from foreigners to indigenous populace through land settlement programmes. Cadastral systems were formulated to support the above policies through the following land administration programmes:

- Adjudication of lands at the Coast.
- European Settlement in the White Highlands
- Land Consolidation and Adjudication programmes
- Land Settlement programmes
- Sub-division of large scale farms and group ranches
- Alienation of town plots
- Land Registration programmes

The programmes were designed on the principle that major operations affecting land cannot achieve their ideal maximum efficiency or production without utilization of survey maps and without security of tenure (Njuki, 2001). Each programme had to contain a component of land survey. Land registration was the end process and ultimate goal.

2.3 Land Adjudication Process in Kenya

The basis for Land Adjudication in Kenya is the Land Adjudication Act chapter 284 of the Laws of Kenya. This Act was a review of the Land Consolidation Act of 1968 to allow for adjudication and registration of different parcels of land as opposed to consolidation of all the parcels together as was required by the Consolidation Act. The land adjudication process is initiated once the Minister of Lands has given a declaration that a Trust Land area be adjudicated. The minister then appoints an adjudication officer who is then expected to steer the process.

The Adjudication Officer appoints demarcation officers, survey officers and recording officers to help administer the process. The Adjudication Officer subdivides the land into adjudication sections and in consultation with the District Commissioner of the area, appoints an adjudication committee for the section. The Provincial Commissioner appoints a panel of officers from which the adjudication officer can form an arbitration board. The Adjudication Officer with the help of the committee, the board and other officers' help to formulate the adjudication registers.

These registers contain records of rights and interests to the land in the adjudication section. Anybody having a claim to the land to be adjudicated must be present to show his boundaries to the demarcation officers. Any person who, during the adjudication process, feels that his rights have not been taken into consideration is required to lodge a complaint with the adjudication committee chaired by the Adjudication Officer. Any complaint with the decision by the Adjudication Officer can further be made to the Land Executive Officer who will submit the complaint to the arbitration board. Any contention on the completeness or correctness of the adjudication register is referred to the Minister of Lands. The Minister makes the final decision on the appeals, but, with orders from the High Court, the Minister's decision may be challenged.

2.3.1 The Impact of Land Adjudication in Kenya

The impact of the land adjudication programme on land administration is assessed by examining whether the objectives of the programmes were achieved and whether the survey maps were of sufficient accuracy to support land registration effectively and efficiently. Maps are considered suitable for land registration if they can unambiguously identify on the ground a plot shown on the register or they can assist in the relocation of a boundary should it be lost or damaged. These two factors will be used as the benchmark to evaluate the effectiveness of the cadastral systems applicable to Kenya.

The cadastral system used in the adjudication of lands at the Coast under the provisions of the Land Titles Ordinance was deficient and consequently the re-establishment of beacons is very difficult and unreliable and also the demarcation did not provide for roads of access to serve individual parcels precipitating many planning problems during sub-divisions and provision of infrastructure. The programme for the settlement of European settlers was successful in that the goals set were achieved. All the land set aside as White Highlands had been alienated, surveyed and registered by the time Kenya gained its independence. The only constraint experienced in the implementation process was delays in the execution of surveys.

Four different types of maps, namely, registry index maps, demarcation maps, preliminary index diagrams and registry index maps (provisional) are produced to implement land settlement, consolidation and adjudication programmes. Apart from the registry index maps, survey standards have been compromised in the production of the other three types of maps thus reducing their importance and efficacy as instruments of land registration. The Government does not guarantee the area of parcels as shown on the register only the parcel's existence on the register. The proprietor has the onus of maintaining his boundaries and enclosures.

The low accuracy attained in these maps can be attributed to the following factors:

- The field survey work is not carried out under the Survey Act and the direction and control of the Director of Surveys.
- The survey work is performed by junior survey assistants with minimal training from the Department of Land Adjudication. Their work performance depends on job training and field experience.
- The use of unrectified aerial photographs. The areas derived from these enlarged photographs are not precise and have error margins of up to twenty five percent.

The intention of the authors of the Registered Land Act was to have all the other laws on land registration superseded by this Act. It had been anticipated that the Act would apply as the substantive law and would be operational throughout the country within a period of six months. This intention has never been realized up to now. The main constraint pending the conversion is the preparation of registry index maps by the Director of Surveys that are necessary to support registration. The Registered Land Act introduced the system of general boundaries whereby a map is not an authority on boundaries. This system has enhanced the evolution of many boundary disputes and litigation.

On recapitulation, the encumbrances encountered in the formulation and implementation of the cadastral systems in Kenya can be attributed to the persistent shortage of surveyors and their inability to cope with the survey demands. An auxiliary constraint has been the failure of surveyors in Kenya to remonstrate with policy makers and to convince them of the importance of survey and maps on all matters related to the management of land (Njuki, 2001). To avoid being blamed for causing delays in programme implementation, surveyors have occasionally succumbed to public pressure to produce maps urgently in total disregard of survey regulations and procedures.

2.3.2 Weaknesses of Land Adjudication Process in Kenya

The Kenyan land adjudication process has been hailed as a success story. Millions of land parcels have been brought to the land register and an equal number of title deeds have been issued (Mwenda, 2001). On the other hand, no land adjudication has taken place in nine administrative districts. These districts include: Tana River, Ijara, Garissa, Wajir, Mandera, Isiolo, Marsabit, Moyale and Turkana. This vast area (Figure 2.2) of 331,370 square kilometers representing 57 % of Kenya's territory is largely arid and semi arid (Njuki, 2001).

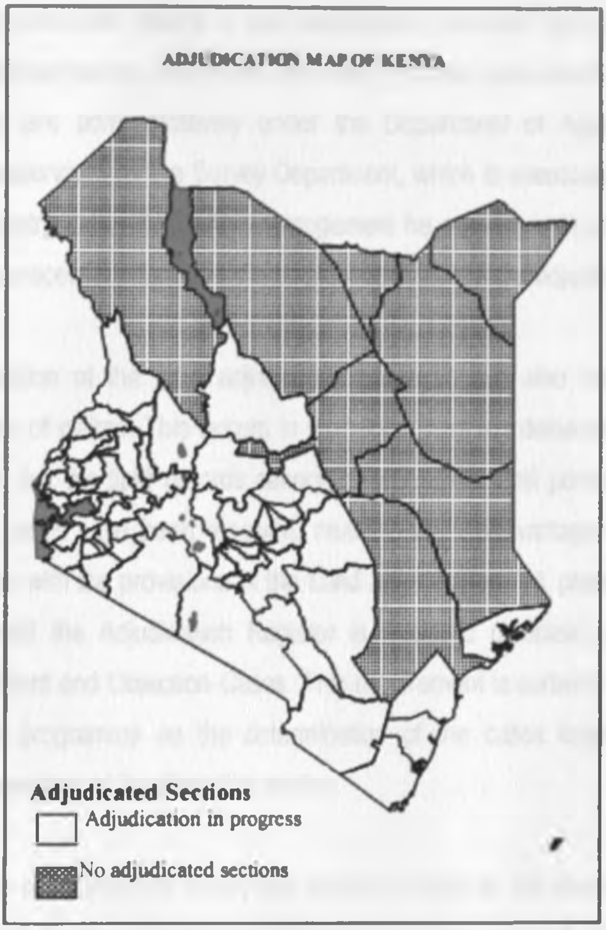


Figure 2.1: The Adjudication Map of Kenya (After Njuki, 2001)

A successful process should always have an end. However in Kenya, 40 years after the beginning of the adjudication process, there are title deeds that have not been issued. This clearly shows that there are problems with this process. Njenga (2004) identified various hurdles with respect to the land adjudication process. These range from inadequate resources to expedite the programmes, outdated survey methods as a result of inappropriate or obsolete survey equipment such as survey chain and plane table, poorly trained technical staff and inadequate transport to supervise the adjudication work. This often compromises the quantity and quality of work. Njenga (2004) goes further to suggest the need for the training of technical staff in modern methods of surveying and the recruitment of surveyors to lead technical teams.

Nyadimo (1990) also noted that delays in land adjudication occurred as a result of institutional arrangements i.e. the junior survey assistants, who carry out the survey work as is required in the adjudication process, are administratively under the Department of Adjudication while their technical duties are supervised by the Survey Department, which is eventually responsible for the production of the Registry Index Maps. This arrangement he argued, is fraught with coordination problems leading to unnecessary delays in the efficient operation of the adjudication process.

Delays in the completion of the land adjudication process have also been adduced to the protracted adjudication of claims. This occurs in situations in which demarcation and the survey have been completed but the field records cannot be processed until pending arbitration board cases and objection cases have been resolved, much to the disadvantage of numerous parcel owners. In accordance with the provisions of the Land Adjudication Act, processing of title deeds cannot commence until the Adjudication Register is declared complete and final i.e., upon determination of all Board and Objection Cases. This requirement is certainly not compatible with any meaningful work programme as the determination of the cases largely depends on the convenience and cooperation of the disputing parties.

An obvious advantage of a cadastral survey and record of rights is that together they give a true and exact description of the legal situation of rights in land at any moment. Only a cadastral map can provide the means of accurate identification necessary to this end and only a continuous and comprehensive record of rights can give an accurate picture of the position at any particular time. This was the intention of the authors of the Registered Land Act. However, this intention has never been realized up to now. The main constraint pending the conversion is the preparation of registry index maps by the Director of Surveys. Meanwhile, preliminary index diagrams based on the system of general boundaries whereby a map is not an authority on boundaries are in use.

2.4 Preliminary Index Diagrams (PIDs)

Through the process of land adjudication, the land owners agreed on the positions of their boundaries and marked them by planting hedges. Aerial photography at a scale of 1:12500 or 1:25000 was then obtained once the hedges had grown sufficiently to be air visible. The un-rectified aerial photographs were then enlarged five times and forwarded to the field where junior survey assistants identified and marked the boundaries of the adjudication parcels on the enlarged photographs. Maps were then produced by making direct tracings of the boundaries as depicted on the enlarged photographs. The boundaries that were not air visible were plotted on the photographs by estimation. Tracings of the boundaries resulted into Preliminary Index Diagrams (PID's) (Mwenda, 2001). Figure 2.1 shows the process of land adjudication.

Initially the PID's were upgraded by a process, known as re-fly, through which maps were plotted accurately by photogrammetric restitution and ground survey methods (Mwenda, 2001).The resulting drawings were referred to as Registry Index Maps. Such maps were produced for parts of Central and Eastern Provinces and were mostly drawn at scales of 1:2,500 and 1:5,000. However the re-fly exercise was abandoned in 1967 due to shortage of funds and change of priorities. This abandonment has ensured the continued use of PIDs as land registration documents.

These maps suffer from non-uniformity of the scale within particular registry map sheet, unreliability of areas calculated using these map sheets and distortion of shapes of plots. Differences exceeding 50% of parcel areas between areas from PIDs and those from more accurate methods have been detected (Mulaku *et. al.*, 1996; Oluande, 2004). These differences vary with the topography of the land. Consequently, land owners never realize the full potential of their parcels in terms of monetary support from the financial institutions for development. The government does not guarantee the area of parcels computed from these maps as shown on the register but only the parcel's existence on the register. This is due to the nature of the general boundaries: they are easier moved or lost either deliberately, carelessly over time or inadvertently during the human activities resulting in disputes.

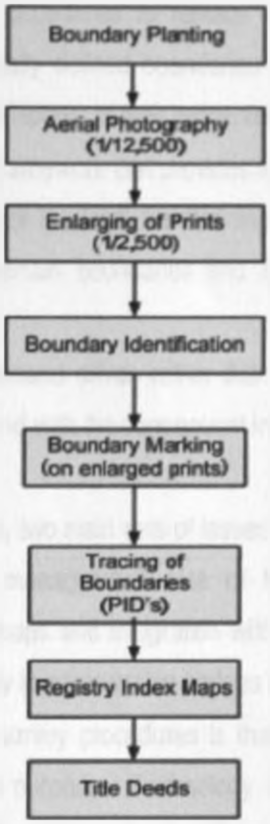


Figure 2.2: The Land Adjudication process

2.5 Summary

Land is a platform for almost all human activities. It is the means of life without which human beings could ever have existed and on which continued existence and progress depend. Naturally, it is fixed in location, immovable and incapable of expansion in supply, (except very marginally through the process of reclamation). The necessity for efficient and effective management of this unique resource cannot therefore be overstressed. Any constraints to the supply of land, therefore, impacts negatively on human settlements development, and thus on socio-economic development. In this context, the poor quality of the PIDs in Kenya retards development of human settlements and, in particular, the availability of suitable land for the increasing needs of shelter, infrastructure and services. To address these problems, the following issues need to be tackled:

- Conversion of the PIDs to RIMs in order to complete the adjudication process

- Creation of general fixed boundaries to replace the general boundary concept. The advantage of more specifically defined boundaries is the confidence which parties can have as to the precise spatial extent of their properties.
- Provision of a geometrical framework that provides a basis for producing maps which can assist in the administration of the land, for planning and controlling its development, for redefining disputed or uncertain boundaries and for structuring geographical or land-information systems.
- Create systems that are demand driven rather than producer driven that can cope both with extending the system and with the consequent increase in the number of dealings and mutations.
- In the technical environment, two main sets of issues exist: data acquisition, including field survey; data and record management. Use of high-resolution satellite imagery for upgrading interim registry maps and integration with geographic information system can offset these issues especially in areas where hedges are fully-grown.
- The premise in looking at survey procedures is that graphic standards of accuracy are sufficient for most practical purposes. Technology is forcing survey data to be held in coordinate, i.e. digital form but this can be stored to plotable accuracy. Thus there is need to embrace technologies that are available to support this course.

3 DESIGN OF THE STUDY

3.1 Introduction

The essence of this chapter is to outline the methodological framework that was used for the research. The chapter opens by putting forward the hypotheses and research questions of the thesis. These were tailored along the research objectives stated in the earlier chapter. Following this, there is a section explaining the conceptual framework that enabled answers to the research questions to be found and the hypotheses to be verified and the data sources; the chapter closes by outlining how the accuracy assessment was measured.

In the earlier chapter, it was propounded that high spatial resolution satellite imageries can provide a more accurate approach to the establishment of boundaries and geo-referencing of parcels in the registration of land parcels under RLA. In light of these discussions, the following broad hypotheses and research questions are proposed.

a) There is significant difference in parcel areas as measured from PIDs obtained from satellite orthoimage and unrectified aerial photographs.
b) There is no significant difference in parcel areas as measured from RIMs and satellite orthoimage.
c) The use of the orthoimages as an input for indirect methodology for PID production is adequate for parcel mapping and for planning cadastral activities.

In order to test the above hypotheses, the following research questions were looked at:

1. How do PIDs parcel areas compare with those derived from RIM and ortho-rectified satellite images obtained values? If differences indeed exist, are they statistically significant and how are they interrelated?
2. What are the requirements of a Registry Index Map and to what extent do maps traced from ortho-rectified satellite images meet these requirements?
3. Do these diagrams, extracted from ortho-rectified satellite images, meet the set tolerances in boundary definition in Kenya?

3.2 The Conceptual Approach

The central objective of a cadastral system is to produce, maintain and distribute current and accurate geographical data in support of land registration to ensure people have security and ownership of land rights and interests. This poses major challenges which require adequate preparation and foresight. The very important ones are the handling of survey data; the application of new technology and the methodology of delivering services.

Currently, the amount of cadastral data held by Survey of Kenya, include survey plans, field notes, computations, registry maps and aerial photographs is immense and is stored and retrieved manually. As a result, there has been such a huge collection of data that has accumulated over a century thus the manual system has progressively became very inefficient and time consuming.

On the other hand, the survey profession has been very conservative in adjusting to new technology. The common equipment used for cadastral surveys include EDMS, theodolites, and chains. Computations and draftsmanship are done manually. Maps to support land adjudication are derived from unrectified and enlarged photographs. New methodologies of carrying out surveys; recording, storage, processing, management, analyzing dissemination, and display of information must be developed. This will require that the country identifies embraces and acquires modern technologies.

At present, the cadastral systems are tailored in support of land registration and they only contain information related to area/dimensional measurements of a parcel. The market is now putting more emphasis on information related to the parcel of land e.g. land use, value, vegetation, communications, tenure, available utilities etc. The land information is required for various purposes: conveyancing, credit security, development control, land reform, environmental assessment, land market support etc. The future trend is to shift from the current manual systems to digital systems by adopting the use of modern geospatial technologies of remote sensing, digital mapping and GPS.

This study proposes a conceptual model (Figure 3.1) to evaluate and analyze field data to determine the suitability of high spatial resolution satellite imagery for use in cadastral mapping.

This technology has proved to be time effective and cost effective to provide such data. High spatial resolution satellite data can be used for base map preparation such as PIDs, among other uses which can be updated frequently. These maps can be made more accurate with the use of GPS. These data, along with GIS software, has enabled creation of more detailed maps for surveys. This information, when further combined with other systems such as communications devices; computers and software can perform a wide range of tasks. GPS, along with GIS software, can provide a reliable and efficient system.

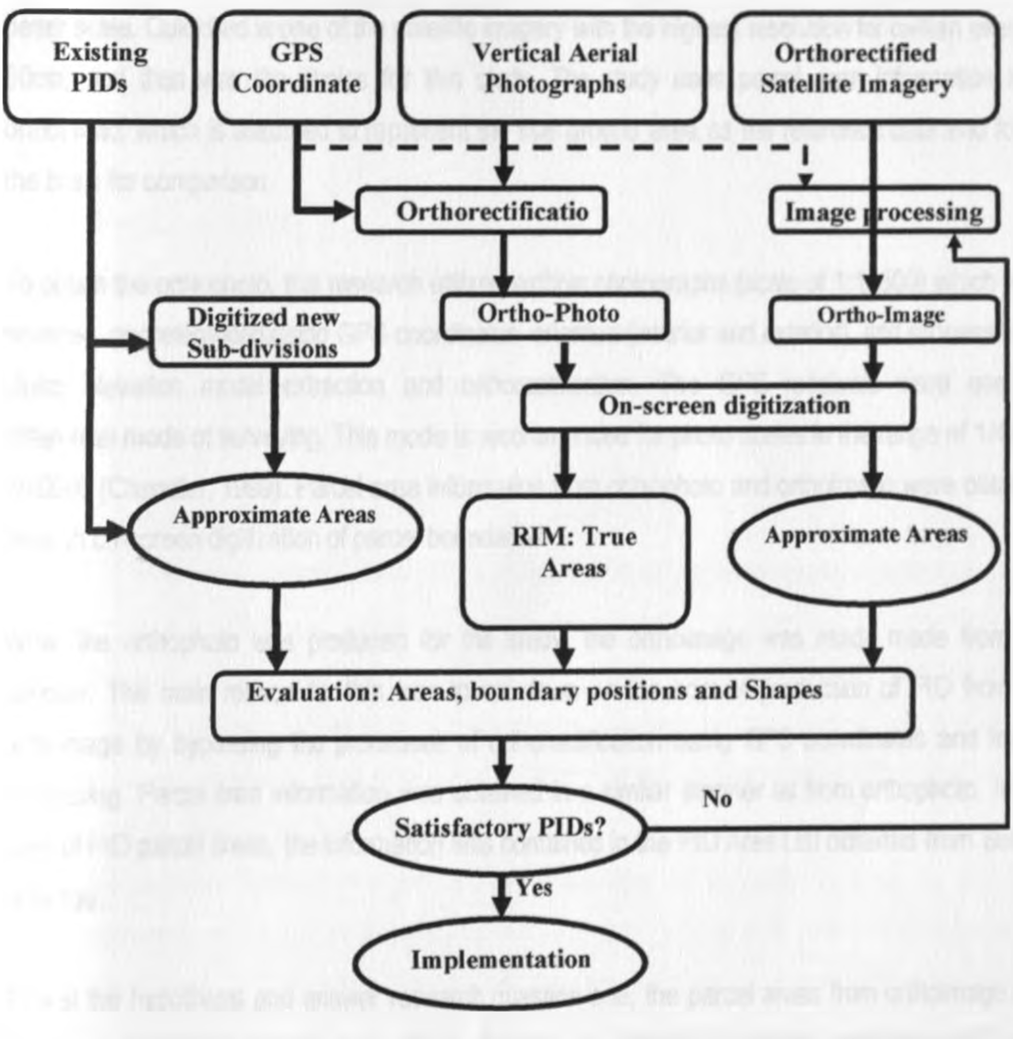


Figure 3.1: The conceptual framework

The overall research approach is mainly focused on the comparison of different datasets from which the parcel areas were extracted and evaluated by means of statistical analysis. The main assumption of the study is that the parcel areas obtained from satellite orthoimage and orthophoto are equal and that there is a difference in the case of PIDs versus orthoimage. These assumptions formed the basis for the hypothesis and the subsequent tests. The study searches the prospect for the integration of geospatial technologies in cadastral studies.

The use of aerial photography played a major role in cadastral mapping and presently high-resolution satellite data is providing the needed accuracy for cadastral level mapping at 1:4000 or better scale. QuickBird is one of the satellite imagery with the highest resolution for civilian uses (at 60cm) and thus was the choice for this study. The study uses parcel area information from orthophoto, which is assumed to represent the true ground area as the reference data and forms the basis for comparison.

To obtain the orthophoto, this research utilized archive photographs (scale of 1:12500) which were scanned, georeferenced using GPS coordinates, oriented (interior and exterior), and processed for digital elevation model extraction and orthorectification. The GPS receivers were used in differential mode of surveying. This mode is recommended for photo scales in the range of 1/4000-1/50000 (Chandler, 1999). Parcel area information from orthophoto and orthoimage were obtained through on-screen digitization of parcel boundaries

While the orthophoto was produced for the study, the orthoimage was ready made from the supplier. The main reason for this was to cut down on the cost of production of PID from the orthoimage by bypassing the processes of orthorectification using GPS coordinates and image processing. Parcel area information was obtained in a similar manner as from orthophoto. In the case of PID parcel areas, the information was contained in the PID Area List obtained from Survey of Kenya.

To test the hypothesis and answer research question one, the parcel areas from orthoimage and PID were compared against each other resulting in: orthophoto/satellite, orthophoto/PID and satellite/PID differences. A smaller α-level of one percent was conveniently chosen so give greater confidence in the determination of significance. Student's *t*-Test was used to assess whether the means of any two of the groups were statistically different from each other. The software used for statistical analysis included Statistical Package for the Social Sciences (SPSS) and Excel. To answer question two and three, a critical review of existing literature was conducted to determine suitability of the PIDs.

Parcel classification according to acreage was conducted according to Labour Force Survey Report of Kenya (1998/9). According to this report, parcels have been classified into:

- Class **A** : (0.01 – 0.99 ha)
- Class **B** : (1.0 – 2.99 ha)
- Class **C** : (3.0 – 4.99 ha)
- Class **D** : (≥5.0 ha)

3.3 The Experiments

This section explains the strategies followed to fulfil the aims and objectives of this research, i.e. the problems that arose in the course of work and the decisions that were taken to overcome them. The process of identifying these issues and their satisfactory solution led to the identification of key issues and recommendations for the potential end-user in Chapter six.

3.3.1 Selection of Study

The first stage in this research comprised the selection of appropriate study site. The site was used to develop the methodologies and also to validate the application of these methods. Especially, in the development stage, it was considered important to have alternative data sources, especially the PIDs and their Area List to compare the results with and to have clear parcel boundaries suitable enough for measurement from aerial photographs and satellite imagery. This leads to the following criteria used for selection of the site:

- Adjudication Section: The process of adjudication is important in order to establish ownership rights. An adjudication section is an area whose land ownership right is to be determined. It is therefore obvious that the site must be an adjudication area and the adjudication process should be complete, as this would guarantee the availability of other relevant data.
- Aerial photography: The photographs are necessary to the study as a resource used for the production of cadastral maps. It is apparent that these aerial photographs are of good

quality, have controls, and of suitable scale. The ideal scale of photography is 1:12500. The photographs should posses similar characteristics as those from which the PIDs were drawn or at least have almost same parcel boundary characteristics as those appearing on the PIDs.

- Satellite imagery: It is of great importance that there is a high resolution satellite imagery of good quality covering the site. The satellite imagery is the resource under investigation for possible adoption in the production of cadastral maps. The ideal imagery should possess similar ground characteristics as the aerial photographs and the PIDs in terms of the parcel boundaries.
- Preliminary Index Diagrams: These are the documents being investigated for improvement hence their availability is paramount. The site should be well covered by these maps and should at least be continuous, i.e. adjoining.
- Size: The area has enough data for conclusive analysis of the research in terms of plot sizes, topography, and sample size.
- Other data: There is alternative data, especially the Area List and other historical records for validation of the research findings.

The field site was searched for in different parts of the country to reflect different topographical characteristics. Three sites were available for choice; Ngong, Machakos and Naivasha. However, as the project progressed the main focus was directed towards the availability of good quality high spatial resolution satellite imagery with good area coverage and minimal cloud cover. A number of sites were either not covered by the satellite imagery or the available images had most of the boundaries obscured by cloud cover hence were found unsuitable. The Machakos site fulfilled most of the requirements and was thus selected for the study.

The choice for Machakos (Kiandani Registration Section) as the subject for the case study was straightforward, since it fulfilled the criteria of selection. The aerial photographs were available at a scale of 1:12 500 and 1:20 000; the satellite imagery was of good quality and had the least cloud cover of 3%; PIDs of continuous coverage and their Area List were available. However, the aerial photography was not controlled hence there was need to provide controls. An advantage of this site is the proximity to Nairobi which was the centre for analysis and ease of access. The location of the field site is displayed in Figure 3.2.

Figure 3.2: The study area, Kiandani Registration Section

The size of study area is approximately (3×3) Km and is characterized by flat, plain and undulating terrain. The site is largely a rural area having varying parcel sizes with clear parcel boundaries. The site also borders Machakos town which is under fixed boundary system. There are also open areas with dense parcels, infrequent parcel distribution covered with crops and forestry related vegetation (Appendix III).

3.3.2 Acquisition of Study Materials

Accomplishment of this objective was most time-consuming. It included the search for and acquisition of aerial photographs, satellite imagery, PIDs, collecting ground control, photogrammetric processing, satellite imagery processing and assessment of the quality of the extracted data.

3.3.3 Acquiring Photographs

Acquiring historical aerial photography is a time-consuming procedure. In Kenya, aerial photographs are distributed over numerous archives and libraries, and are held by a range of institutions, among them the Survey of Kenya (SoK) and the Kenya Institute of Surveying and Mapping (KISM), as well as other private commercial mapping companies. Some of these organisations have standardised their search and request systems, which makes the archives easily accessible to public. However, in some cases this standardisation makes it more difficult to deal with specialist demands, such as acquisition of high resolution scans of photogrammetric quality.

It was important to visually inspect the photographs before purchase to assure the coverage and quality. Either photocopies or diapositives of the frames were requested. The final selection of aerial photographs for purchase was based on the following considerations (in order of importance):

- Ground coverage – The area of interest should be completely covered by stereoscopic overlap of the images.
- Scale – The scale of the photograph determines the precision with which the photo-coordinates can be measured and what feature sizes can be discerned.
- Geometry – Best cadastral maps are obtained using vertical photographs in which the amount of tilt is not more than 3°.
- Format – Best results are obtained when using high-resolution scans (15-20 µm) of contact diapositives from the original negatives, using a photogrammetric quality scanner. However, as these are not always available, use of scans from contact prints was considered.
- Time – The period should be chosen such that the photographs possess almost similar boundary characteristics as the photographs used to produce the PIDs.

Costs for aerial photography were variable. In all cases cover searches were conducted free of charge. Sometimes small charges applied to requests for photocopies, or travel expenses were involved in case the institution needed to be visited personally for inspection of the photographs. In general, non-profit organisations supplied photographs at lower prices than the commercial sector. To give an indication, the price for one stereo-pair of digitally scanned images acquired during this project ranged from KShs. 500 (poor quality scanned contact prints) to KShs. 1,500 (high quality scanned diapositives). Eventually, two sets of photography were bought; a 1978 and 2003 photography at scale of 1:20 000, 1:12 500 respectively.

Photogrammetric Modeling

The photogrammetric modelling process was done using Leica Photogrammetric Suite (LPS) version 9.0 software. The photographs were scanned, georeferenced, oriented (interior and exterior), and processed for digital elevation model extraction and orthorectification. The project area was covered in two strips. Consequently, processing was also done in two ways. First, each strip was processed individually then mosaicked together. A misalignment occurred at the point of joinery. Secondly, a self calibrating bundle block adjustment for aerial triangulation of the whole area was done. Convergence was achieved after four iterations. In this method, the whole block was processed in one step thus misalignment associated with the creation of mosaics was resolved. This later method was adopted for further work. Figure 3.3 represents a general photo restitution process; however terrain editing was not done since the resultant digital elevation model was within the accuracy requirement.

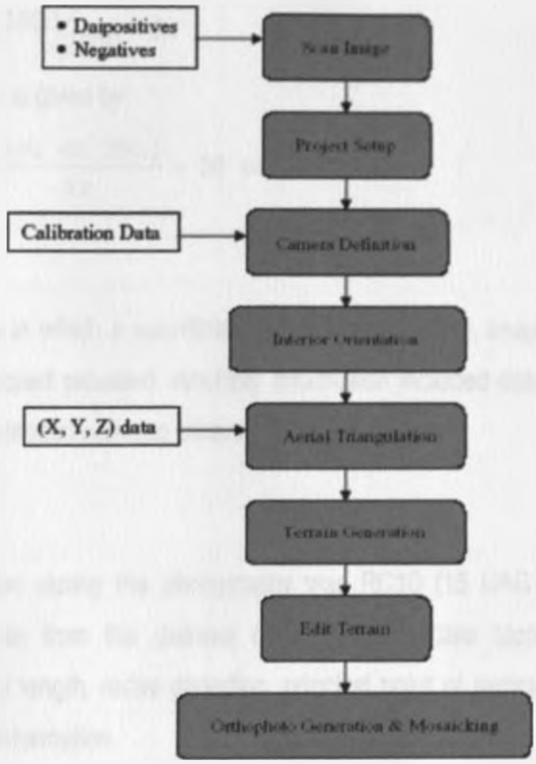


Figure 3.3: Digital photogrammetric restitution process

Scanning

The black and white analogue photographs and the diapositives were scanned on a *Contex Wide Format Scanner* at a resolution of 1200*dpi* (dots per inch), approximately 20.8μm. This resolution corresponds to a ground resolution of (0.26-1.25) meters at nominal scale. Scan resolution can be varied depending on the accuracy requirements of the mapping. A good approximation of this value was obtained by dividing the output pixel dimension value by the enlargement factor required to bring the original photo to the output orthophoto scale (Welch *et. al.*, 1996). For this research, the scanning resolution was arrived at as shown below;

Photo scale: 12 500

PID scale: 2 500

Output pixel size giving optimum visual quality for digital orthophoto ranges between: 100 to 200μm

Enlargement factor is given by:

$$EF = 12500/2500 = 5x$$

Scanning Range is given by:

$$SR = \frac{[100 \Leftrightarrow 200]}{5x} \approx 20 \Leftrightarrow 40\ \mu m$$

Project Setup

This was the initial step in which a coordinate system was defined, images added, and general information about the project provided. Ancillary information included data such as flying height, camera type, and photo direction among others.

Camera Information

The type of camera used during the photography was RC10 (15 UAG II; 3104). The camera information was available from the camera calibration certificate (appendix II). It contained information such as focal length, radial distortion, principal point of symmetry, fiducial marks and photographic resolution information.

Interior Orientation (IO)

This process is automated in LPS. IO established a relationship between an image and the internal camera film coordinates. The major work here involved measuring the coordinates of fiducial marks. One fiducial mark was approximately measured for a start, and the rest done automatically, Figure 3.4. LPS uses a similarity transformation to correct for translation and rotation during the scanning process (Equation 3.1). The underlying algorithm is a least square template matching hence the fiducial marks can be found very accurately (Leica, 2005).

$$\begin{bmatrix} x = a_o + m(x^{"} \cos\alpha - y^{"} \sin\alpha) \\ y = b_o + m(x^{"} \sin\alpha + y^{"} \cos\alpha) \end{bmatrix} \qquad 3.1$$

Where *x* and *y* are the photo coordinates; x'' and y'' are the digital image coordinates; a_0 and b_0 are offset of the origin; ά is the angle between the two systems; and *m* is a scale factor.

Figure 3.4: Automatic Fiducial Measurement: (a) Manually measured fiducial mark, (b) Automatically measured fiducial mark, (c) Automatically measured fiducial marks in a strip

Aerial Triangulation (AT)

This process was performed to orient the images to one another and to the ground coordinate system. The goal was to solve the orientation parameters (X, Y, Z, omega, phi, and kappa) for each image and to establish the true ground coordinates for each measured point. The AT process was time-consuming but a critical component of the digital photogrammetric work flow. The AT process included:

- Measurement of ground control points (GPS points)
- Establishment of an initial approximation of the orientation parameters (rough orientation)
- Measurement of tie points (an automated procedure in LPS)
- Performing the bundle adjustment
- Refinement of the solution by removal or re-measurement of inaccurate points until the solution is within an acceptable error tolerance

Figure 3.5 represents the tie points automatically generated. Though it's an automated process, user intervention was required especially to refine the measured tie points.

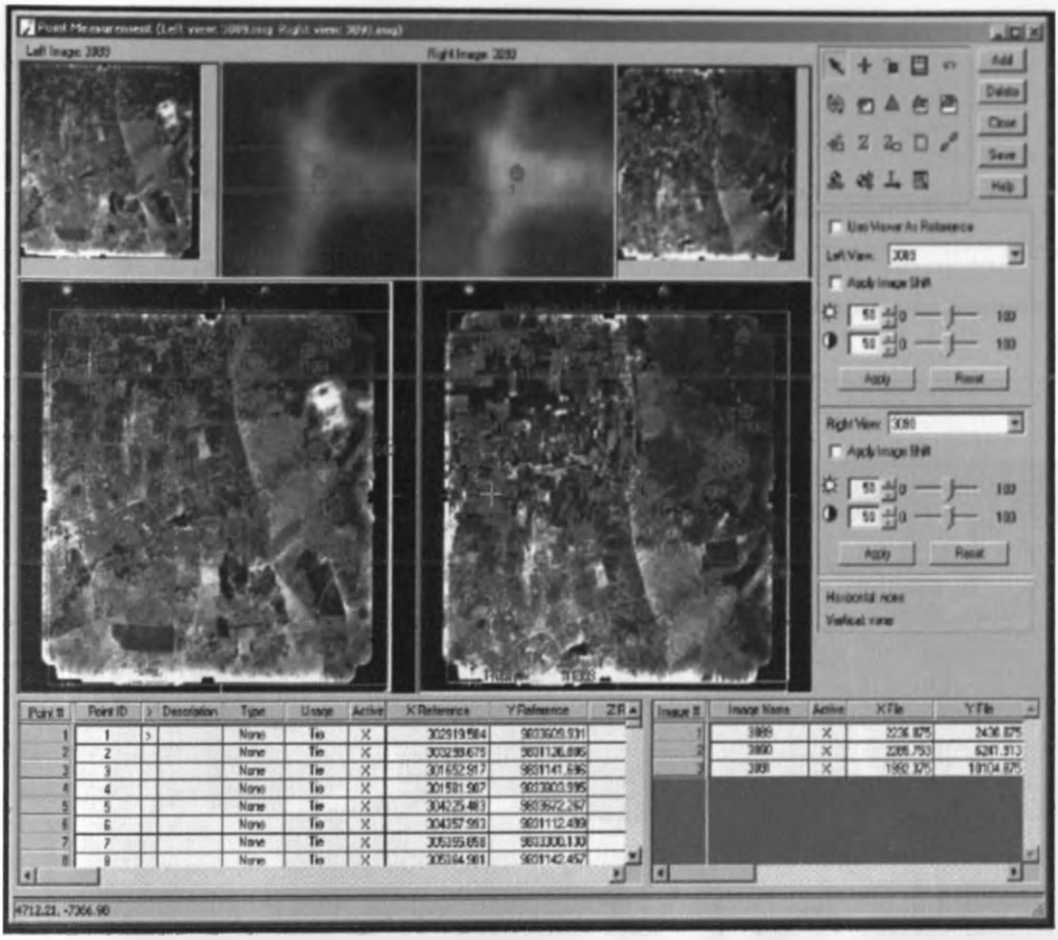


Figure 3.5: Automatic tie point measurement

Figure 3.6 (a) and (b) shows the individual strips after the process of aerial triangulation. Strip 1 had all its photographs with a phi (φ) (rotation) in the range of 5.8461°-6.7913°. These values are greater than the allowable limit of 3° for vertical photography. This has been captured in figure 3.6a. Strip 2 fulfilled all the conditions for a vertical photograph, also noticeable in figure 3.6b. Further processing (mosaicking) of these images resulted in misalignment when the two strips are mosaicked as shown in figure 3.7. The distance of mismatch is approximately 34m.

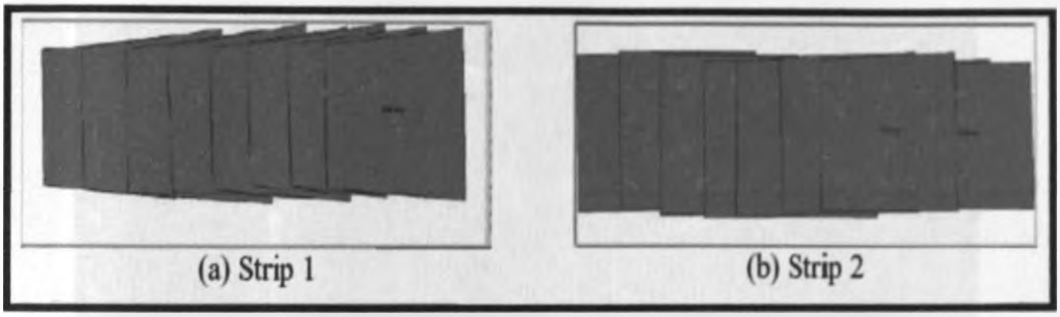


Figure 3.6: Products of strip by strip AT

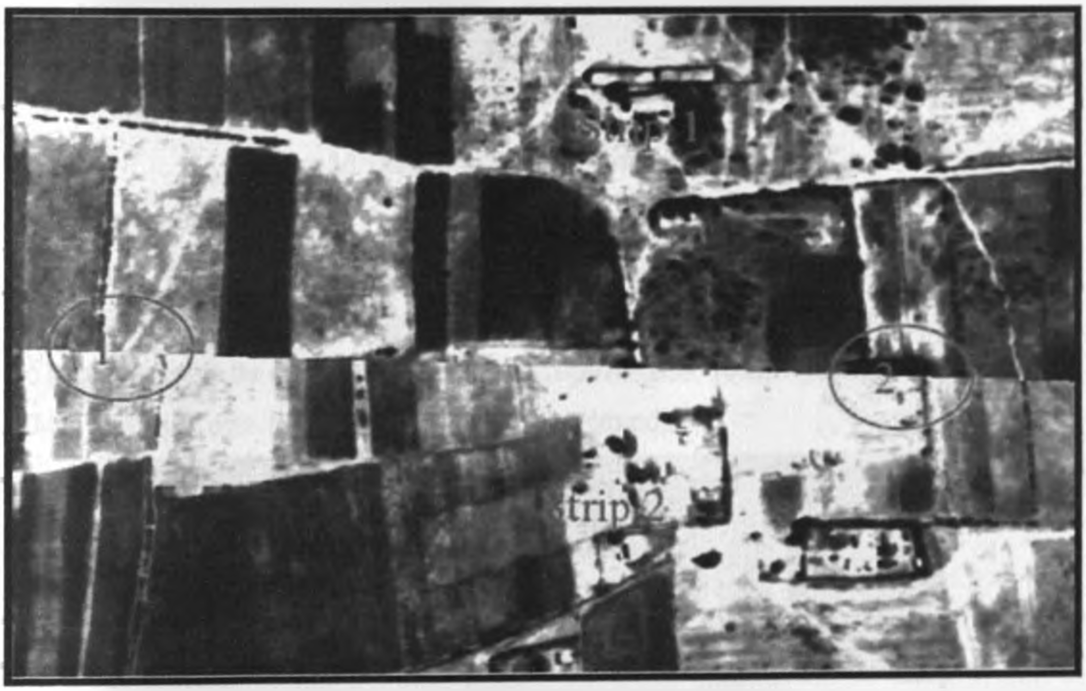


Figure 3.7: Misaligned boundaries resulting from mosaicking of strips 1 and 2

In the second method, a self calibrating bundle block adjustment was performed. Tie points were visually defined while others automatically generated before the bundle block adjustment. The solution was refined by removing or re-measuring inaccurate points until the solution was within acceptable error tolerance. Further processing was done and the resulting orthophoto had no misaligned features, figure 3.8.

Figure 3.8: Orthophoto after combined block adjustment

Terrain Generation

This process was run as an automatic process in LPS. Automatic terrain generation algorithms typically match "terrain points" on two or more overlapping images. Points appearing in more than two images increase the reliability of the point (Leica-geosystems, 2005). Figure 3.9 represents the DTM of the project area. Brighter areas indicate higher grounds.

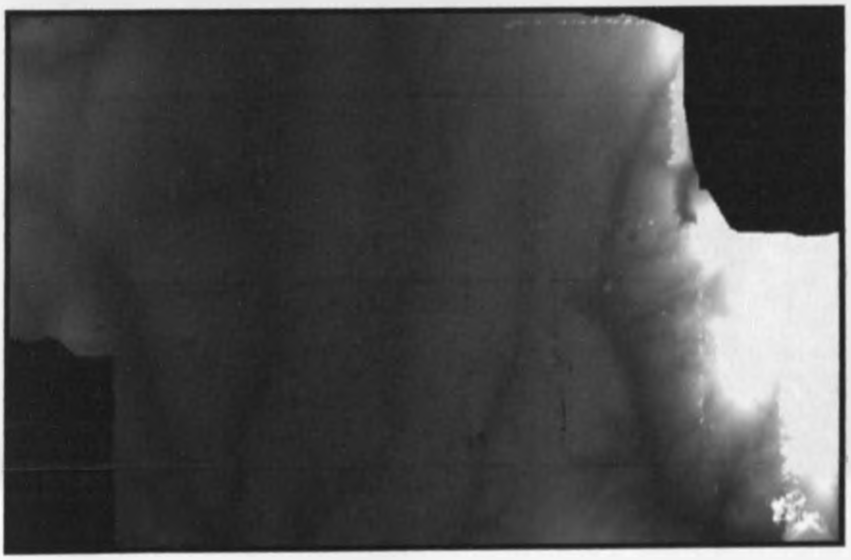


Figure 3.9: DTM

Orthophoto Generation and Mosaicking

The orthophoto production involved the following steps:

- Selection of the images to be orthorectified
- Choosing of the DTM to be used for orthorectification
- Defining orthophoto options such as output Ground Sample Distance (GSD), the image re-sampling method, projection, and output coordinates. The GSD was set at 0.4m, image re-sampling done using nearest neighbour, a UTM projection adopted.

The orthorectification process was not an interactive process. However, the mosaicking process did involve some operator interaction. After images were chosen for the mosaic process, seams were defined (polygons or lines used to determine which areas of the input images will be used in the output mosaic). Figure 3.10 represents the orthophoto of the project area.

Figure 3.10: Orthophoto of the study area

3.3.4 Acquiring High Resolution Satellite Imagery

High resolution satellite data is becoming as an indispensable data source in large scale mapping due to affordable cost and possibility of supplying data on-demand (Mamoru *et. al.*, 2002) . Among currently available and most successful sources are IKONOS and QuickBird that belong to commercial agencies. Although the IKONOS satellite has provided the world's first source of commercially available high-resolution satellite imagery, QuickBird is currently (as at the time of this study) the satellite with the highest resolution for civilian uses. Panchromatic band of QuickBird is providing 0.61 meters ground resolution that can easily be used to derive high accuracy large-scale maps from space data.

Furthermore, it also has a long-track and/or across-track stereo capability, large area coverage, and the ability to take images over any area, especially hostile areas where airplanes cannot fly. The successful launch of these two high-resolution satellites has narrowed the gap between satellite images and aerial photographs. In the near future, it could even replace aerial photographs for some applications depending on the resolution and accuracy requirements.

For this study, a panchromatic imagery with 0.61m spatial resolution and 2.44m multi-spectral spatial resolution was used. The image is an archive acquired on the 17th December 2003. This QuickBird image (Figure 3.11) was provided as *Standard Imagery Products*, which is designed for users acquainted with remote sensing applications and image-processing tools that require data of modest absolute geometric accuracy. These standard imagers are radiometrically calibrated, corrected for sensor and platform-induced distortions, and map to a projection system (DigitalGlobe, 2004). This particular image has a cloud cover of 3% and covers a total area of 25 km^2.

Figure 3.11: QuickBird image taken over Kiandani Registration Section in Machakos

Preliminary Index Diagrams

In this study, six adjoining sheets of cadastral maps covering the whole study site were acquired from Machakos District Survey of Kenya office. The maps were prepared in 1986 using 1978 aerial photography. Each sheet contained an average of seventy parcels except for one sheet adjacent to Machakos town council with over ninety parcels. It was necessary to have these maps to aid in the delimitation of parcel boundaries on the satellite imagery and on aerial photographs. The parcel area information was contained in a PID Area List obtained at Survey of Kenya Headquarters.

Table 3.1: Characteristics of acquired datasets

Dataset	Date	Source	Scale/Resoln	Scan Resoln	Image Type	Format
PIDs	1986	Machakos	1:2 500	400dpi*2	-	-
Photographs	1978	SoK	1:20 000	800dpi	B/W*3 (Vertical)	23 x 23cm
Photographs	2002	KISM*1	1:12 500	1200dpi	B/W (Vertical)	23 x 23cm
Diapositives	2002	KISM	1:12 500	1200dpi	B/W (Vertical)	25 x 25cm
Topo-sheet	2000	SoK*4	1:50 000	-	-	-
QB-Image	2002	Ramani	0.61m	-	Color (Orthorectified)	5 x 5Km

**4 Survey of Kenya; *2 dots per inch; *3 Black & White; *1 Kenya Institute of Surveying & Mapping*

3.3.5 Collecting Ground Control

Once the photographs and diapositives were acquired, suitable points were identified and marked on the photos prior to the survey to make sure they were visible on the images. These points were well-defined natural features, easily accessible in the field and clearly identifiable on the photographs. A minimum of two planimetric and three height points were needed to define a datum. Control points were identified evenly over the area to ensure a strong geometry in the photogrammetric models.

Three high-precision geodetic GPS receivers were available for the ground control survey; 1 Leica and 2 Sokkia receivers. The GPS receivers were used in differential mode of surveying. This mode is recommended for photo scales in the range of 1/4,000-1/50,000 (Chandler 1999). For the principles of GPS surveying, reference can be made to standard text books (e.g. Leick 1995; Uren & Price 2006). In this section only the practical considerations relevant for this study are discussed.

One of the receivers was fixed on a tripod and served as a base station, while the other two (rovers) were mounted on tripod and moved inter-changeably (one hour interval) to record the positions of all control points relative to the base station.

Figure 3.12 shows the satellite availability plot versus PDOP and GDOP (Point Dilution of Precision and Geometric Dilution of Precision respectively) values for the selected location and time. From the graph, the green line indicates the satellite availability with respect to time of the day, blue line indicates the GDOP with respect to satellite availability and the red line indicates the PDOP with respect to the same. There were approximately 11 satellites on average at the time of data collection with a GDOP of two (2). An elevation mast of 15° above the horizon was set to exclude excessive systematic effects arising from the atmosphere. It was also noted that at this latitude (i.e. in the Kenya) most satellites are in the eastern section of the sky, as can be seen in the 'sky plot', figure 3.13.

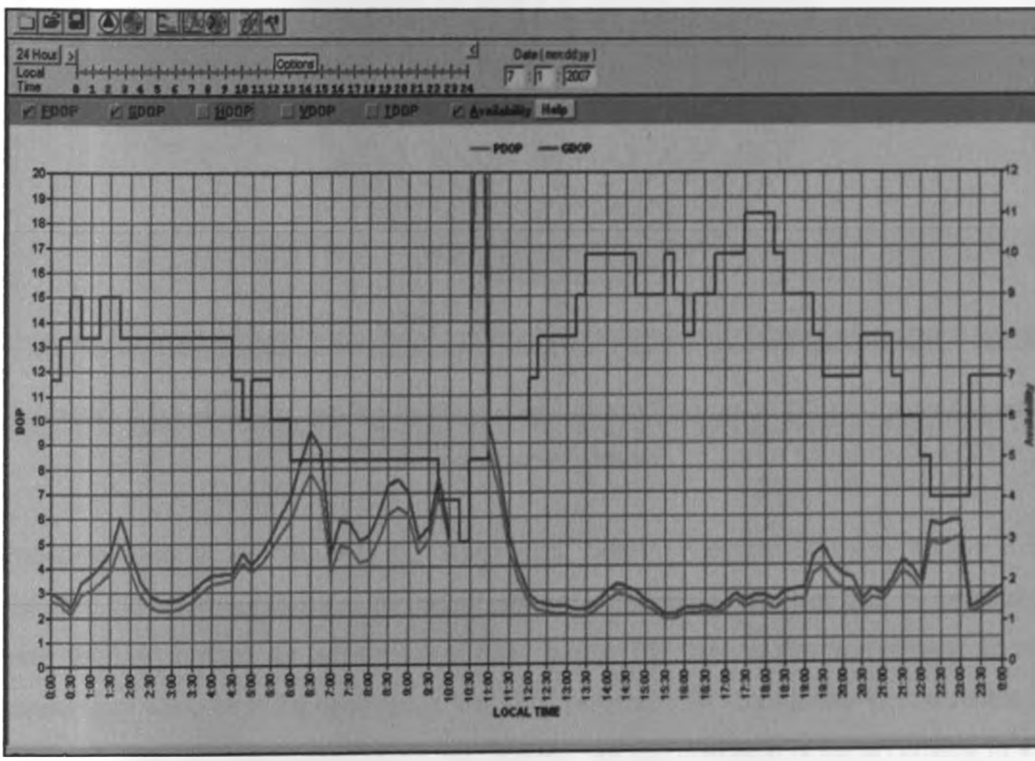


Figure 3.12: A typical plot of satellite availability throughout a day; note the high peaks in GDOP value during the morning, which should be avoided for observations. This plot was created using Ashtech Solutions software

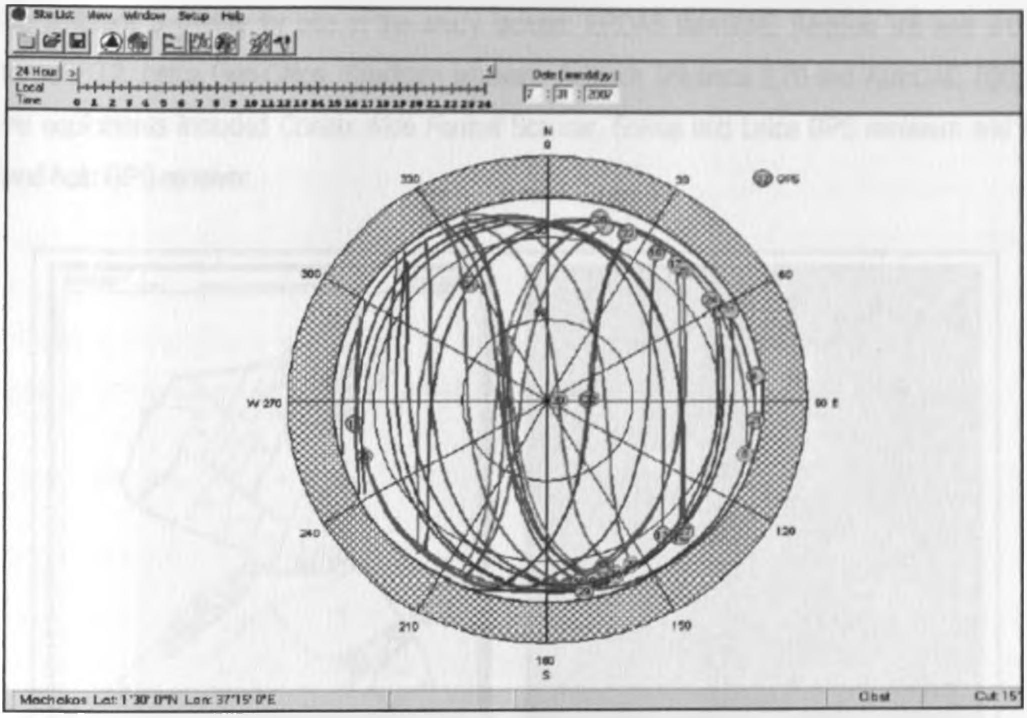


Figure 3.13: A typical sky plot, showing the tracks of satellites throughout a day. This plot was created using Ashtech Solutions software

Post-processing of the data was performed using Sokkia, Spectrum software (Version 3.3), revealing the relative positions of the control points to a precision of less than 0.01 m. Two points were used as controls for adjustment of other points. The base station was allowed to run continuously throughout the observation time. The processed 2-D coordinates are presented in Table 4.1. The GPS height component was however not used because of the uncertainty in the geoidal undulations. Currently, there are no reliable geoidal undulations for Kenya, hence GPS heights cannot be used for mapping purpose.

3.3.6 Miscellaneous Information

The auxiliary sources of information included information on parcel sizes contained on PID Area List, topographical map of Konza (162/1, 1:50 000) available at Survey of Kenya Headquarters. Other data such as area information of newly subdivided parcels were derived from the PIDs using digital planimeter and computer digitizing

The software available for use in the study include: ERDAS IMAGINE (Version 8.6 and 9.0), ArcView 3.2, Leica Geo-Office, Spectrum software, Ashtech Solutions 2.70 and AutoCAD 2005. The equipments included *Contex Wide Format* Scanner, Sokkia and Leica GPS receivers and a hand held GPS receiver.

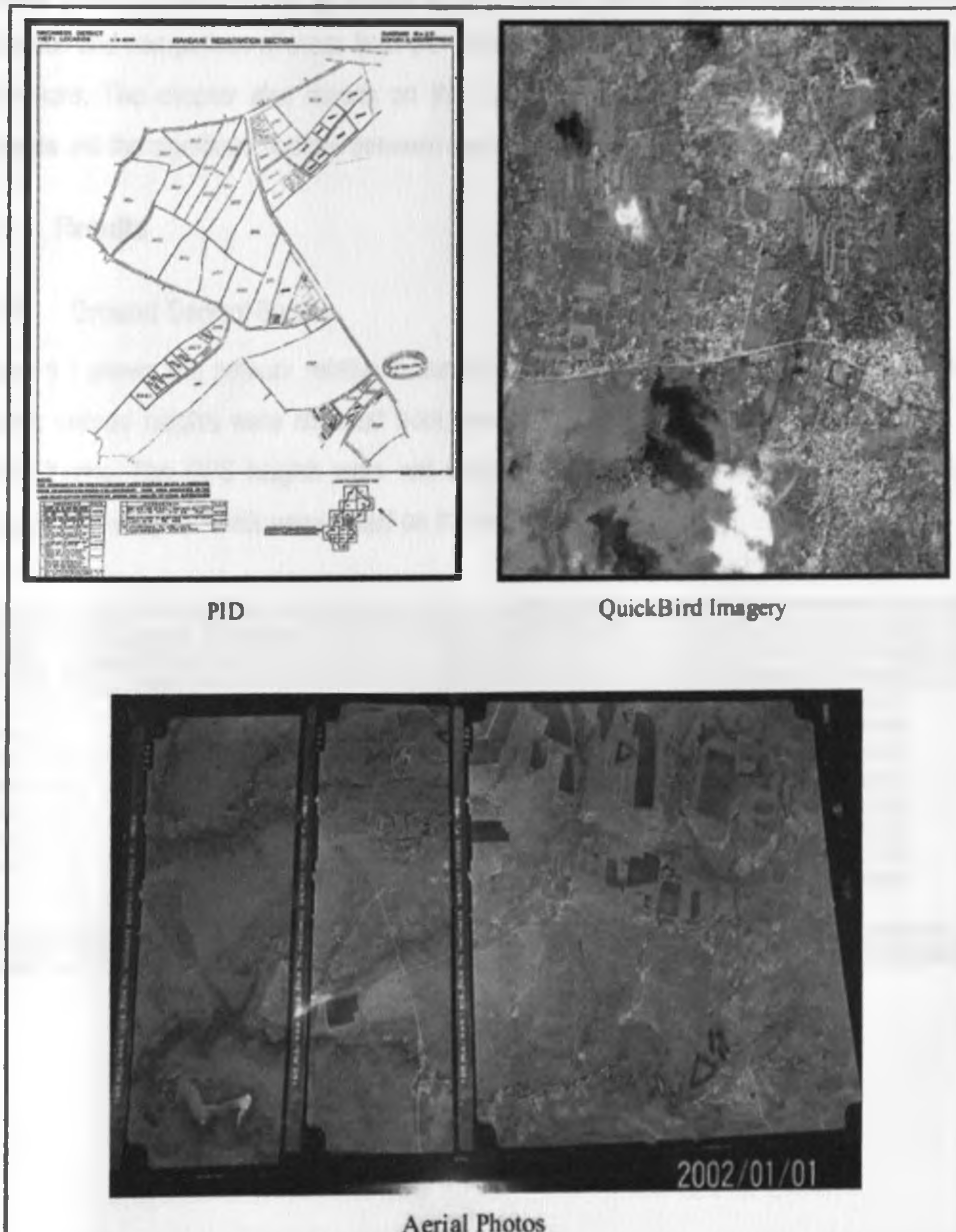


Figure 3.14: Datasets used in the study

4 RESULTS

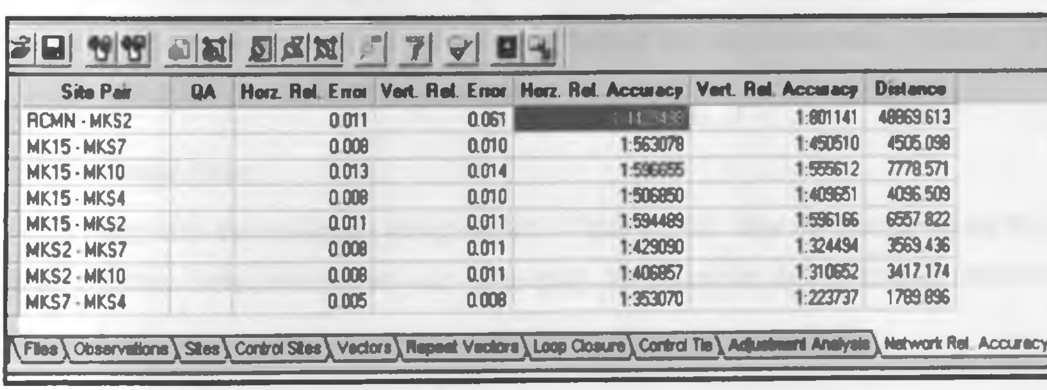
4.1 Introduction

The previous chapter described the methodology for investigating the research questions. This chapter presents different sets of results of GPS control survey, the photogrammetric process, extraction and comparison of areas from the different datasets and the test results regarding their differences. The chapter also reports on the statistical analysis on the parcel areas from the datasets and the significant findings between methodologies used to extract them.

4.2 Results

4.2.1 Ground Control Survey

Figure 4.1 shows the network relative accuracies. The vertical component was not used in the project; instead heights were obtained from traverse points used by the Ministry of Roads and Public Works. The GPS heights were not used because of the geoidal undulations while the heights by Ministry of Roads were based on the local datum.



Site Pair	QA	Horz. Rel. Error	Vert. Rel. Error	Horz. Rel. Accuracy	Vert. Rel. Accuracy	Distance
RCMN - MKS2		0.011	0.061	[illegible]	1:801141	48869.613
MK15 - MKS7		0.008	0.010	1:563078	1:450510	4505.098
MK15 - MK10		0.013	0.014	1:596655	1:555612	7778.571
MK15 - MKS4		0.008	0.010	1:506850	1:409651	4096.509
MK15 - MKS2		0.011	0.011	1:594489	1:596166	6557.822
MKS2 - MKS7		0.008	0.011	1:429090	1:324494	3569.436
MKS2 - MK10		0.008	0.011	1:406857	1:310652	3417.174
MKS7 - MKS4		0.005	0.008	1:353070	1:223737	1789.896

Figure 4.1: The Ground control network relative accuracies

Table 4.1: GPS coordinates for ground control points

	Pt. Name	Easting (m)	Northing (m)	Height (m)
1	MK 16	302974.127	9833991.075	1670.126
2	MK 24	306630.415	9835490.341	
3	MK 18	306713.216	9834299.249	
4	MK 02	300629.401	9831300.725	1644.097
5	MK 04	303024.222	9832202.220	
6	MK 10	299710.329	9834590.115	
7	MK 15	307119.788	9832229.926	1662.025
8	RCMN	265499.328	9865267.663	

4.2.2 Photogrammetric Processing

A Check point analysis was done to compare the photogrammetrically computed ground coordinates of check points to their original values. The result of this analysis yielded a RMSE of 0.389m. This is the degree of correspondence of the computed values to their original values. The DTM vertical accuracy had a RMSE of 1.2338m, while the orthophoto resolution was 0.30m.

4.2.3 Area Extraction

PID Areas

As indicated in the previous chapter, PID areas are direct extraction of mean areas from the official Area List. Four planimeter readings were used to compute the mean area value. A total of 126 parcels were used in the study and are presented in Table 4.2 (a).

Satellite Image Areas

Parcel areas from the orthoimage are presented in Table 4.2 (c). They are average values from three readings. Area measurement was done using the measuring tool of ERDAS IMAGINE version 8.6.

Orthophoto Areas

The parcel areas from orthophoto are presented in Table 4.2 (b). They are mean areas from three readings. Measurement was done using the measuring tool of ERDAS IMAGINE version 8.6. Table 4.3 shows the differences in percentages between the reference dataset with respect to both PIDs and orthoimage.

Table 4.2: Sample Parcel Areas in hectares from Satellite image, Orthophoto and PID

KIANDANI REGISTRATION SECTION				
Parcel areas in hectares				
		[a]	[b]	[c]
No.	Plot No.	Satellite	Orthophoto	PID
1	2474	0.10	0.11	0.21
2	65	0.14	0.14	0.22
3	3870	0.19	0.18	0.22
4	225	0.21	0.22	0.20
5	2355	0.24	0.24	0.16
6	2401	0.30	0.31	0.30
7	2402	0.30	0.31	0.32
8	3869	0.32	0.33	0.30
9	3459	0.34	0.34	0.30
10	56	0.35	0.34	0.39
11	3846	0.35	0.35	0.35
12	64	0.35	0.36	0.30
13	172	0.44	0.44	0.47
14	2028	0.47	0.47	0.80
15	42	0.49	0.47	0.60
16	9	0.47	0.48	0.38
17	53	0.44	0.49	0.60
18	3001	0.49	0.50	0.51
19	3002	0.49	0.51	0.46
20	154	0.50	0.53	0.70

It was noted from the above table that the parcel areas from satellite and orthophoto are close. The closeness of the areas from both methods was attributed to the corrections already applied to both the aerial photographs and the satellite imagery. However the minor differences were associated to the level of correction on each image, geo-referencing and the digitization process. On the other hand, the variations of parcel areas from PIDs and the rest of the other datasets were associated to the non rectification of the aerial photographs used in the production of the PIDs.

4.3 Parcel Area Differences

Table 4.3: Area comparison between: orthophoto / Satellite and orthophoto / PID

Area differences between the datasets					
No.	Parcel No.	Orthophoto-PID	% difference	Orthophoto-Satellite	% difference
1	2474	-0.10	-86.9	0.01	4.7
2	65	-0.08	-57.1	0.00	0.0
3	3870	-0.04	-20.9	-0.01	-3.7
4	225	0.02	9.1	0.01	4.5
5	2355	0.08	33.3	0.00	0.9
6	2401	0.01	3.2	0.01	3.2
7	2402	-0.01	-2.2	0.01	3.2
8	3869	0.03	9.4	0.01	4.3
9	3459	0.04	11.7	0.00	1.2
10	56	-0.05	-14.7	-0.01	-4.0
11	3846	0.00	0.0	0.00	0.0
12	64	0.06	16.7	0.01	2.8
13	172	-0.03	-6.8	0.00	0.0
14	2028	-0.33	-70.2	0.00	-1.0
15	42	-0.13	-27.7	-0.02	-4.3
16	9	0.10	21.3	0.01	3.0
17	53	-0.11	-22.2	0.05	10.2
18	3001	-0.01	-1.3	0.01	2.0
19	3002	0.05	9.6	0.02	3.9
20	154	-0.17	-32.1	0.03	6.2

4.4 Statistical Tests

As earlier discussed in section 3.2, a smaller confidence level of one percent was conveniently chosen to minimize Type I error. Double tailed Student's t-Test was then used to assess whether the means of any two of the groups were statistically different from each other.

4.4.1 T-Test (Orthophoto Areas Vs PID Areas)

Table 4.4a: Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PID Area-	2.0214	126	1.9223	0.1713
	Orthophoto Area	1.9313	126	1.7939	0.1598

Table 4.4b: Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PID Area-Orthophoto Area	126	0.993	0.000

Table 4.4c: Paired Samples Test

		Statistics				
		Paired Differences				
					99% Confidence Interval of the Difference	
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper
Pair 1	PID Area-Orthophoto Area	9.003E-02	0.2559	2.279E-02	3.040E-02	0.1497

Table 4.4c cont.: Paired Samples Test

		Statistics		
		t	df	Sig. (2-tailed)
Pair 1	PID Area-Orthophoto Area	3.949	125	0.000

The test procedure compared the means of two areas extracted from orthophoto and PID area list areas of each parcel.

4.4.2 T-Test (Orthophoto Areas Vs Satellite Areas)

Table 4.5a: Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 2	Satellite Area	1.9261	126	1.7969	0.1601
	Orthophoto Area	1.9313	126	1.7939	0.1598

Table 4.5b: Paired Samples Correlations

		N	Correlation	Sig.
Pair 2	Satellite Area-Orthophoto Area	126	1.000	0.000

Table 4.5c: Paired Samples Test

		Statistics				
		Paired Differences				
		Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference Lower	99% Confidence Interval of the Difference Upper
Pair 2	Satellite Area-Orthophoto Area	-5.28E-03	2.66E-02	2.37E-03	-1.15E-03	9.32E-04

Table 4.5c cont.: Paired Samples Test

		Statistics		
		t	df	Sig. (2-tailed)
Pair 2	Satellite Area-Orthophoto Area	-2.223	125	0.028

The test procedure compared the means of two areas extracted from orthophoto and satellite image of each parcel.

4.4.3 T-Test (Satellite Areas Vs PID Areas)

Table 4.6a: Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 3	Satellite Area	1.9261	126	1.7969	0.1601
	PID Area	2.0214	126	1.9223	0.1713

Table 4.6b: Paired Samples Correlations

		N	Correlation	Sig.
Pair 3	Satellite Area-PID Area	126	0.993	0.000

Table 4.6c: Paired Samples Test

		Statistics				
		Paired Differences				
		Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference	
					Lower	Upper
Pair 2	Satellite Area-PID Area	-9.53E-02	0.2494	2.222E-02	-0.1534	-3.72E-02

Table 4.6c cont.: Paired Samples Test

		Statistics		
		t	df	Sig. (2-tailed)
Pair 2	Satellite Area-Orthophoto Area	-4.289	125	0.000

The test procedure compared the means of two areas extracted from satellite orthoimage and PID area list of each parcel.

4.5 Delimitation of Properties

Figure 4.2 represents an overlay of an orthophoto onto the orthoimage. The overlay had a perfect match as no misalignments occurred. Figure 4.3 represents digitized parcel boundaries while figure 4.4 represents the same parcels as digitized on the orthophoto. An overlay of the two vector data and their difference is represented in figure 4.5.

Figure 4.2: Orthophoto overlaid on satellite image

Figure 4.3: Delimitation of parcels on the satellite image

Figure 4.4: Delimitation of parcels on the orthophoto image

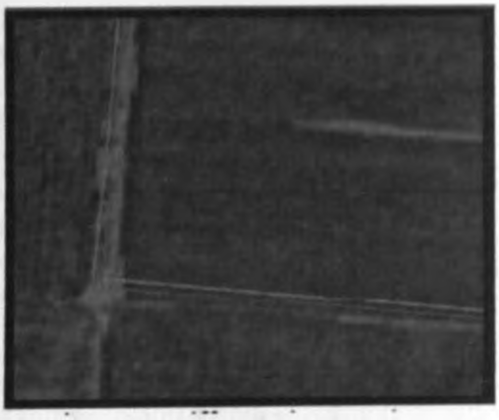


Figure 4.5: Difference between overlaid parcel on orthophoto (blue) & satellite orthoimage (pink)

4.6 Parcel Sizes

Figure 4.6 provides a summary of land distribution by size in the study area and shows that, only 6 percent of the local population own 5 ha or more. Majority of the local own land parcels in category ***B*** followed by ***A*** then ***C***. Table 4.7 shows the analysis of different categories as per the chosen criteria.

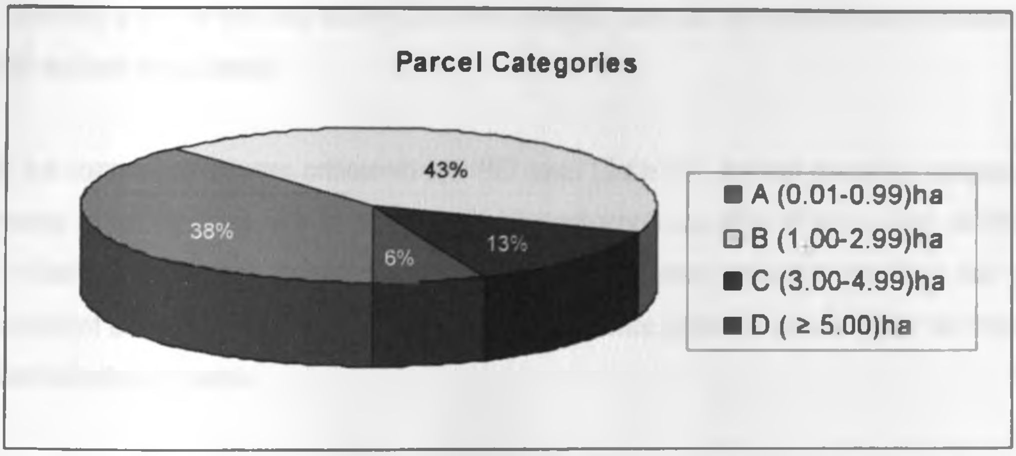


Figure 4.6: Percentage representation with respect to parcel size

Table 4.7: Parcel categories

Parcel Sizes				
Category	Freq.	% Var1.	% Var2.	% Var 3.
A (0.01-0.99) ha	48	16.2	16.6	2.6
B (1.00-2.99) ha	54	8.7	8.8	1.0
C (3.00-4.99) ha	16	6.6	6.6	0.3
D (≥ 5.00) ha	8	3.4	3.3	0.3

Var1 = Average parcel area difference between orthophoto & PID
Var2 = Average parcel area difference between Satellite & PID
Var3 = Average parcel area difference between orthophoto & Satellite

4.7 Discussion of Results

The study was carried out on rural properties bordering an urban centre. The land parcels considered in the study were easily identified on both the orthophoto and the satellite orthoimage. The parcel boundaries were characterized by trees, live enclosure or fences with presence of vegetation, roads or foot paths and water drainage with the presence of low altitude vegetation.

Statistical tests carried out on the parcels indicated that there was no significant difference between the orthorectified aerial photographs (orthophoto) and satellite image (orthoimage) for computing areas for land registration. On the other hand, there was significant difference between PID and orthophoto areas.

In the comparison between orthophoto and PID areas (Table 4.4), the test procedure compared means of two variables, that is, parcel areas from orthophoto and PIDs of each parcel. At 99% confidence level, a low significance value of zero was obtained indicating that there was a significant difference between the two areas. The confidence interval (0.03↔0.15) for the mean also indicated the same.

The paired sample test yielded a mean value of 0.09. This value being positive indicated that PID areas tend to be bigger as compared to the orthophoto areas. Bigger parcel areas were attributed to the variation of scale due to tilt. As the angle of tilt increases, the scale of photography becomes smaller. When scale gets smaller, the error quantity increases, consequently the bigger the distortion of parcel size and shape.

In comparing the orthophoto and satellite orthoimage areas at 99% confidence level (table 4.5), a significance value of 0.028 (2.8%) was obtained indicating that there was no significant difference between the two areas. Further, the confidence interval (-0.0012↔0.0932) for the mean was investigated and gave similar results.

The mean difference between orthophoto and satellite orthoimage areas was obtained as (-0.0053). This value was both negative and small in magnitude. It indicated that the satellite areas tend to be smaller in magnitude when compared to orthophoto areas. This change was attributed to the geometric accuracy /resolution of the satellite image. The satellite orthoimage had a coarse resolution compared to the orthophoto. The orthoimage and orthophoto had a resolution of 0.61 and 0.30m respectively.

In comparing PID and satellite orthoimage parcel areas at 99% confidence level (table 4.6), a low significance value of zero was obtained indicating that there was a significant difference between the two areas. The confidence interval (-0.1534↔0.0372) for the mean also indicated that the difference was significant. The mean difference (-0.0953) was negative indicating that the satellite areas are always smaller in size as compared to PID areas. This was attributed to the scale variation due to tilt and relief displacement.

It was also noted that the mean area difference of PID from orthophoto (0.090) and satellite (0.095) areas are comparable in magnitude. This was interpreted to mean that the departure of PID areas from orthoimage and orthophoto areas are approximately equal.

A summary of percentage difference in areas was also performed and the following results tabulated below.

Table 4.8: Frequency table: % area difference between orthophoto and satellite

Range (%)	Frequency	Percent
≤10	125	99.2
11-20	1	0.8
Total	**126**	**100**

Table 4.9: Frequency table: % area difference between orthophoto and PID

Range	Frequency	Percent
≤10	83	65.9
11-20	28	22.2
21-30	11	8.7
31-40	1	0.8
41-50	3	2.4
Total	**126**	**100**

Majority of the parcels from satellite orthoimage had their area differences below 10%. A similar trend was repeated with the PID areas. In comparison to orthoimage areas, the PID areas had fewer parcels in the same range. Some of the PID parcel areas were found to be in error of up to 50%. Mulaku, (1995) indicated that an error up to ±2% in area and ±2m in position was acceptable to the majority of map users in Kenya. With this level of accuracy, 81% of parcel areas from the satellite orthoimage were found to be within this range.

Further analysis was carried out to find out the average area variation when parcels were classified into different categories with respect to their sizes. Four categories were defined according to the "Labour Force Survey Report (1998/9)". This classification revealed that 38% of the parcels were less than one hectare, 56% were in the range between one and five hectares while 6% of the parcels were above five hectares. Parcel No. 2474 was treated as an extreme case thus was excluded in this analysis. Further analysis indicated that the smaller the parcel, the greater the error on their areas and vice versa. Figure 4.3 shows a summary of average area variation and the general trend taken by this variation on the parcel categories.

It was also observed that land parcels with an elongated shape had larger errors in their areas as compared to the rest. This error can be attributed to the identification and measuring process of shorter lengths. Parcels with longer sides are measured more accurately as compared to parcels with shorter lengths. Sampled parcels in this category included 53, 225, 42, 154, 29, 16, 65, 3870, 2355, 2028, 42, and 154. Using the satellite data, the first 6 parcels had area differences above 3% while the last six including parcel number 154 had area differences above 30% using PID area list. Figure 4.4 gives a pictorial view of their shapes.

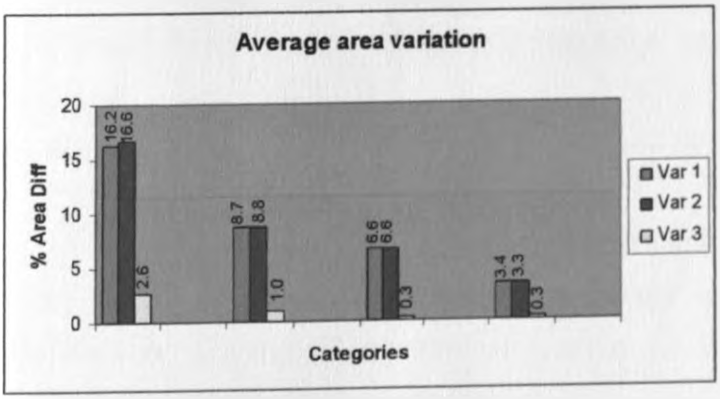


Figure 4.7: Area variation per category

Figure 4.8: Parcels (in red) with biggest errors

5 DISCUSSION

Through the integration of Remote Sensing, GIS and ground data, an assessment on the accuracy of Preliminary Index Diagrams from high spatial resolution orthoimage and factors affecting the accuracy has been executed. "The use of the high spatial resolution remote sensing images as an input for indirect methodology for cadastral projects is adequate for properties presenting low variation of topography, medium extensions and for planning cadastral activities among other activities" (Corlazzoli *et. al.*, 2004).

The logic behind the use of high-spatial resolution imagery over aerial photography is that, land titling can now be achieved much more rapidly than in the past by combining indigenous local knowledge of traditional boundaries with use of modem geospatial technologies. The introduction of high-resolution satellite imagery presents another opportunity for quick, cheap and accurate mapping and hence a quick solution to current land conflicts in Kenya today.

The operational method for this study can be suggested for the integration of remote sensing data and field data for the production of accurate registry index maps. Feature extraction from satellite imagery can be done through on-screen digitization with input of spatial information from field data. Thus the output can estimate the parcel areas more accurately in the form of a continuous parcel map with geographical extent, which will best compare with the actual parcel areas on the ground. This map can as well be referred to as registry index map due to their levels of accuracy.

Apart from the parcel boundaries, the satellite imagery would show extra details such as the vegetation type, houses, road types, infrastructural services etc. These features would improve the quality of existing cadastral maps thus making them more suitable for land transaction, infrastructural mapping, land valuation and taxation purposes.

5.1 Research Questions and Hypothesis

RQ1. How do PID parcel areas compare with those derived from RIM and ortho-rectified satellite images? If differences indeed exist, are they statistically significant and how are they interrelated?

Null hypothesis

Assumption: ($\mu_s = \mu_{RIM} \neq \mu_{PID}$).

a) There is no significant difference in parcel areas as measured from RIMs and satellite orthoimage i.e. (H_o: $\mu_s = \mu_{RIM}$).

Where μ_s is mean parcel area from orthorectified satellite image and μ_{PID} is mean parcel area from RIMs

Alternative hypothesis

b) There is significant difference in parcel areas as measured from satellite orthoimage and PIDs i.e. (H_a: $\mu_s \neq \mu_{PID}$).

Where μ_s is mean parcel area from orthorectified satellite image and μ_{PID} is mean parcel area from PIDs

Three sets of area data were sampled and used for comparison. The areas as obtained from the orthophoto were used as reference. The study shows that there is significant difference in parcel areas as measured from PIDs obtained from unrectified aerial photographs and satellite orthoimage thus rejecting the alternative hypothesis. The study also shows that PID areas are often bigger than the actual ground areas while the areas obtained from the orthoimage were either slightly less than the actual ground area or exactly equal to the ground area. The difference in parcel areas between the two can be attributed to the errors inherent in the unrectified photographs from which the PIDs were prepared. These errors in the satellite imagery were corrected in the ortho-rectification process which resulted into an orthoimage.

On the other hand, the study also shows that there is no significant difference in parcel areas as measured from RIMs and satellite orthoimage. An average variation in areas ranges from 2.6% for very small parcels to 0.3% for large parcels. Features required for larger scale mapping (e.g. roads, hedges and woodland boundaries at 1:2500 scale) were captured. The major exceptions to this are narrow linear features (such as electricity transmission lines, walls, and fences), which are generally difficult to distinguish in imagery of this resolution. We have that area variation in small parcels is large because of the approximation of their boundaries.

RQ2. What are the requirements of a Registry Index Map and to what extent do maps traced from ortho-rectified satellite images meet these requirements?

Research statement

The use of the orthoimages as an input for indirect methodology for PID production is adequate for parcel mapping and for planning cadastral activities.

Land tenure mapping requirement in Kenya are of two (2) kinds: Base mapping and Registry Index Mapping (RIM). The base mapping is done at a scale of 1:2500 with contours at 10 feet vertical interval. The accuracy requirements for ground controls for these maps should be as good as ±4 feet for height while the planimetric positions are plotted to within plotable accuracy. The RIMs are provided on standard sheet-lines at 1:50000, 1:10000, 1:5000 and 1:2500 depending on the size of the farm. Their accuracy is such that they conform to the accepted international standards i.e. that 90% of all well defined points shall be plotted to within 0.5mm of their true position at map scale.

Results and observations of the study show that high spatial resolution satellite imagery like QuickBird has a potential as a source of data within a national mapping agency. It has been demonstrated that imagery of this type can be used for several different purposes, and it is this multiple use which makes the imagery a viable tool in this context. Recent works show that the geometry of QuickBird or Ikonos imagery are accurate enough for mapping purposes up to scale of 1:5000 (Büyüksalih and Jacobsen, 2005; Alexandrov *et. al.*, 2004). Further research has shown that QuickBird satellite image can be used for mapping up to a scale of 1:2000 with enough GPS control points (Trần, 2005) accurately plotted with a root mean square in the range of 0.9m-7.3m (Ahmed, 2007). It therefore meets the requirements of accuracy in standard of Kenya.

RQ3. Do these diagrams, extracted from ortho-rectified satellite images, meet the set tolerances in boundary definition in Kenya?

Research statement

The diagrams extracted from the satellite orthoimages are adequate for parcel mapping and for planning cadastral activities

For a map scale of 1:5000 and a pixel size of 0.5m, Beata (2005) and Kay (2003) on behalf of the Joint Research Commission (JRC) of the European Union gives a tolerance of 2.5% on area measurement and 0.75m on distances for maps and orthophoto/images. With these specifications, the QuickBird orthoimage can be used to map land parcels in all the three categories; small, medium and large. With regard to the minimum requirements for a Land Registry Index Map to be of sufficient accuracy to perform its core functions of parcel identification, boundary relocation, mutation surveys and area computation, it can be reasonably concluded that PIDs from QuickBird orthoimage at a scale of 1:5000 met these requirements. From the results and discussion above, features extracted from orthorectified QuickBird satellite imagery can be used to produce cadastral maps for land registration in areas of similar terrain characteristics as the study area.

5.2 Sources of Errors

The best way to state the accuracy of cadastral features is to describe the survey/processing methods used in creating them. Thus, the accuracy of digital ortho-imagery is a result of accurate ground control, image resolution, DEM data and the image handling procedures. In addition to these, there are other potential sources of errors limiting the accuracy of satellite imageries.

The raw satellite images contain a number of errors. Geometric distortions are present primarily due to the earth's rotation while the imagery is being collected and by the elevation variation of the earth's surface that is being captured in the imagery. The latter error is known as relief displacement. Additionally, radiometric and atmospheric errors affect the visual quality of the image (Mark, 2000).

However, most of the distortions in the imagery can be corrected. The price of the imagery increases as more corrections are made to it. An entry-level price for satellite imagery normally includes radiometric and geometric corrections. In other words, the imagery is corrected for the earth's rotation and for general radiometric errors. Orthorectified images are corrected for the effects of elevation variation and represent the most accurate imagery available.

Other factors affecting the accuracy can be summarized as: digitizing errors, scanning errors, and finally the lack of ground truth that can fairly represent the reality with high accuracy taking into consideration the cost associated with such requirement.

For this study, the following are the main sources of errors:

Cloud Cover, Haze and Bright Spots

The image used in this study presented some limitations; the presence of clouds and haze restricts the area of utility and the identification of parcel borders is more complex. It is recommended to work with enhanced images, as boundaries are most of the time linear and thus more easily identified.

Parcel Size, Shape and Fence Type

The accuracy of identification depends directly on the size and shape of the property, the topography of the area, the type of fences and vegetation coverage present on the study area as well as the scale of the orthoimage used in the identification process (Corlazzoli, 2004). Depending on the average size of the properties, an adequate scale was chosen for clarity of parcel boundary. The demarcations of smaller parcels are defined by narrow linear features which are generally difficult to distinguish in imagery of this resolution. This explains why area variation in small parcels is large because of the approximation of their boundaries which is thus reflected in the area computation.

The variation of parcel area also depended on the number of vertices; in this study most of the parcels surveyed presented squared and rectangular shapes, reducing the number of vertices. The identification on the orthoimage of parcels presenting curved boundaries, as it is the case when the border is a river, will be less accurate. This is because the curved lines are approximated by linear lines of shorter lengths which is thus reflected in the overall parcel area. If this condition is combined with topographical accidents, parcels of reduced size as well as a dense vegetation cover, the use of QuickBird orthoimage for cadastral purpose will be limited.

Digitizing error

Plannimetric detail extracted from "heads up" digitizing procedures is less accurate than stereo compilation procedures (PaMagic, 2002). Previous works have estimated the digitizing error to be ±0.3mm. To ensure that no information in the orthoimage is lost, the digitizing interval must be adapted to the resolution of the orthoimage. This is normally not the case.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The principal objective of this study was to investigate the potential use of QuickBird orthoimage for use in cadastral surveying. To achieve this, comparisons of data from PID Area List, orthophoto and QuickBird orthoimage identification for different types of parcels were evaluated. Statistical tests carried out on the parcels indicated that there was no significant difference of areas (at 99% significance level) between orthorectified aerial photographs and satellite image for computing areas for land adjudication. On the other hand, there was significant difference in areas between PID and orthophoto areas.

6.2 Conclusions

The following can be concluded on the overall objective of the study, i.e. to evaluate the suitability of high spatial resolution satellite imagery for use in the production of PIDs for adjudication survey in Kenya.

- Good results were obtained for large and medium land parcels; although it presented its limits in identifying accurately small parcels and peri-urban land. The large and medium parcels had an average area difference of 0.3% (Category C and D) and 1.0% (Category B) respectively and 2.6% (Category A) for small parcels. In the category of small parcels.
- Parcels with elongated shape tend to have larger errors in their areas computation.
- The accuracy of identification depends directly on the size and shape of the property, the topography of the area, the type of fences and vegetation coverage present on the study area as well as the scale of the orthoimage used in the identification process.
- Very high resolution space images can be used for the generation of large scale cadastral maps. The geometric accuracy is not the limiting factor for the map scale; it is limited by the information contents of the images; that means the possibility of object identification.

The study has demonstrated that high-resolution satellite imagery with its utility to survey large areas at a time can be considered as an input for indirect land surveying methodology. This means that the re-fly process suggested by Adams (1969) as a means to upgrade the PIDs can be skipped for this alternative method. However, with regard to the minimum requirements for a Land

Registry Index Map to be of sufficient accuracy to perform its core functions of parcel identification, boundary relocation, mutation surveys and area computation, it can be reasonably concluded that PIDs from QuickBird orthoimage met these requirements.

Orthoimages are essential visualization medium containing both quantitative and qualitative information thus is ideal for assessing the correctness and completeness of data. Orthoimage production has already reached a high level of maturity as far as aerial images are concerned. In the case of cadastral and land management, orthoimages are extremely valuable. Provided suitable raw data acquisition, orthoimages may well replace traditional line drawings, while at the same time they contain the precious qualitative image information.

In general, when choosing a base framework for digital parcel mapping, digital ortho-imagery offers a logical choice due to their accuracy of measurement and feature representation, along with their usefulness for future applications. Advances in computer technology have made digital ortho-imagery more readily available, while improvements in computer processing, storage, and software have made them an increasingly practical choice.

Few countries are in the enviable position of having a uniform and complete system of land registration covering all land within the territory. These countries need no longer have recourse to adjudication; the land register will at all times provide particulars of land parcels and the rights held in them. Many countries, however, will still need to resort to adjudication in some form in order to introduce, expand or unify a system of land registration. Various factors pertaining in these countries will obviously affect the forms of adjudication to be adopted. One such factor is the degree of urgency accorded by governments to rapid compilation of a land register and the costs involved, particularly costs of cadastral surveying and mapping of parcels.

In the interests of speed and economy the use of high spatial resolution orthoimages are likely to be adopted, but this will only be viable if all parcels in a substantial area of land can be surveyed and mapped in a single operation, and this will involve a systematic form of adjudication. Another factor is the existence, when adjudication is first undertaken of other systems of land record such as registration of deeds, and their reliability. This factor may enable a form of adjudication by 'conversion' of deeds registers to be adopted.

6.3 Recommendations

Satellite positioning systems, geo-information systems and remote sensing constitute the modern geospatial technologies. All these technologies today find quite significant application in Kenya, but have not been fully exploited due to limiting technical, legal, institutional and political bottlenecks. There is therefore need to address these issues to ensure that Kenya does not lag behind technologically.

Topography as a factor that affects accuracy of orthoimage map was not considered in this research. Additional research over varying topography would be necessary to find out how high resolution satellite large scale mapping is affected by varying topography.

In the earlier paragraphs, handheld GPS receiver for cadastral work has been suggested for use to overcome the problem of undefined boundaries. This is an area that requires further research to find out how the two datasets can be merged harmoniously to achieve greater utility maps.

One important factor for any successful mapping anywhere in the world today is a good geodetic network in terms of accuracy and distribution. Kenya presently is faced with the problem of a very unreliable geodetic network. The network is dated back to British survey in the dawn of last century. Most of the original points had been destroyed deliberately or by accident. There is therefore the need for initial investment in this area among others such as hardware, software and personnel.

A number of technical aspects will have to be dealt with for mapping purposes. One of the most crucial aspects is overcoming low visibility caused by cloud cover in certain areas. This aspect may be considered along with applications of other data which are less weather dependent to achieve so-called all weather mapping capability.

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APPENDICES

APPENDIX I

PID Area List

KIANDANI REGISTRATION SECTION				
Parcel areas in hectares				
		[a]	[b]	[c]
No.	Plot No.	Satellite	Orthophoto	PID
21	2362	0.53	0.54	0.50
22	2359	0.53	0.56	0.60
23	67	0.56	0.57	0.60
24	3000	0.60	0.59	0.54
25	173	0.60	0.60	0.70
26	3457	0.61	0.62	0.64
27	29	0.61	0.65	0.90
28	2358	0.65	0.65	0.80
29	3456	0.65	0.66	0.61
30	3468	0.66	0.66	0.86
31	14	0.62	0.67	0.60
32	3469	0.71	0.70	0.64
33	3458	0.70	0.70	0.54
34	624	0.71	0.70	0.81
35	3425	0.72	0.71	0.68
36	2331	0.72	0.72	0.70
37	37	0.77	0.76	0.90
38	43	0.80	0.78	0.80
39	91	0.80	0.80	0.80
40	2418	0.79	0.81	1.00
41	72	0.81	0.83	0.90
42	36	0.86	0.87	0.90
43	16	0.98	0.89	0.90
44	109	0.89	0.91	1.00
45	371	0.90	0.91	1.10
46	3455	0.91	0.94	1.04
47	3178	0.97	0.96	0.87
48	63	0.98	0.98	1.00
49	110	0.97	1.00	1.00
50	156	0.98	1.00	1.10
51	3453	1.05	1.04	1.01
52	87	1.03	1.04	1.00
53	179	1.03	1.05	1.20
54	170	1.17	1.15	1.10
55	227	1.17	1.16	1.30
56	2419	1.19	1.17	0.90

KIANDANI REGISTRATION SECTION				
Parcel areas in hectares				
		[a]	[b]	[c]
No.	Plot No.	Satellite	Orthophoto	PID
57	2251	1.18	1.20	1.20
58	18	1.22	1.22	1.30
59	3452	1.22	1.23	1.21
60	58	1.22	1.23	1.40
61	357	1.26	1.25	1.30
62	352	1.30	1.33	1.60
63	89	1.33	1.36	1.20
64	181	1.41	1.43	1.40
65	28	1.41	1.46	1.30
66	23	1.48	1.48	1.40
67	73	1.51	1.50	1.50
68	351	1.54	1.52	1.70
69	71	1.55	1.54	1.60
70	155	1.52	1.54	1.70
71	61	1.55	1.54	1.70
72	354	1.60	1.59	1.60
73	2252	1.57	1.60	1.50
74	52	1.59	1.60	1.60
75	2292	1.62	1.64	1.50
76	355	1.63	1.64	1.80
77	356	1.69	1.72	1.90
78	11	1.72	1.73	2.33
79	157	1.84	1.83	1.80
80	2029	1.82	1.85	1.70
81	178	1.95	1.95	1.80
82	177	1.94	1.96	2.20
83	88	2.02	1.98	2.40
84	3454	1.99	2.01	1.90
85	3845	2.04	2.06	2.09
86	12	2.04	2.06	2.80
87	15	2.18	2.19	2.20
88	126	2.31	2.31	2.40
89	49	2.32	2.32	2.60
90	1313	2.40	2.37	2.53
91	39	2.39	2.40	2.40
92	1951	2.48	2.46	2.40
93	55	2.44	2.47	2.60
94	57	2.47	2.47	2.60
95	1952	2.52	2.50	2.40
96	176	2.48	2.50	3.00
97	1950	2.55	2.55	2.11
98	353	2.73	2.74	2.80

KIANDANI REGISTRATION SECTION				
Parcel areas in hectares				
		[a]	[b]	[c]
No.	Plot No.	Satellite	Orthophoto	PID
99	33	2.71	2.75	2.60
100	40	2.81	2.81	2.80
101	399	2.87	2.89	3.00
102	75	2.93	2.92	3.80
103	95	3.13	3.13	3.00
104	34	3.22	3.18	3.40
105	2782	3.21	3.21	3.72
106	38	3.23	3.27	3.40
107	60	3.44	3.44	3.60
108	139	3.45	3.46	3.80
109	59	3.51	3.49	3.80
110	90	3.65	3.63	3.80
111	66	3.74	3.72	4.00
112	94	3.81	3.87	3.40
113	127	4.44	4.42	4.80
114	86	4.44	4.42	4.20
115	92	4.34	4.44	4.40
116	45	4.56	4.60	4.80
117	54	4.75	4.70	5.00
118	50	5.00	4.92	4.80
119	85	5.40	5.45	5.60
120	26	6.32	6.36	6.40
121	35	6.52	6.45	7.20
122	197	6.51	6.53	7.00
123	188	6.55	6.59	6.40
124	189	6.88	6.83	7.60
125	121	6.90	6.95	6.80
126	1973	11.15	11.10	12.80

APPENDIX II

Area Comparison between various datasets

No.	PRN	P-Pld	% diff	P-SL	% diff	No.	PRN	P-Pld	% diff	P-SL	% diff
1	2474	-0.10	86.9	0.01	4.7	64	181	0.03	2.0	0.02	1.4
2	65	-0.08	57.1	0.00	0.0	65	28	0.16	11.0	0.06	3.4
3	3870	-0.04	20.9	-0.01	3.7	66	23	0.08	5.4	0.00	0.3
4	225	0.02	9.1	0.01	4.5	67	73	0.00	0.0	-0.01	0.7
5	2355	0.08	33.3	0.00	0.9	68	351	-0.18	11.8	-0.02	1.3
6	2401	0.01	3.2	0.01	3.2	69	71	-0.06	3.9	-0.01	0.5
7	2402	-0.01	2.2	0.01	3.2	70	155	-0.16	10.4	0.02	1.3
8	3869	0.03	9.4	0.01	4.3	71	61	-0.16	10.4	-0.01	0.6
9	3459	0.04	11.7	0.00	1.2	72	354	-0.01	0.6	-0.01	0.8
10	56	-0.05	14.7	-0.01	4.0	73	2252	0.10	6.3	0.03	1.9
11	3846	0.00	0.0	0.00	0.0	74	52	0.00	0.0	0.01	0.6
12	64	0.06	16.7	0.01	2.8	75	2292	0.14	8.5	0.02	1.2
13	172	-0.03	6.8	0.00	0.0	76	355	-0.16	9.8	0.01	0.6
14	2028	-0.33	70.2	0.00	1.0	77	356	-0.18	10.5	0.03	1.7
15	42	-0.13	27.7	-0.02	4.3	78	11	-0.60	34.8	0.01	0.6
16	9	0.10	21.3	0.01	3.0	79	157	0.03	1.6	-0.01	0.8
17	53	-0.11	22.2	0.05	10.2	80	2029	0.15	8.1	0.03	1.7
18	3001	-0.01	1.3	0.01	2.0	81	178	0.15	7.7	0.00	0.0
19	3002	0.05	9.6	0.02	3.9	82	177	-0.24	12.2	0.02	1.0
20	154	-0.17	32.1	0.03	6.2	83	88	-0.42	21.2	-0.04	2.0
21	2362	0.04	7.4	0.01	1.0	84	3454	0.11	5.3	0.02	1.0
22	2359	-0.04	7.1	0.03	6.1	85	3845	-0.03	1.4	0.02	1.0
23	67	-0.03	5.3	0.01	2.2	86	12	-0.74	35.9	0.02	1.0
24	3000	0.05	7.7	-0.01	1.7	87	15	-0.01	0.5	0.01	0.5
25	173	-0.10	16.7	0.00	0.0	88	126	-0.09	3.9	0.00	0.2
26	3457	-0.02	2.9	0.01	1.8	89	49	-0.28	12.1	0.00	0.0
27	29	-0.25	38.5	0.04	5.4	90	1313	-0.16	6.9	-0.03	1.3
28	2358	-0.15	23.1	0.00	0.6	91	39	0.00	0.0	0.01	0.4
29	3456	0.05	6.9	0.01	1.5	92	1951	0.06	2.4	-0.02	0.8
30	3468	-0.20	30.1	0.00	0.0	93	55	-0.13	5.3	0.03	1.2
31	14	0.07	10.4	0.05	7.5	94	57	-0.13	5.3	0.00	0.0
32	3469	0.06	9.1	-0.01	1.4	95	1952	0.10	4.0	-0.02	0.8
33	3458	0.16	23.2	0.00	0.2	96	176	-0.50	20.0	0.02	0.8
34	624	-0.11	15.6	-0.01	1.7	97	1950	0.44	17.3	0.00	0.0
35	3425	0.03	4.8	-0.01	1.4	98	353	-0.06	2.2	0.01	0.4
36	2331	0.02	2.8	0.00	0.0	99	33	0.15	5.5	0.04	1.5
37	37	-0.14	18.4	-0.01	1.3	100	40	0.01	0.4	0.00	0.0
38	43	-0.02	2.6	-0.02	2.6	101	399	-0.11	3.8	0.02	0.7
39	91	0.00	0.0	0.00	0.0	102	75	-0.88	30.1	-0.01	0.3
40	2418	-0.19	23.5	0.02	2.5	103	95	0.13	4.2	0.00	0.0
41	72	-0.07	8.4	0.02	2.7	104	34	-0.22	6.9	-0.04	1.2

No.	PRN	P-Pld	% diff	P-SL	% diff	No.	PRN	P-Pld	% diff	P-SL	% diff
42	36	-0.03	3.4	0.01	1.1	105	2782	-0.51	15.8	0.00	0.0
43	16	-0.01	1.1	-0.09	10.2	106	38	-0.13	4.0	0.04	1.2
44	109	-0.09	9.9	0.02	2.7	107	60	-0.16	4.7	0.00	0.0
45	371	-0.19	20.9	0.01	1.1	108	139	-0.34	9.8	0.01	0.3
46	3455	-0.10	10.3	0.03	3.2	109	59	-0.31	8.9	-0.02	0.6
47	3178	0.09	9.7	-0.01	1.0	110	90	-0.17	4.7	-0.02	0.6
48	63	-0.02	2.0	0.00	0.0	111	66	-0.28	7.5	-0.02	0.5
49	110	0.00	0.0	0.03	3.3	112	94	0.47	12.1	0.06	1.7
50	156	-0.10	10.0	0.02	2.0	113	127	-0.38	8.6	-0.02	0.5
51	3453	0.03	3.2	-0.01	1.0	114	86	0.22	5.0	-0.02	0.5
52	87	0.04	3.8	0.01	1.0	115	92	0.04	0.9	0.10	2.3
53	179	-0.15	14.3	0.02	1.6	116	45	-0.20	4.3	0.04	0.8
54	170	0.05	4.3	-0.02	1.7	117	54	-0.30	6.4	-0.05	1.1
55	227	-0.14	12.1	-0.01	0.9	118	50	0.12	2.4	-0.08	1.6
56	2419	0.27	23.1	-0.02	1.7	119	85	-0.15	2.8	0.05	0.9
57	2251	0.00	0.2	0.02	1.7	120	26	-0.04	0.6	0.04	0.6
58	18	-0.08	6.6	0.00	0.4	121	35	-0.75	11.6	-0.07	1.1
59	3452	0.02	1.8	0.01	0.8	122	197	-0.47	7.2	0.02	0.3
60	58	-0.17	13.8	0.01	0.8	123	188	0.19	2.9	0.04	0.6
61	357	-0.05	4.0	-0.01	0.5	124	189	-0.77	11.3	-0.05	0.7
62	352	-0.27	20.3	0.03	2.3	125	121	0.15	2.2	0.05	0.7
63	89	0.16	11.8	0.03	2.2	126	1973	-1.70	15.3	-0.05	0.5

APPENDIX III

Camera Calibration Certificate

CAMERA CALIBRATION CERTIFICATE

CAMERA TYPE : RC10

LENS TYPE : 15 UAG II

LENS NO. : 3104

Calibration date: 13.05.1997

LEICA AG, HEERBRUGG

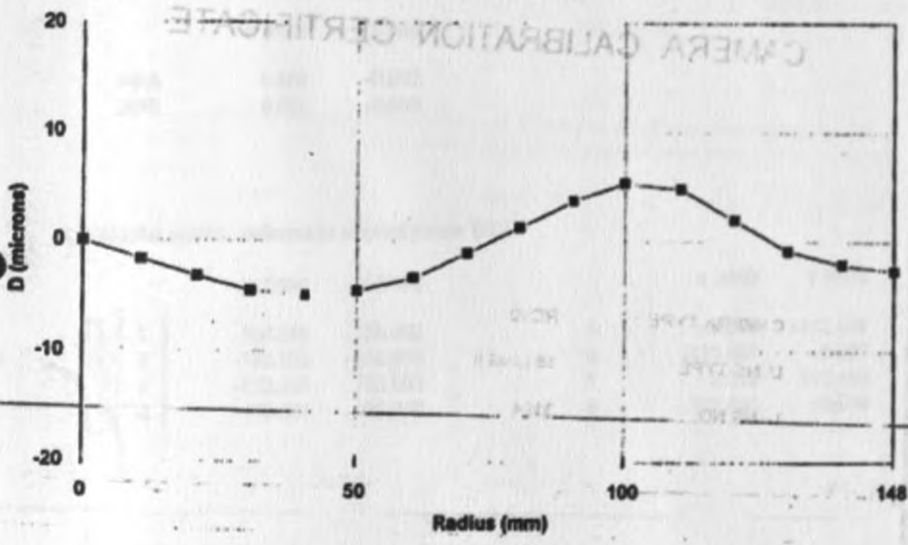
Leica

Leica Heerbrugg Ltd
CH-9435 Heerbrugg
Calibration Department
Supervisor

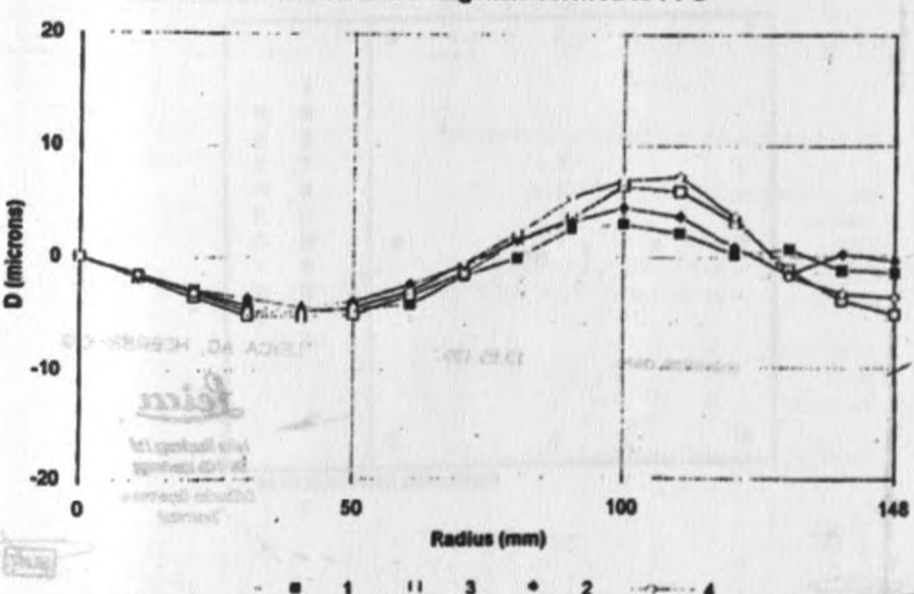
RC10	15 UAG II	No. 3104	13.05.1997

Aperture:	**5.6**
Filter on goniometer:	**450 NM**
Filter on camera:	**–**
C.F.L. :	**153.31 mm**

Mean radial distortion



Radial distortion for semi-diagonals referred to PPS



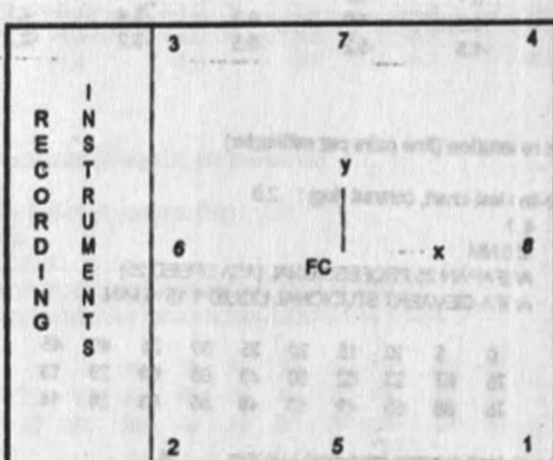
RC10 | 15 UAG II | No. 3104 | 13.05.1997

Principal point of autocollimation (PPA) and principal point of symmetry (PPS) referred to central cross (FC), see diagram

	x (mm)	y (mm)
PPA	0.002	-0.002
PPS	0.001	-0.006

Fiducial marks, referred to central cross (FC)

	x (mm)	y (mm)		x (mm)	y (mm)
1	106.006	-106.003	5	0.015	-112.488
2	-106.003	-106.002	6	-112.465	-0.007
3	-105.998	105.995	7	0.019	112.440
4	106.001	106.000	8	112.495	-0.006



as seen on focal plane frame

RC10 15 UAG II No. 3104 13.06.1997

Aperture: 5.6
Filter on goniometer: 450 NM
Filter on camera: --
C.F.L. : 153.31 mm

Radial distortion (micrometers) referred to principal point of symmetry (PPS)
(Positive values denote image displacement away from center)

Radius	Half - Sides				Mean
mm	1	3	2	4	
10	-1.6	-1.9	-1.8	-1.6	-1.7
20	-3.0	-3.6	-3.0	-3.2	-3.2
30	-4.4	-5.2	-3.7	-4.8	-4.5
40	-4.8	-5.3	-4.5	-5.0	-4.9
50	-4.6	-5.1	-4.0	-4.5	-4.5
60	-4.2	-3.4	-2.5	-3.1	-3.3
70	-1.7	-1.5	-0.8	-0.6	-1.1
80	-0.1	1.5	1.5	2.1	1.2
90	2.6	3.5	3.2	5.3	3.6
100	3.0	6.4	4.5	6.9	5.2
110	2.2	5.9	3.7	7.2	4.7
120	0.2	3.2	0.9	3.6	1.9
130	0.7	-1.2	-1.6	-1.8	-0.9
140	-1.3	-4.0	0.2	-3.4	-2.1
148	-1.5	-5.2	-0.5	-3.7	-2.7

Photographic resolution (line pairs per millimeter)

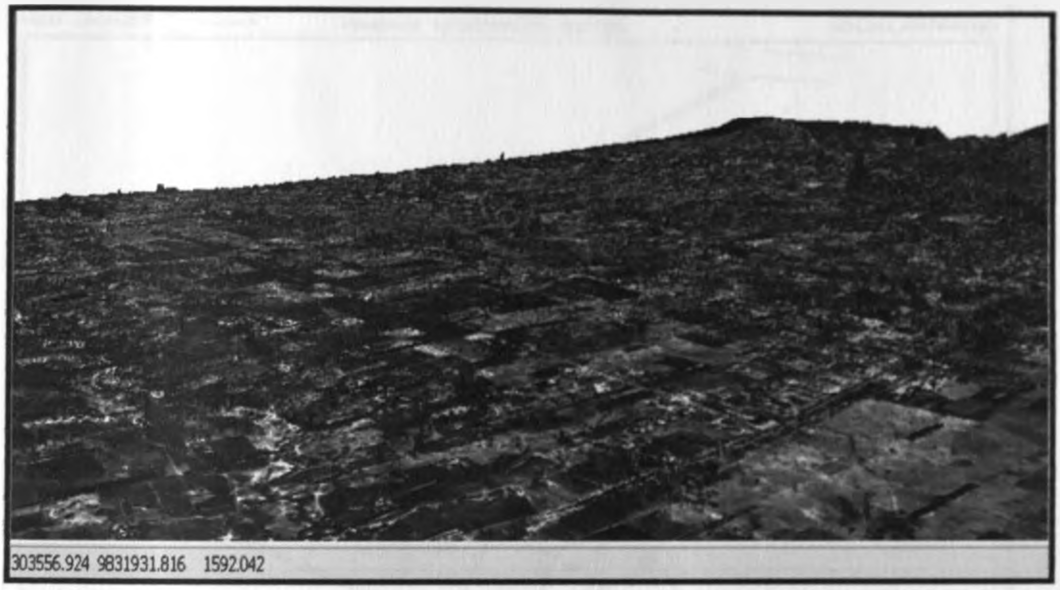
International 3-line test-chart, contrast (log) : 2.0
Aperture: 4.0
Filter: 450 NM
Film: AGFAPAN 25 PROFESSIONAL (ASA SPEED:25)
Developer: AGFA-GEVAERT STUDIONAL LIQUID 1:15 6 MIN.

Angle (deg)	0	5	10	15	20	25	30	35	40	45
Radial:	75	67	93	62	50	43	66	69	29	13
Tangential:	75	66	65	49	53	49	56	63	28	14

AWAR (Area weighted average resolution) in lp/mm: 54

APPENDIX IV

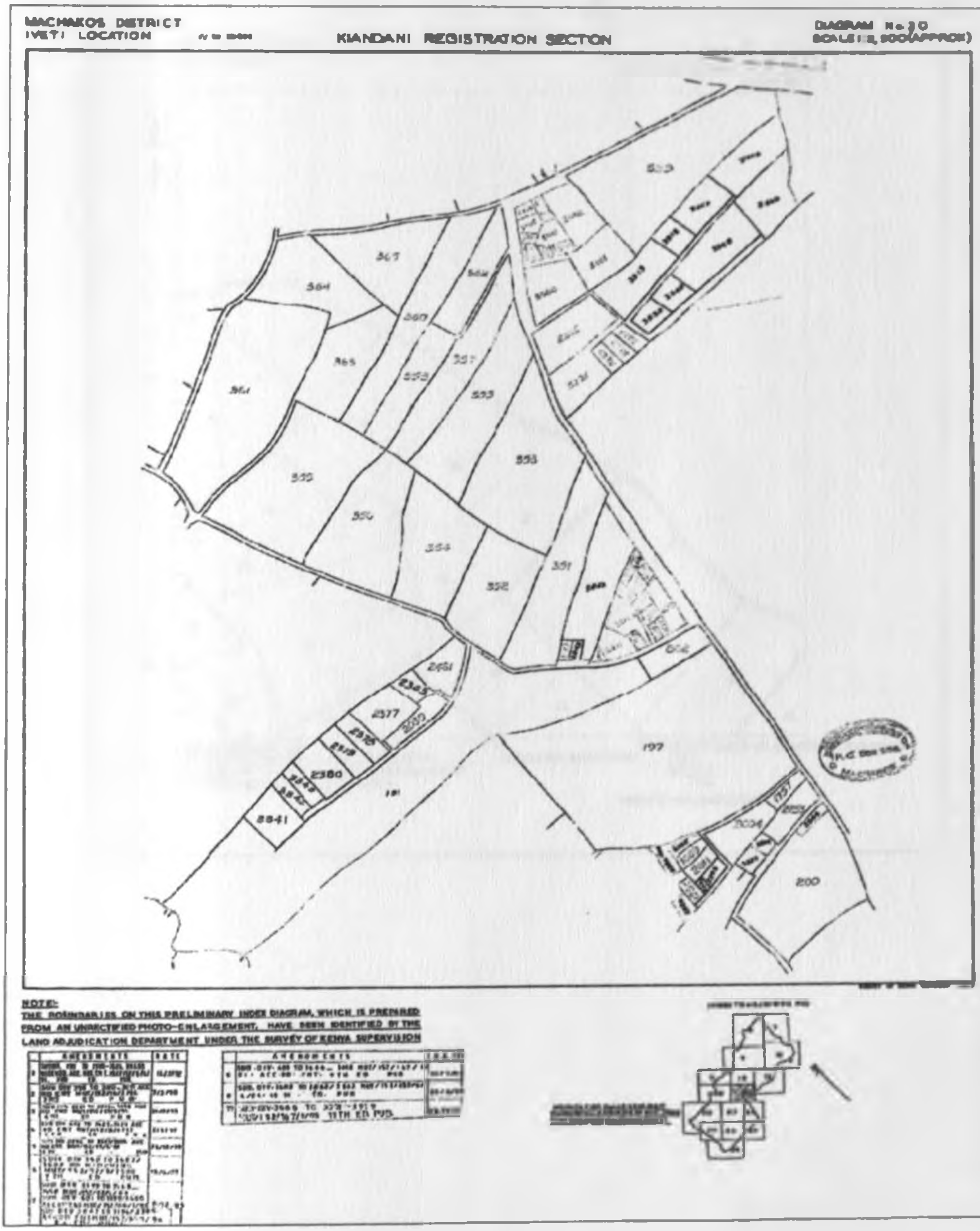
Study Area



Study Areas: Orthophoto mosaic superimposed onto digital elevation model (DTM)

APPENDIX V

Preliminary Index Diagram (PID)



Registry Index Map (RIM)