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# Harmonization of Spatial Discrepancies from Land-related Data and Information Using Geospatial Technologies：A Case Study of Ol-Kalou Township in Nyandarua County, Kenya

Paul K. Towett Tubei, and Patroba Achola Odera

*Department of Geomatic Engineering and Geospatial Information Systems, Jomo Kenya University of Agriculture and Technology, Kenya*

**Abstract:** This paper explores potential of Remote Sensing and Geospatial Information Systems as viable tools for data collection, processing, transformation and adjustment of cadastral data discrepancies often noted by geospatial practitioners during rasterization and vectorization of land related data. Necessary datasets were collected employing main approach/procedure of scanning, georeferencing, digitization, transformation and analysis in that order, to amalgamate and harmonize all datasets into one common projection and coordinate system (Universal Transverse Mercator (UTM) on Arc-Datum 1960). Discrepancies in derived areas against recorded values in land registries were noted, smaller parcels exhibited smaller discrepancies and vice versa. Discrepancies were found to be directly proportional to the parcel areas/sizes although large parcels (> 1000 $m^2$) exhibited abnormally high discrepancies. This procedure yielded systematic discrepancies that could be minimized by use of a fifth order polynomial. Resultant residuals were found to be tolerably low and could be ignored for small parcels (< 1000 $m^2$). Final outputs included automated GIS geodatabase cadastre, containing cadastral attributes harmonized to one projection and coordinate system that can be overlaid to other datasets from engineering design and construction works, geological and geotechnical investigation surveys, etc. tied to Remote Sensing data without the requirement of further transformations.

**Keywords:** Coordinate transformation, georeferencing, projection systems, cadastre, spatial data discrepancies, spatial data harmonization.

## 1. Introduction

Remote Sensing (RS) and Geospatial Information Systems (GIS) are effective tools for collection, manipulation, modeling and archiving of large amounts of spatial data for diverse applications ranging from planning, engineering works, land and environmental management among others [1]. RS and GIS offer a novel way to collect enormous amounts of spatial data quickly with better accuracies [2] and at minimal costs compared to traditional survey methods used to carry out cadastral survey in Kenya.

This project explores the practical application and demonstrates the potential of RS and GIS as viable tools for data collection, data processing and adjustment of cadastral data, plotting and to recommend creation of a land information system that can be adopted as a standard practice at the Ministry of Lands, Housing and Urban Development. The project particularly aims at addressing and minimizing the spatial discrepancies and disharmony in the projection systems between various data sets used in the Ministry of Lands, Housing and Urban Development (especially Survey of Kenya) to administer land ownership and conveyance in both fixed and general boundaries, e.g.,

**Corresponding author:** Paul Kibichii Towett Tubei, Masters in Geospatial Information Systems and Remote Sensing, research fields: improvement of geospatial technologies and effective application of GNSS in local and regional positioning, cadastral surveying, geospatial information systems and remote sensing. E-mail: ptubeieng@gmail.com.

the folio registry (FR's) maps, the Relative index Maps (RIM's), the Block Plans and Development Plans used by physical planners.

The outcomes are an automated GIS geodatabase cadastre that contains cadastral attributes harmonized to one projection and coordinate system that can be used as a standard and a base map for all property boundary plans which can be overlaid to many other geospatial Variables.

## 2. Literature Survey

### *2.1 Land Tenure and Cadastral Surveying in Kenya*

Land tenure is the relationship, whether legally or customarily defined, among people, as individuals or groups, with respect to land. According to FAO, land tenure is an important part of social, political, and economic structures. It is multi-dimensional, bringing into play social, technical, economic, institutional, legal, and political aspects that are often ignored but must be taken into account [3].

### *2.2 Fixed Boundary Surveys*

Fixed boundary surveys result to precise boundaries that can be re-established through measurements. Fixed boundary surveys consist of the construction of coordinated beacons at rectilinear points of the boundary line. Further, natural features such as roads, rivers, and oceans are occasionally used as boundary lines. Due to the sensitivity of land issues in Kenya, all fixed boundary surveys must be examined and authenticated by the Director of Surveys. The result of a fixed boundary survey is a parcel plan indicating area, bearings, and distances between the boundary beacons [4].

Areas which were surveyed under the fixed boundary method included: new grant allocations, urban leases, Trust Lands that have been set-apart for public use, Forest Reserves, National Parks and National Game Reserves, and company and cooperative farms where shareholders opt for a fixed survey. One advantage of fixed boundaries is their ease of relocation and re-establishment [5]. Previously, the fixation of these boundaries was optional; however, with the enactment of Land Registration Act No. 3 of 2012, it is now mandatory that all survey boundaries presented for registration must be georeferenced. The enactment of this Act made general boundary survey obsolete. Although no reliable data is available, it is estimated that approximately 300,000 parcels are mapped under fixed boundary survey with a total area of 3.4 million hectares [6].

### *2.3 Coordinate Conversion among Systems*

Exact or approximate mathematical formulae have been developed to convert to and from geographic latitude and longitude to all commonly used coordinate projections. These formulae are incorporated into "coordinate calculator" software packages, and are integrated into most GIS software. For example, given a coordinate pair in the State Plane system, you may calculate the corresponding geographic coordinates [7]. A formula can then be applied that converts geographic coordinates to UTM coordinates for a specific zone using another set of equations. Since the backward and forward projections from geographic to projected coordinate systems are known, we may convert among most coordinate systems by passing through a geo-graphic system. Care must be taken when converting among projections that use different datums. If appropriate, we must insert a datum transformation when converting from one projected coordinate system to another [8].

Until quite recently, spatial errors due to improper datum transformation have been below a detectable threshold in many analyses, so they caused few problems. GNSS receivers can now provide centimeter-level accuracy in the field, so what were once considered small discrepancies often cannot now be overlooked [9]. As data collection accuracies improve, datum transformation errors become more apparent. Datum transformation method within any hardware or software package should be documented and the accuracy of the method known before it is adopted. There are a number of factors that we should keep in mind when applying datum transformations.

First, changing a datum changes our best estimate of the coordinate locations of most points [10]. These differences may be small and ignored with little penalty in some specific instances, typically when the changes are smaller than the spatial accuracy required for our analysis. However, many datum shifts are quite large, up to tens of meters. One should know the magnitude of the datum shifts for the area and datum transformations of interest. Second, datum transformations are estimated relationships, which are developed with a specific data set and for a specific area and time. Spatial/positional data contained in a GIS can easily be transformed and/or reprojected from one global coordinate system and datum to another. These spatial data include coordinates that define the location, shape, and extent of geographic objects. To effectively use GIS, we must develop a clear understanding of how coordinate systems are established for the Earth, how these coordinates are measured on the Earth's curving surface, and how these coordinates are transferred to flat maps [11]. Survey of Kenya has facilitated the conversion of local coordinate systems data to a global coordinate system (WGS84 Arc 1960) for mapping purposes.

### *2.4 GPS and Ancient Surveys in Boundary Surveys*

At relatively low cost, GPS provides a reliable means to get both relative and absolute positional information. The low cost of the technology has led to a proliferation of GPS receivers, making this technology common not only among scientists and surveyors but also in non-technical fields. Unfortunately, the proliferation of receivers has often resulted in the misuse of the technology in locating boundaries.

To understand the problems with using GPS in boundary retracement, knowledge of past survey practice is necessary [12]. The early surveyors used the compass and chain and later the transit and tape in establishing many of today's boundaries. Land was inexpensive, training was haphazard, and obstacles in the path of the survey were many. The chain and tape were unwieldy and inexpertly employed. Slope measurements were sometimes the norm where correcting the chain and tape for sag, temperature differences, and stretching was seldom done. Magnetic readings were often erratic or failed to account for local attractions and diurnal variations. Consequently, inconsistencies and errors in measurements were so common in early surveys that measurements were not held in high regard [13].

In many boundary retracement surveys, there is an indirect correlation between precise measurements and accurate measurements. Precise measurements become less useful in finding the position of original corners than more imprecise measurements that had better replicate the original measurements [14]. Measurements that replicate the deficiencies of the original equipment are more accurate in locating the original bounds than precise measurements that remove or are not influenced by local magnetic anomalies and terrain conditions between two points on the earth's surface. According to [15], in many boundary retracement surveys, there is an indirect correlation between precise measurements and accurate measurements. It is often disconcerting to the non-surveyor to be told that in fixing old boundaries, the law favours the old hedge that meanders several meters off a straight line rather than sophisticated equipment that can measure to the nearest centimeter [16].

The fact is that GPS can be used to a great advantage in boundary retracement by surveyors. It provides an efficient means of locating the position of evidence within a relative or absolute geometric framework especially if the evidence is separated by long distances or a difficult terrain to traverse. Without question, it can provide precise coordinates of properly re-established corners or in fixing the position of new corners in a subdivision [17].

### *2.5 Aerial Mapping in Boundary Survey*

Aerial photography is one of the oldest and most widely used methods of remote sensing where cameras mounted in light aircrafts flying at altitudes between 200 and 15,000 m captured large quantity of detailed information. Aerial photos provide an instant visual inventory of a portion of the earth's surface and can be used to create detailed topo-cadastral maps. For cadastral purposes or generation of PID's, Vertical aerial photography is normally taken with the large format (23 cm × 23 cm) mapping quality cameras fitted on specially modified aircrafts. The resulting images depict ground features in plan form and are easily compared with maps. These photographs are highly desirable and are mostly useful for resource surveys in areas where no maps are available. They also depict various features such as field patterns and vegetation which are often omitted on maps and these enable a clear comparison of old and new aerial photos that can be analyzed to capture changes within an area over time [18].

PID's are normally generated from un-rectified vertical aerial photos that contain subtle displacements due to relief, tip and tilt of the aircraft and lens distortion. Vertical images are also taken with overlaps of about 60% along the flight line and about 30% between lines. These overlapping images form/ create a stereo model when viewed with a stereoscope which typically creates a three-dimensional view, hence contours could also be deduced though stereographic process and plotted using stereo plotters. These data are the main source of the topo-cadastral maps in Kenya [19]. The main benefit of aerial photography methods of mapping and surveying is that they are unobtrusive, and do not require setting foot on the actual terrain. This is advantageous in situations with limited access to the land or dangerous terrain, such as areas with steep slopes.

### *2.6 Remote Sensing in Boundary Survey*

The emerging new satellite technologies enabling earth observation at a spatial resolution of 0.60 m or even 0.41 m together with powerful and high-speed computing and processing capabilities have brought revolutionary changes in the field of GIS-based cadastral land information system. The high-resolution satellite imagery (HRSI) is showing its usefulness for cadastral surveys. In effect, traditional cadastre and land registration systems have been undergoing major changes worldwide. In this way, the traditional surveying concept has taken up into new shape from discipline-oriented technologies, such as geodesy, surveying, photogrammetry, and cartography into a methodology-oriented integrated discipline of geo-information. Such methodologies are based on global positioning system (GPS), remote sensing (RS), and digital photography for spatial data acquisition [20]. The most common high resolution sensors available today include SPOT, IRS, IKONOS, GeoEye, PLEIADES etc.

With the emergence of high resolution solid-state multispectral scanners and other raster input devices, we now have available digital raster images of spectral reflectance data. The biggest milestone for having such data in digital form is simply because they allow application of computer analysis techniques to the image data. Such techniques are mostly concerned with four basic operations namely; image restoration, image enhancement, image classification, and image transformation. Image restoration is concerned with the correction and calibration of images in order to achieve as faithful a representation of the earth surface as possible which is a fundamental consideration for all applications. Image enhancement is predominantly concerned with the modification of images to optimize their appearance to the visual system which is a key element during digital image processing, and image classification refers to the computer-assisted interpretation of images, an operation that is vital to GIS. Finally, image transformation refers to the derivation of new imagery because of some mathematical treatment of the raw image bands. In order to undertake the operations listed in this section, it is necessary to have access to image processing software like IDRISI among others. While IDRISI is known primarily as a GIS software system, it also offers a full suite of image processing capabilities [12].

*2.7 GIS in Boundary Survey*

The developments in the field of GIS technologies have given a new insight in addressing a variety of land development, management, and planning activities for better use of land in resource management. Due to rapid development in the space-borne technology, nowadays it is possible to generate thematic maps on various scales keeping in mind end users' requirements. The locational accuracy of maps is utmost important for certain applications like cadastral survey, infrastructure/utility maps, urban land use, land planning and land consolidation works etc. [2] showed that using one-meter resolution imagery and GPS controls, it is possible to achieve an accuracy of +/- 2 meters. Recent advances in space-based data capturing techniques (imaging) have revolutionized the field of cadastral surveying and mapping. All these improvements in satellite imaging have led to availability of better quality data/pictures for mapping applications. Ref. [4] considered the possibility of IKONOS imagery for making topo-cadastral maps and their results suggested that IKONOS imagery has advantageous characteristics of interpretation for making and updating middle-scale topographical maps such as 1:25,000 compared with analogue aerial photographs. They showed that horizontal accuracy of IKONOS ortho-imagery varies between 1.0 to 1.2 m in flat areas and is worse in mountainous areas.

Updating land related information is very important so that changes of ownership and division of property can be recorded in a timely fashioned manner for documentation. One advantage of using images (either aerial photographs or HRSI) is that they provide a historical record of the areas that can be revisited in the future to see what changes have taken place. In this way, old images can provide valuable evidence where conflicts occur in parcel boundaries. Furthermore, traditional land surveying approaches are time consuming and require lot of effort. Sometimes it is very difficult to do cadastral survey in remote areas especially in mountainous areas when the weather is harsh. In this case, HRSI can be used as an alternative to traditional land surveying approach for spatial data acquisition where most measurements can be done in the office [21]. The question in this case would be how would the old traditional data which is currently used for allotment and conveyance merge and compare with the new technology and what would be the probable discrepancies and how can they be minimized [20].

## 3. Statement of the Problem

Fixed boundary surveys are far so expensive that they inhibit access to land for so many especially in the urban areas. The changes in registration requirements over time have not been reflective on the technical requirements in the preparation of the relevant registration documents. The actionable problem tasks of cadastral surveying in Kenya may be broadly identified as challenges in the fixation of general boundaries, group ranches and adjudication surveys; provision of survey controls and adjudication of land in the arid and semi-arid lands (ASALS) of Kenya. Additional challenges include harmonizing data captured under different projection systems, e.g., Cassini Soldner and Universal Transverse Mercator (UTM). Processing such data is further hampered by their existence in hard copies that are prone to damage and distortions.

Other limitations to the current system of land adjudication is its centralized nature and unwarranted bureaucratic management approach. There is a need for a decentralized records keeping and access to all information by all Survey of Kenya clients who include citizens in general, government departments, non-governmental organizations, private organizations, and business agencies. Therefore, there is a dire need to have a standard format for capturing, storing, updating and redistributing land information. A Land Information System (LIS) based on such data can easily be migrated to web-based platforms to enable rapid data distribution and access. Fig. 1 is a general representation of the problem.

## 4. Study Area

Ol'kalou Township is located in Nyandarua County, Kenya. It spans between 0°14'59"S - 0°17'59"S, and 36°20'59"E-36°24'0"E. Ol'kalou township is an upcoming urban area in Nyandarua County and hosts the County Headquarters. Development of the town has been slow and inconsistent due to land management challenges and political factors revolving around land as a resource and the main factor of production. The following factors were considered as the qualifiers of Ol'kalou as a viable study area: the township has cadastral data in both fixed and general boundaries survey; all the required maps and plans were readily available at the Survey of Kenya offices; the area had a recently acquired high resolution satellite imagery using the Pleiades twin satellites; the area has old control points in both Cassini-Soldner and UTM used to derive the transformation parameters; and the local authorities were willing to participate in this study especially the leaders in the Ministry of Lands, Housing and Urban Development, and department of Physical Planning. Fig. 2 below is a depiction of the study area in context of Kenya.

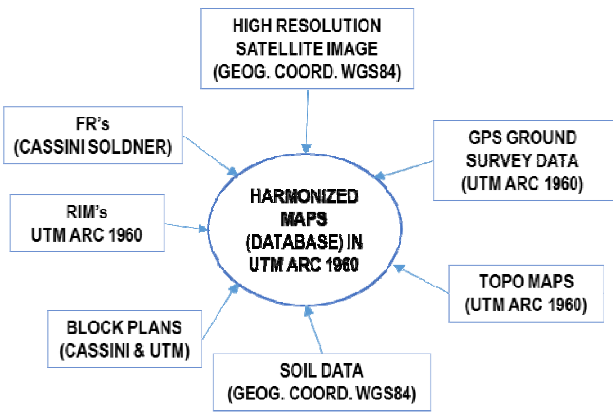


**Fig. 1 General representation of the problem.**

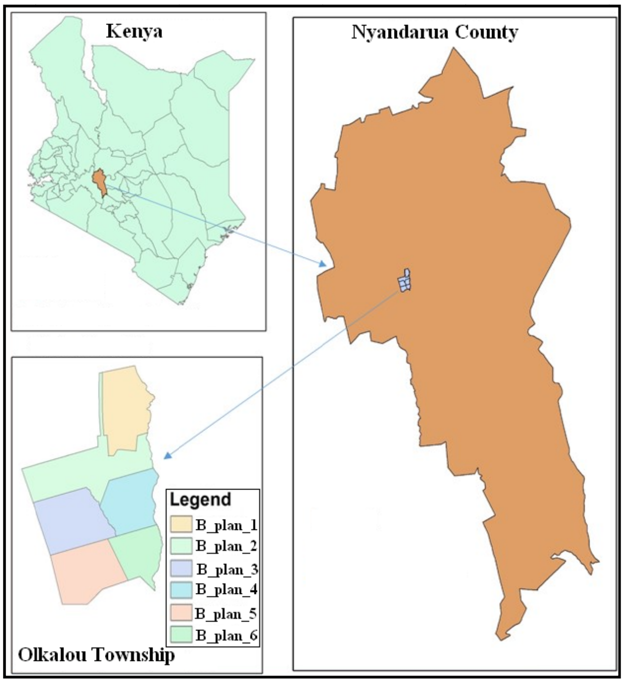


**Fig. 2 The study area (B refers to block).**

## 5. Methodology

The project considers practical approaches of harmonizing spatial discrepancies arising from transformation of land information in Kenya using geospatial technologies with Ol'kalou as a model project area. To achieve the objectives of the research, we adopted a conceptual procedure that involves scanning, georeferencing, digitization, transformation and analysis (SGDTA) towards achieving re-projected vector maps of the study area. The first task during the research was to conduct a reconnaissance survey. This familiarized us with prevailing ground conditions. It further informed on the expected source of data in addition to highlighting where it could be sourced. Fig. 3 illustrates the flow diagram that depicts the steps adopted during the research. This was then followed by data acquisition process, which entailed the acquisition of satellite imagery, cadastral data and establishment of ground control points (GCPs). The satellite image and GCPs underwent post processing to ascertain their conformity to the required standards by Survey of Kenya. The cadastral data sourced from authentic warehouses such as Survey of Kenya were scanned,

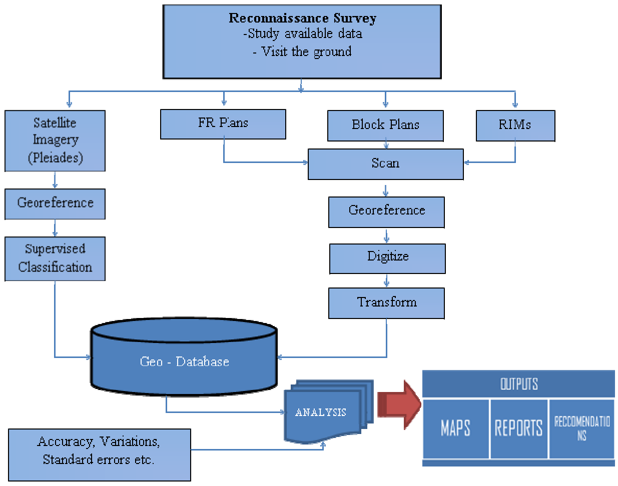


**Fig. 3 Research methodology workflow.**

georeferenced, harmonized, and vectorized while taking into consideration all elements that can affect the outcome.

The SGDTA approach was adopted for the digitization part. This approach entailed georeferencing of the scanned map in the local coordinate system (Cassini Soldner), then digitizing them, and finally transforming the vector data using known control points/beacons to a local coordinate system (UTM Arc 1960). The results from the raster data, point data, and vector data from the above process were merged as per the approach adopted under the data overlay process and the results stored in a GIS geodatabase. This data was then retrieved for sequential analysis that yielded maps of each area of interest.

### *5.1 Data Collection*

Primary collection of survey data was performed using RTK-GPS systems and aerial data acquisition sensors (satellites). Secondary data, such as FRs, RIMs, and Block Plans were acquired from Survey of Kenya (SoK). The consequent task during primary data collection exercise was to establish sufficient ground control points (GCPs) through geodetic GPS survey. These were later used in georeferencing the satellite imagery and as checks of accuracy and precision. These tasks were conducted concurrently with the acquisition and vectorization of cadastral data. Most of these data existed in print format hence it was necessary to scan, georeference, digitize, and harmonize the resulting vector data. Merged data covered the entire area of interest.

Pleiades-1B twin satellites were the preferred source of high-resolution imagery based on the sensor capabilities in Table 1. The topographic map resulting from the satellite imagery enabled the extraction of significant man-made features such as buildings, dams, utilities, roads, quarries, as well as naturally occurring features such as rivers, streams, swamps, rock out-crops, and cliffs that are within the area of study. Satellite images were acquired through the Regional Centre for Mapping of Resources for Development (RCMRD).

### *5.2 GPS Data and Digital Image Processing*

The satellite imagery acquired was in WGS84 coordinate system hence it was necessary to re-project it to meet the mapping specifications defined in Table 2 (UTM Arc1960 Zone 37S). This was achieved using Global Mapper and ArcGIS ArcMap. Prior to using the satellite imagery to extract information, it was digitally processed to correct for radiometric and geometric distortions then enhanced, transformed, classified and analyzed. These steps were vital in ensuring that the data was the best representation of the actual ground. Further, the appearance of GCPs in the imagery acted as a secondary accuracy check of the data. RTK-GPS data was also transformed to suite the required projection and datum parameters. No further processing was necessary for this type of data.

### *5.3 Vectorization of Paper Maps*

Vectorization entailed the conversion of scanned hardcopy maps (raster maps) to their vector equivalent with the aid of the following GIS software: ArcMap, Global Mapper, and QuantumGIS. Vectorization of scanned maps is an expensive and time-consuming process that is highly dependent on the amount of data

**Table 1 Pleiades-1B satellite capabilities.**

| Item | Specification(s) |
|---|---|
| Spatial resolution | Panchromatic 50 cm<br>Multispectral 2.0 m |
| Nominal swath width | 20 km at Nadir |
| Bands supported | Pan: 450-830 nm<br>Blue: 430-550 nm<br>Green: 500-620 nm<br>Red: 590-710 nm<br>Near IR: 740-940 nm |
| Stereo availability | Yes |
| Best Scale | 1:2000 |
| Programmability | Yes |
| Temporal resolution | 24 hrs |

**Table 2 Mapping parameters.**

| Item | Specification(s) |
|---|---|
| Grid | UTM Zone 37S |
| Projection | Universal Transverse Mercator |
| Spheroid | Clarke 1880 (modified) |
| Units of measurement | Meter |
| Meridian of Origin | 39°E |
| Latitude of Origin | Equator |
| Scale factor at origin | 0.9996 |
| False coordinates at origin | 500,000 mE; 10,000,000 mN |
| Datum | Arc1960 |
| Scale | 1:2500 |

to be captured. It also depends on the level of abstraction needed for each feature class. As such, it was imperative to determine the projection system of each map sheet prior to processing it using transformation parameters obtained from SoK in readiness for harmonization.

Using the georeferencing tool in ArcMap, each of the scanned maps was georeferenced. This produced overlapping maps that would easily be digitized and the different sources of data harmonized. To ease the process of updating the maps in the future, each scanned map output was assigned to a unique layer using the name/reference number of the map. It was imperative to unify all data in one projection system to ensure that despite working from whole to parts, it was possible to overlay them in a single data frame and conduct analysis. Database design for this project was done in ArcGIS Arc-Catalogue where the geodatabase and feature classes were defined.

### *5.4 Transformation of Coordinates*

Data used in the research consisted of nine authenticated cadastral plans with coordinates in Cassini-Soldner projection. In total, there were nine Folio registration sheets containing a total of 628 plots. All plots from the scheme were chosen for the analysis of the variations due to transformation. In order to acquire soft copy of the cadastral data, the plans were digitized using ArcGIS software and co-registered with the ortho-rectified satellite imagery acquired in February 2014. Transformation equations were used to determine the parameters (two translations in N and E directions, a uniform scale factor and one rotation angle) to convert the Cassini coordinates into UTM (1960 Arc Datum) coordinates system. This was necessary to provide compatibility between cadastral plan coordinates and the GIS system.

Generally, GIS systems operate in UTM while the cadastral plans in Kenya are in Cassini system. A transformation sheet as shown in Fig. 4 was obtained from Survey of Kenya (SoK) with coordinates in both Cassini and UTM systems. The study area lies in sheet 119/4/3 as highlighted in Fig. 4, the four corner coordinates (Table 3) in both systems were used to derive the transformation parameters.

The basic linear model for this transformation is given as,

$$X' = aX - bY + C \,;\, Y' = aY + bX + D \tag{1}$$

Where, $a$ and $b$ are scaling and rotation parameters respectively, while $C$ and $D$ are the translation

**Table 3 List of datum coordinates (source: SoK).**

| Cassini-Soldner | | UTM | |
|---|---|---|---|
| X (ft) | Y (ft) | X (m) | Y (m) |
| -237682.700 | -91354.200 | 205013.100 | 9972340.200 |
| -219422.300 | -91352.500 | 210582.700 | 9972341.400 |
| -219420.800 | -109491.000 | 210583.900 | 9966809.700 |
| -237681.300 | -109491.900 | 205014.300 | 9966808.500 |

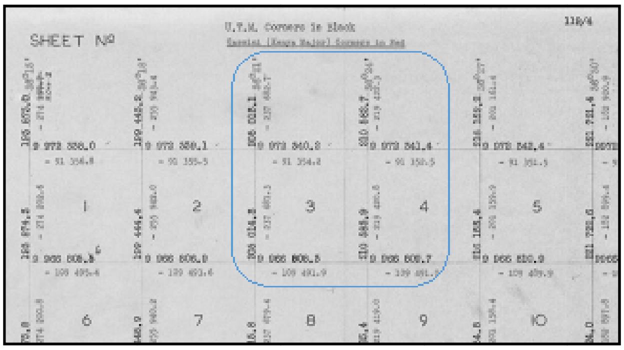


**Fig. 4 Transformation index sheet (source: SoK).**

parameters in X- and Y-axes respectively. These transformation parameters are used for conversion from one system ( $X'-Y'$ ) to another system ($X$-$Y$) and vice versa.

After obtaining the transformation parameters, the SGDTA procedural approach was adopted in this research. These were tailored to highlight variations that arise in vectorized data based on when transformation was implemented. This procedure involved georeferencing raster images in their native projection (Cassini-Soldner), vectorizing the maps, and

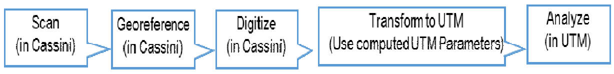


**Fig. 5 SGDTA procedure workflow diagram.**

transforming the resulting vector data to UTM Arc1960 and analyzing them as shown in Fig. 5.

## 6. Results and Discussion

### *6.1 Transformation of Known Survey Points*

The analysis involved examination of data accuracy, precision, variations, and standard. Table 4 shows a sample of the native and transformed coordinates of the reference points present in all the map sheets. Data from RIMs, and the satellite image were already in the desired projection system and did not have to be transformed. However, it was necessary to georeference either of the two to UTM prior to digitization and running of unsupervised classification respectively. Unsupervised classification aided in the extraction of land cover/land use data that constituted the base map of the project. Of interest in the project were the vector products of the Block Plans and FRs.

**Table 4 A sample of plane coordinates on Arc-Datum 1960 used for georeferencing purpose.**

| | Cassini Coordinates | | UTM Coordinates | | Description |
|---|---|---|---|---|---|
| **Point** | **X (feet)** | **Y (feet)** | **X (meter)** | **Y (meter)** | |
| CK7 | -214345.100 | -89825.200 | 212130.981 | 9972807.631 | UNKOWN |
| M13 | -228867.760 | -98919.460 | 207702.062 | 9970033.323 | OLD I.P.C.U |
| K7 | -229194.860 | -98972.810 | 207602.301 | 9970017.037 | OLD I.P.C.U |
| BE3 | -231523.000 | -104070.000 | 206892.454 | 9968462.330 | OLD I.P.C.U |
| BE4 | -224987.600 | -102184.400 | 208885.624 | 9969037.705 | OLD I.P.C.U |
| NW43 | -230782.900 | -107112.300 | 207118.310 | 9967534.482 | OLD I.P.C.U |
| 13D | -228734.050 | -98100.900 | 207742.808 | 9970282.983 | OLD I.P.C.U |
| 13C | -228634.300 | -98094.040 | 207773.231 | 9970285.080 | OLD I.P.C.U |
| 13F | -228628.820 | -98173.850 | 207774.905 | 9970260.739 | NEW I.P.C |
| 13E | -228728.580 | -98180.710 | 207744.480 | 9970258.642 | NEW I.P.C |
| G1 | -228295.730 | -98650.620 | 207876.516 | 9970115.341 | NEW I.P.C |
| G2 | -228301.490 | -98787.540 | 207874.765 | 9970073.582 | NEW I.P.C |
| G3 | -228320.550 | -98859.020 | 207868.955 | 9970051.780 | NEW I.P.C |
| G4 | -228366.240 | -98947.850 | 207855.024 | 9970024.685 | NEW I.P.C |
| G5 | -228448.840 | -99042.460 | 207829.835 | 9969995.826 | NEW I.P.C |
| D1 | -228622.830 | -98253.460 | 207776.736 | 9970236.458 | OLD I.P.C.U |
| D15 | -228567.300 | -99061.550 | 207793.707 | 9969989.999 | OLD I.P.C.U |
| C06Y | -214956.200 | -100573.800 | 211945.061 | 9969529.357 | OLD I.P.C.U |
| RM3 | -213068.600 | -100512.200 | 212520.763 | 9969548.226 | OLD I.P.C.U |
| RM4 | -213039.200 | -101661.600 | 212529.780 | 9969197.668 | OLD I.P.C.U |

*6.2 Area Variations in Block Plans and FRs*

Table 5 shows a comparison of derived/computed areas ($A_1$) deduced after applying the SGDTA procedure against the recorded areas ($A_0$) in the original block plans. Although land reference numbers of the parcels are available to this research, we do not have authority to publish them in this paper; hence only parcel areas have been used. Fig. 6 shows the distribution of parcels by size in the block plans used in this study. It is evident that small sized parcels dominated the maps hence the large percentile. Table 6 shows a sample of the data used in the consecutive analysis of data from FR maps using the same procedure like what was used in block plans while Fig. 7 shows the distribution of parcels by size in the FRs.

**Table 5 A sample of block plans analysis for 63 parcels (areas are in m$^2$).**

| **Actual parcel area in Cassini** | **Computed areas and area variations after applying SGDTA procedure** | | |
|---|---|---|---|
| Area ($A_0$) | Area ($A_1$) | ($A_0$-$A_1$) | ($A_0$-$A_1$)/ $A_0$ |
| 192.26 | 192.50 | -0.24 | -0.00126680 |
| 208.16 | 208.43 | -0.26 | -0.00126678 |
| 208.50 | 208.76 | -0.26 | -0.00126679 |
| 210.97 | 211.24 | -0.27 | -0.00126681 |
| 211.64 | 211.91 | -0.27 | -0.00126680 |
| 213.48 | 213.75 | -0.27 | -0.00126678 |
| 214.86 | 215.13 | -0.27 | -0.00126679 |
| 215.17 | 215.44 | -0.27 | -0.00126680 |
| 215.27 | 215.54 | -0.27 | -0.00126683 |
| 215.99 | 216.26 | -0.27 | -0.00126679 |
| 216.37 | 216.65 | -0.27 | -0.00126680 |
| 216.52 | 216.80 | -0.27 | -0.00126683 |
| 217.26 | 217.53 | -0.28 | -0.00126681 |
| 388.32 | 388.82 | -0.49 | -0.00126683 |
| 390.10 | 390.59 | -0.49 | -0.00126689 |
| 391.55 | 392.05 | -0.50 | -0.00126679 |
| 468.35 | 468.95 | -0.59 | -0.00126684 |
| 469.31 | 469.91 | -0.59 | -0.00126670 |
| 469.45 | 470.05 | -0.59 | -0.00126685 |
| 469.50 | 470.09 | -0.59 | -0.00126695 |
| 469.74 | 470.33 | -0.60 | -0.00126690 |
| 469.81 | 470.41 | -0.60 | -0.00126685 |
| 469.96 | 470.56 | -0.60 | -0.00126682 |
| 546.91 | 547.60 | -0.69 | -0.00126687 |
| 547.26 | 547.95 | -0.69 | -0.00126683 |
| 551.42 | 552.11 | -0.70 | -0.00126686 |
| 554.81 | 555.52 | -0.70 | -0.00126688 |
| 611.08 | 611.86 | -0.77 | -0.00126686 |
| 615.56 | 616.34 | -0.78 | -0.00126683 |
| 629.38 | 630.17 | -0.80 | -0.00126686 |
| 634.33 | 635.13 | -0.80 | -0.00126680 |
| 647.85 | 648.67 | -0.82 | -0.00126684 |
| 777.46 | 778.44 | -0.98 | -0.00126671 |
| 782.35 | 783.34 | -0.99 | -0.00126698 |
| 799.51 | 800.52 | -1.01 | -0.00126698 |
| 805.96 | 806.98 | -1.02 | -0.00126697 |
| 1,560.73 | 1,562.71 | -1.98 | -0.00126688 |
| 1,574.56 | 1,576.55 | -1.99 | -0.00126688 |
| 1,587.01 | 1,589.02 | -2.01 | -0.00126689 |
| 1,589.48 | 1,591.49 | -2.01 | -0.00126682 |
| 1,596.99 | 1,599.02 | -2.02 | -0.00126688 |
| 1,624.11 | 1,626.17 | -2.06 | -0.00126689 |
| 2,559.71 | 2,562.95 | -3.24 | -0.00126684 |
| 3,748.28 | 3,753.03 | -4.75 | -0.00126691 |
| 4,062.94 | 4,068.09 | -5.15 | -0.00126691 |
| 4,847.79 | 4,853.93 | -6.14 | -0.00126684 |
| 6,095.18 | 6,102.90 | -7.72 | -0.00126697 |
| 6,573.81 | 6,582.14 | -8.33 | -0.00126672 |
| 7,519.99 | 7,529.51 | -9.53 | -0.00126676 |
| 7,865.85 | 7,875.82 | -9.96 | -0.00126683 |
| 8,014.34 | 8,024.49 | -10.15 | -0.00126680 |
| 8,058.68 | 8,068.89 | -10.21 | -0.00126686 |
| 10,008.61 | 10,021.29 | -12.68 | -0.00126680 |
| 10,088.37 | 10,101.15 | -12.78 | -0.00126682 |
| 11,958.90 | 11,974.06 | -15.15 | -0.00126691 |
| 14,988.82 | 15,007.81 | -18.99 | -0.00126689 |
| 15,413.80 | 15,433.32 | -19.53 | -0.00126704 |
| 15,994.11 | 16,014.37 | -20.26 | -0.00126688 |
| 16,122.83 | 16,143.25 | -20.43 | -0.00126689 |
| 19,216.71 | 19,241.06 | -24.34 | -0.00126682 |
| 20,222.10 | 20,247.72 | -25.62 | -0.00126691 |
| 33,559.81 | 33,602.32 | -42.52 | -0.00126690 |
| 39,081.06 | 39,130.56 | -49.51 | -0.00126680 |

**Table 6 A sample of FRs analysis for 34 parcels (areas are in m²).**

| Actual parcel area in Cassini | Computed areas and area variations after applying SGDTA procedure | | |
|---|---|---|---|
| Area ($A_0$) | Area ($A_1$) | ($A_0$ - $A_1$) | ($A_0$ - $A_1$)/$A_0$ |
| 220.38 | 220.655 | -0.28 | -0.00127 |
| 222.80 | 223.079 | -0.28 | -0.00127 |
| 223.56 | 223.846 | -0.28 | -0.00127 |
| 232.31 | 232.601 | -0.29 | -0.00127 |
| 275.94 | 276.295 | -0.35 | -0.00127 |
| 277.16 | 277.508 | -0.35 | -0.00127 |
| 285.40 | 285.760 | -0.36 | -0.00127 |
| 288.22 | 288.587 | -0.37 | -0.00127 |
| 290.03 | 290.393 | -0.37 | -0.00127 |
| 292.45 | 292.820 | -0.37 | -0.00127 |
| 295.98 | 296.354 | -0.38 | -0.00127 |
| 296.44 | 296.811 | -0.38 | -0.00127 |
| 298.14 | 298.520 | -0.38 | -0.00127 |
| 300.48 | 300.860 | -0.38 | -0.00127 |
| 300.70 | 301.085 | -0.38 | -0.00127 |
| 303.30 | 303.683 | -0.38 | -0.00127 |
| 308.33 | 308.722 | -0.39 | -0.00127 |
| 673.41 | 674.263 | -0.854 | -0.00127 |
| 709.11 | 710.010 | -0.899 | -0.00127 |
| 734.90 | 735.833 | -0.932 | -0.00127 |
| 799.24 | 800.248 | -1.013 | -0.00127 |
| 830.81 | 831.867 | -1.053 | -0.00127 |
| 1,007.15 | 1,008.426 | -1.277 | -0.00127 |
| 1,260.13 | 1261.728 | -1.598 | -0.00127 |
| 2,253.70 | 2,256.562 | -2.857 | -0.00127 |
| 2,805.79 | 2,809.342 | -3.557 | -0.00127 |
| 14,739.86 | 14,758.542 | -18.686 | -0.00127 |
| 20,346.08 | 20,371.868 | -25.793 | -0.00127 |
| 131,484.64 | 131,651.317 | -166.679 | -0.00127 |
| 524,679.57 | 525,344.766 | -665.198 | -0.00127 |
| 579,353.95 | 580,088.510 | -734.557 | -0.00127 |
| 766,967.12 | 767,939.397 | -972.273 | -0.00127 |
| 2,413,520.77 | 2,416,580.642 | -3059.875 | -0.00127 |
| 5,908,849.88 | 5,916,338.117 | -7488.234 | -0.00127 |

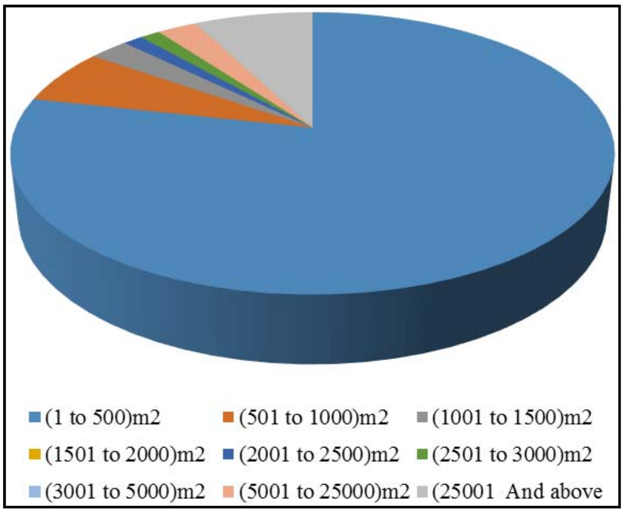


**Fig. 6 Block plans parcels distribution.**

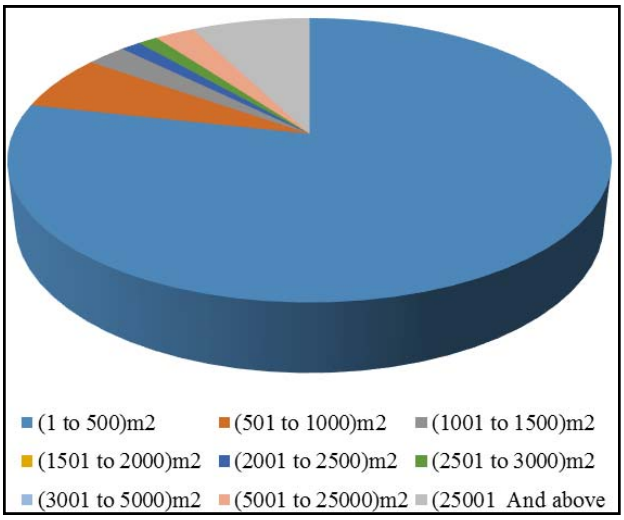


**Fig. 7 FRs parcels distribution.**

A comparative analysis was done for the variations in derived areas calculated when the data was in Cassini-Soldner coordinate system and those calculated after applying the SGDTA procedure on the block plans and FRs. From the area variations in Tables 5 and 6, it is clear that smaller areas exhibited small variations whereas larger areas exhibited large variations both in the block plans and in the FR's. The variations are further illustrated in Figs. 8 and 9 for block plans and FRs respectively.

Note that despite the large variations in parcel sizes based on FRs (Fig. 9), the increase had a similar graphical characteristic to what is observed in block plans (Fig. 8). Also, in both scenarios the parcels

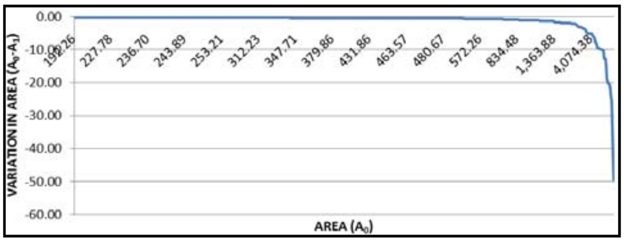


**Fig. 8 Block plans area variations against parcel sizes (units in m$^2$).**

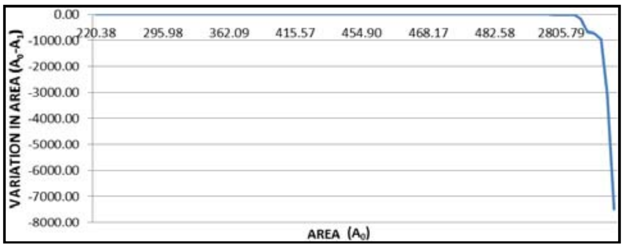


**Fig. 9 FRs area variations against parcel sizes (units in m$^2$).**

resulting from SGDTA procedure ($A_1$) had larger areas compared to parcels in Cassini Soldner coordinate system ($A_0$).The graphs in the same quadrants take similar shape, showing that the discrepancies are largely systematic. This implies that one can apply similar treatment to resolve or minimize the discrepancies noted in both cases.

### *6.3 Harmonization of Spatial Discrepancies*

The magnitude of discrepancy variations and the associated implications could result into serious disputes if used without applying relevant corrective measures. This study has gone a step ahead to generate a mathematical model to minimize discrepancies obtained during digitization of land related data. A 5$^{th}$ order polynomial was found to fit the discrepancies best in the area of study. This equation was generated with the aid of MatLab application though several trials to obtain the best line of fit by subjecting the discrepancies to a series of equations starting from linear, cubic and higher order polynomial equations. It is given as,

$$A^{corr} = (2\times10^{-31})A_1^5 - (1.8\times10^{-24})A_1^4 + (4.3\times10^{-18})A_1^3 - (2.7\times10^{-12})A_1^2 - 0.0013A_1 - 0.00036 \quad (2)$$

where, $A^{corr}$ is the correction to the area obtained after applying SGDTA procedure ($A_1$). The improved area is then obtained as,

$$A_{improved} = A_1 + A^{corr} \quad (3)$$

**Table 7 Sample of minimized discrepancies (units in m$^2$).**

| ($A_0$) | ($A_1$) | ($A_0$–$A_1$) | ($A^{corr}$) | Residual |
|---|---|---|---|---|
| 220.38 | 220.66 | -0.28 | -0.29 | 0.01 |
| 222.80 | 223.08 | -0.28 | -0.29 | 0.01 |
| 223.56 | 223.85 | -0.28 | -0.29 | 0.01 |
| 232.31 | 232.60 | -0.30 | -0.30 | 0.01 |
| 275.94 | 276.30 | -0.35 | -0.36 | 0.01 |
| 277.16 | 277.51 | -0.35 | -0.36 | 0.01 |
| 285.40 | 285.76 | -0.36 | -0.37 | 0.01 |
| 288.22 | 288.59 | -0.37 | -0.38 | 0.01 |
| 290.03 | 290.39 | -0.37 | -0.38 | 0.01 |
| 292.45 | 292.82 | -0.37 | -0.38 | 0.01 |
| 295.98 | 296.35 | -0.38 | -0.39 | 0.01 |
| 296.44 | 296.81 | -0.38 | -0.39 | 0.01 |
| 298.14 | 298.52 | -0.38 | -0.39 | 0.01 |
| 300.48 | 300.86 | -0.38 | -0.39 | 0.01 |
| 300.70 | 301.09 | -0.38 | -0.39 | 0.01 |
| 303.30 | 303.68 | -0.39 | -0.40 | 0.01 |
| 308.33 | 308.72 | -0.39 | -0.40 | 0.01 |
| 358.08 | 358.54 | -0.45 | -0.47 | 0.01 |
| 361.18 | 361.64 | -0.46 | -0.47 | 0.01 |
| 362.01 | 362.47 | -0.46 | -0.47 | 0.01 |
| 362.09 | 362.55 | -0.46 | -0.47 | 0.01 |
| 366.68 | 367.15 | -0.47 | -0.48 | 0.01 |
| 367.03 | 367.50 | -0.47 | -0.48 | 0.01 |
| 367.47 | 367.93 | -0.47 | -0.48 | 0.01 |
| 367.63 | 368.09 | -0.47 | -0.48 | 0.01 |
| 372.72 | 373.20 | -0.47 | -0.49 | 0.01 |
| 374.30 | 374.77 | -0.48 | -0.49 | 0.01 |
| 376.52 | 376.99 | -0.48 | -0.49 | 0.01 |
| 380.52 | 381.00 | -0.48 | -0.50 | 0.01 |
| 413.01 | 413.54 | -0.52 | -0.54 | 0.01 |
| 415.57 | 416.10 | -0.53 | -0.54 | 0.01 |
| 421.26 | 421.79 | -0.53 | -0.55 | 0.02 |
| 435.47 | 436.02 | -0.55 | -0.57 | 0.01 |

| | | | | |
|---|---|---|---|---|
| 439.51 | 440.07 | -0.56 | -0.57 | 0.01 |
| 444.85 | 445.41 | -0.56 | -0.58 | 0.02 |
| 445.12 | 445.69 | -0.56 | -0.58 | 0.02 |
| 446.59 | 447.16 | -0.57 | -0.58 | 0.02 |
| 449.79 | 450.36 | -0.57 | -0.59 | 0.02 |
| 450.41 | 450.98 | -0.57 | -0.59 | 0.02 |
| 450.83 | 451.40 | -0.57 | -0.59 | 0.02 |
| 454.90 | 455.47 | -0.58 | -0.59 | 0.02 |
| 457.80 | 458.38 | -0.58 | -0.60 | 0.02 |
| 457.93 | 458.52 | -0.58 | -0.60 | 0.02 |
| 458.06 | 458.64 | -0.58 | -0.60 | 0.02 |
| 458.90 | 459.48 | -0.58 | -0.60 | 0.02 |
| 462.55 | 463.14 | -0.59 | -0.60 | 0.02 |
| 462.81 | 463.40 | -0.59 | -0.60 | 0.02 |
| 463.52 | 464.11 | -0.59 | -0.60 | 0.02 |
| 463.72 | 464.31 | -0.59 | -0.60 | 0.02 |
| 465.32 | 465.91 | -0.59 | -0.61 | 0.02 |
| 468.17 | 468.77 | -0.59 | -0.61 | 0.02 |
| 468.66 | 469.26 | -0.59 | -0.61 | 0.02 |
| 468.97 | 469.56 | -0.60 | -0.61 | 0.02 |
| 470.46 | 471.06 | -0.60 | -0.61 | 0.02 |
| 470.94 | 471.54 | -0.60 | -0.61 | 0.02 |
| 472.34 | 472.94 | -0.60 | -0.62 | 0.02 |
| 474.35 | 474.95 | -0.60 | -0.62 | 0.02 |
| 476.04 | 476.65 | -0.60 | -0.62 | 0.02 |
| 477.28 | 477.88 | -0.61 | -0.62 | 0.02 |
| 482.12 | 482.73 | -0.61 | -0.63 | 0.02 |
| 482.58 | 483.19 | -0.61 | -0.63 | 0.02 |
| 485.76 | 486.38 | -0.62 | -0.63 | 0.02 |
| 673.41 | 674.26 | -0.85 | -0.88 | 0.02 |
| 709.11 | 710.01 | -0.90 | -0.92 | 0.02 |
| 734.90 | 735.83 | -0.93 | -0.96 | 0.02 |
| 799.24 | 800.25 | -1.01 | -1.04 | 0.03 |
| 830.81 | 831.87 | -1.05 | -1.08 | 0.03 |
| 1007.15 | 1008.43 | -1.28 | -1.31 | 0.03 |
| 1260.13 | 1261.73 | -1.60 | -1.64 | 0.04 |
| 2253.70 | 2256.56 | -2.86 | -2.93 | 0.08 |
| 2805.79 | 2809.34 | -3.56 | -3.65 | 0.10 |
| 14739.86 | 14758.54 | -18.69 | -19.19 | 0.50 |
| 20346.08 | 20371.87 | -25.79 | -26.49 | 0.69 |
| 131484.64 | 131651.30 | -166.68 | -171.18 | 4.50 |
| 524679.57 | 525344.70 | -665.20 | -683.19 | 17.99 |
| 579353.95 | 580088.50 | -734.56 | -754.37 | 19.81 |
| 766967.12 | 767939.30 | -972.27 | -998.53 | 26.26 |
| 2413520.77 | 2416580.60 | -3059.87 | -3141.50 | 81.63 |
| 5908849.88 | 5916338.10 | -7488.23 | -7650.80 | 162.57 |
| **Mean** | | 166.80 | | 3.99 |
| **SD** | | ±914.2 | | ±20.65 |

The area correction model (Eq. (2)) should be applied to all the areas computed from the SGDTA procedure to obtain improved areas. We demonstrate this fact in Table 7 using FRs covering a total of 79 parcels in the area of study. FRs give fairly accurate areas, hence more appropriate for accuracy analysis than block plans. The results obtained after applying Eq. (3) to all the computed areas indicate that the discrepancies between the improved ($A_{improved}$) and actual areas$A_0$, referred to as residuals in Table 7, are smaller than the discrepancies between the areas computed from the SGDTA procedure and actual areas. The standard deviation (SD) improves from ±914.20 m$^2$ to ±20.65 m$^2$, representing an improvement of 97.7%. This is good but it presents a great challenge, “how to deal with discrepancies associated with digitization of paper plans or maps” in the geodatabases. We have only dealt with the discrepancies in areas (although not conclusively) but the discrepancies in distances, angles etc should also be considered. The harmonized topo-cadastral and base maps of the study area are presented in Figs. 10 and 11 respectively.

## 7. Conclusion and Recommendations

This project has demonstrated a process for developing a harmonized spatial data from various data sources or data sets. A number of discrepancies have been identified during the harmonization procedure (SGDTA). A method for minimizing discrepancies in areas has been proposed as a 5$^{th}$ order polynomial that was found to fit the discrepancies best in the area of


Fig. 10 Olkalou township topo-cadastral map.

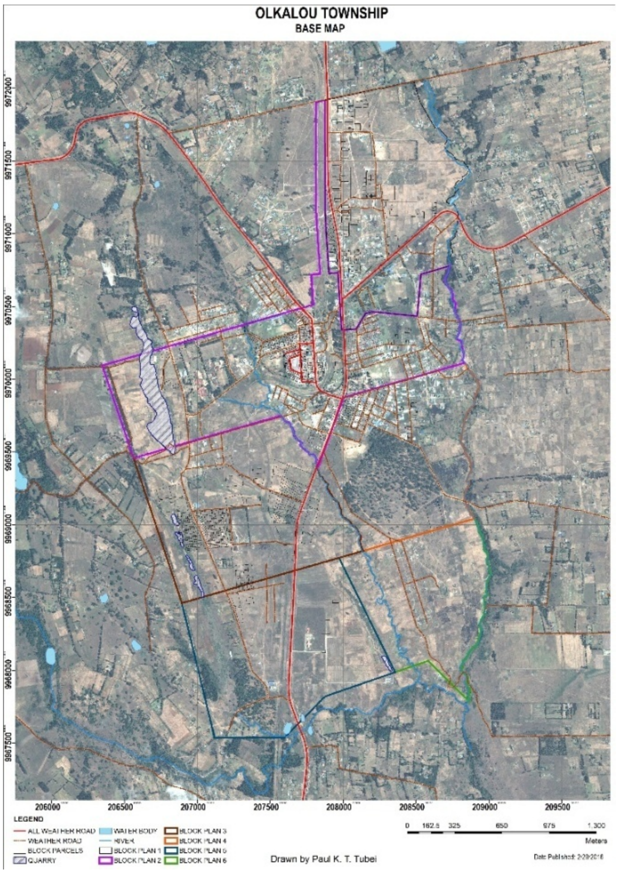


Fig. 11 Olkalou township base map.

study. The following is a summary of the results in the form of conclusion and recommendations.

(1) Digitization process of land related data introduces discrepancies to the final product; geospatial practitioners should therefore minimize errors in the derived areas from digitization by applying a locally determined correction model (we have used a 5$^{th}$ order polynomial in the current study).

(2) During harmonization it was noted that bigger parcels of land still contained big errors even after subjecting the discrepancies to the 5$^{th}$ order polynomial, this phenomenon needs to be studied further in order to establish ways of reducing such errors while dealing with larger areas of land.

(3) The project's output is a harmonized automated GIS geodatabase cadastre that contains cadastral attributes harmonized to one projection and coordinate system that can be used as a standard and a base map for all property boundary plans which can be overlaid to datasets from other industries/ministries like engineering design, urban/regional planning, construction works, geological and geotechnical investigation surveys, tied to Remote Sensing data without the requirement of further transformations and with minimized errors.

(4) It is further noted that although RTK GPS surveys are highly accurate, the variation between their observations and those contained in map surveys ranges between a few millimeters to several hundreds of centimeters. As a result, it is important for qualified Surveyors and Geomatic engineers alike to follow traditional procedures while resolving land disputes. They should subsequently pick the GPS coordinates of the parcel to facilitate future surveys in the same area.

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