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SATELLITE POSITIONING BASED EXTENSION OF GEODETIC REFERENCE NETWORK TO SUPPORT GEOSPATIAL APPLICATIONS

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ABSTRACT

A national geodetic network provides the fundamental framework that enables attainment of high accuracy geodetic measurements. It plays a key role in the efficiency and reliability of operations in land surveying, mapping, remote sensing, Geographic Information System, engineering surveying and other related applications. The geodetic framework provides the basis for integrating all mapping and survey activities. About eighty per cent of the primary geodetic control points in Kenya, established in the early twentieth century, have been destroyed. This has resulted in expensive and time consuming operations and processes for geospatial professionals and scientists. This situation is particularly worse in central Kenya, hence the need to extend the geodetic control by establishing more control points on secure and accessible sites for use by geospatial professionals and scientists in a wide variety of applications.

In this study, modern satellite positioning techniques were utilised to extend geodetic reference network in central Kenya. Existing geodetic control points were used to facilitate establishment of new geodetic control points distributed within the region. Field observations were carried out using Global Positioning System. The raw data were downloaded, edited, processed and adjusted using Leica Geo-Office software. The resulting final adjusted coordinates had a maximum standard deviation of 2cm and 5cm on horizontal and vertical coordinates respectively, and a general loop misclosure of less than one part per million. The results showed that the quality of established control point positions was high, and demonstrated the efficient extension of geodetic control network using modern satellite positioning systems and efficient computational techniques in situations such as the ones currently prevailing in central Kenya.

Key Words: Geodetic control network, Global Navigation Satellite System (GNSS), Geospatial applications

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INTRODUCTION

The British colonial government in Kenya established evenly distributed geodetic control points throughout the country. However, since the attainment of Kenya's independence in 1963, the established geodetic network has over the years been extensively destroyed. As a result, about 80 per cent of the primary geodetic control points in Kenya, established in the early twentieth century on hilltops, have been destroyed (Okumu, 1990; Aduol 1998). The status of the geodetic reference network in Kenya is thus in dire need of re-establishment and extension applying methodologies that can guarantee high degree of accuracy, reliability, integrity and sustainability.

The destruction of the primary geodetic control points has resulted in expensive and time consuming operations and processes for geospatial professionals and scientists. This situation is particularly worse in the central Kenya. There is need therefore to extend the geodetic control by establishing more control points on secure and accessible sites for use by geospatial professionals and scientists in a wide variety of applications.

A geodetic network consists of control monuments, often referred to as control points that are distributed across the landmass for surveyors and other users to occupy and access the geodetic grid as well as provide a reference to control survey work (Obel, 1985). However, with advancement in technology and especially the advent of Global Navigation Satellite System (GNSS), geodetic control establishment from space has become possible and with high accuracy, leading to establishment of active spatial reference systems (Arinola, 1990; Brown, 1977; Slama 1978; Gomaa and Tarek, 2003; Dixon, 2006; Aponte *et al*., 2009). This active reference system consists of a network of continuously operating Global Navigation Satellite System receivers that continuously track satellites and compute their precise orbits eventually determining their (receivers) precise locations horizontally and vertically (Cai and Cao, 2009; Feng and Rizos; 2009). A national geodetic network provides the fundamental support for land surveying, mapping, remote sensing, engineering and related applications and provides the basis for integrating all such activities for enhanced economic growth and development.

Kenya Vision 2030, the long-term vision to guide the country's development towards realization of a globally competitive and a prosperous nation, identifies a comprehensive national land policy as crucial to providing an overarching framework for facilitating planning, management and administration of land in the country (Kenya Vision 2030, 2007). The lack of such a framework has derailed many development projects due to the contentious and unresolved nature of status of land in pre and post-colonial Kenya. Land is not only regarded as a factor of production among other factors, but also a vital factor that directly and indirectly influences the performance of all other factors. It has a high aesthetic, cultural and traditional value so large to be quantified and subsequently, its access and utilization by key sectors of the economy has been affected greatly.

A comprehensive and accurate geodetic reference framework for control and reference provision for all types of survey, and also for scientific research, exploration, mining, engineering, and other development projects is a vital part of the national land policy (Lwangasi, 1993; Mathew *et al*, 2013). The framework is expected to realize a common reference to all surveys carried out in the country as well as for providing proper integration with those of neighboring countries. A Geographical Information System based Land Information System and National Spatial Data Infrastructures have also been proposed in the national land policy to facilitate effective and reliable management of land resources and all its parameters. The objective of this study therefore, was to utilize modern satellite positioning techniques to create a reliable and accurate geodetic reference network connected to the existing local reference frame in central Kenya. This would facilitate spatial applications and consequently contribute to the attainment of national development goals and associated requirements.

STUDY AREA

This study focuses on central Kenya (Figure 1) due to its central geographical location with respect to the international boundaries of Kenya. Two Counties in central Kenya, - Nyeri and Kirinyaga counties were chosen as the study area because they form good study cases for areas facing unreliable and inaccurate geodetic reference network needed to facilitate sustainable development. The two Counties form part of Kenya's eastern highlands. The study area cover a total area of approximately 4,744 sq km situated between Longitudes 36º and 38º east and between the equator and Latitude 0º 38´ south. The main physical features in this region include Mt. Kenya (altitude, 5,199m) to the north and the Aberdare Range (altitude, 3,999m) to the west.

METHODOLOGY

The methodology adopted for extending geodetic reference network to support geospatial applications in central Kenya is summarized in Figure 2. The study involved various components including desktop study, project planning, network adjustment and eventual coordinate transformations. Desktop study was carried out to identify existing geodetic control points in Central Kenya to provide reference control and facilitate geodetic measurements as well as for connecting the new network to the existing one.

To achieve this, technical teams from Survey of Kenya national headquarters and County Survey Offices of the two Counties; Nyeri and Kirinyaga were consulted to provide required information.

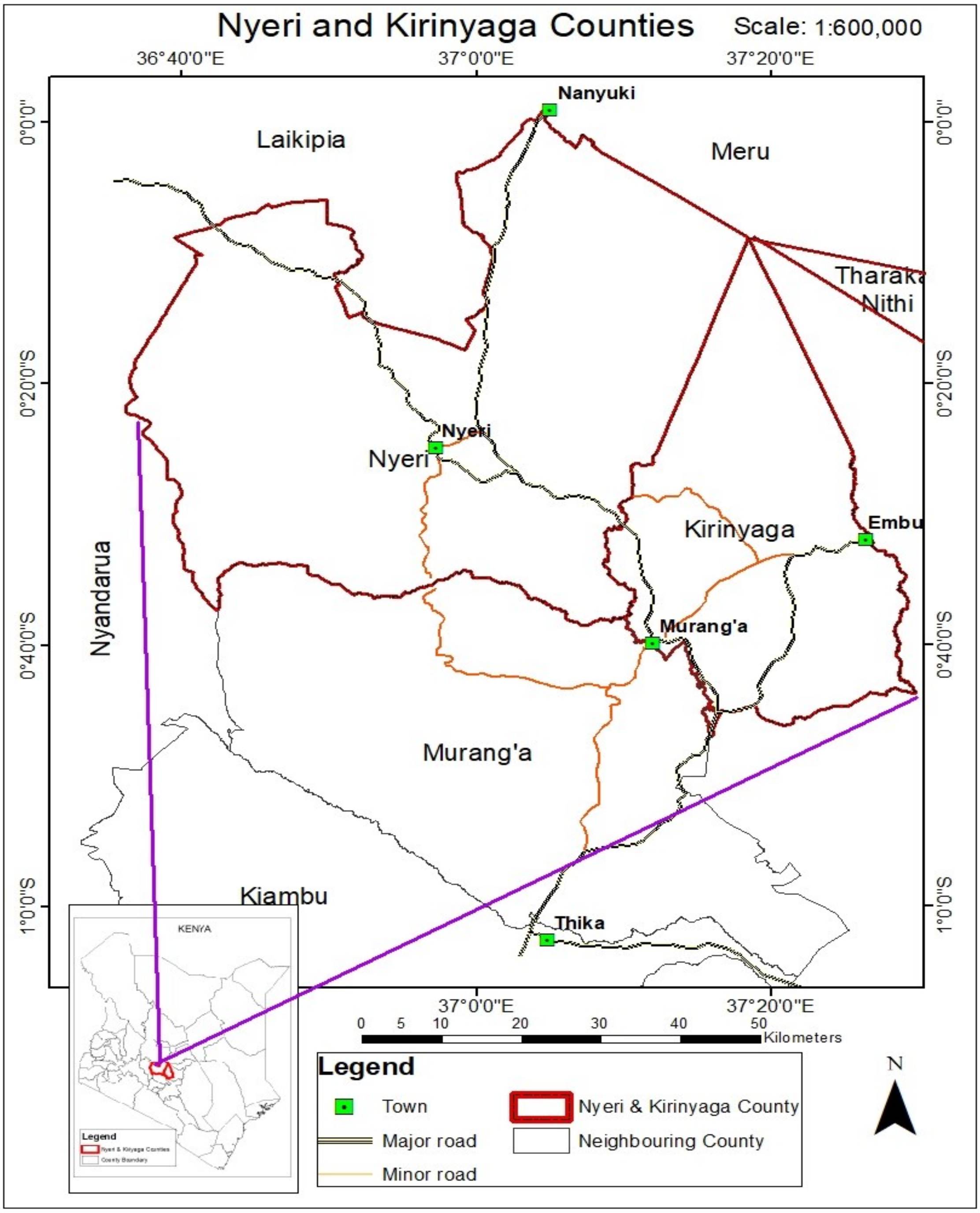

Figure 1: Map showing the study area

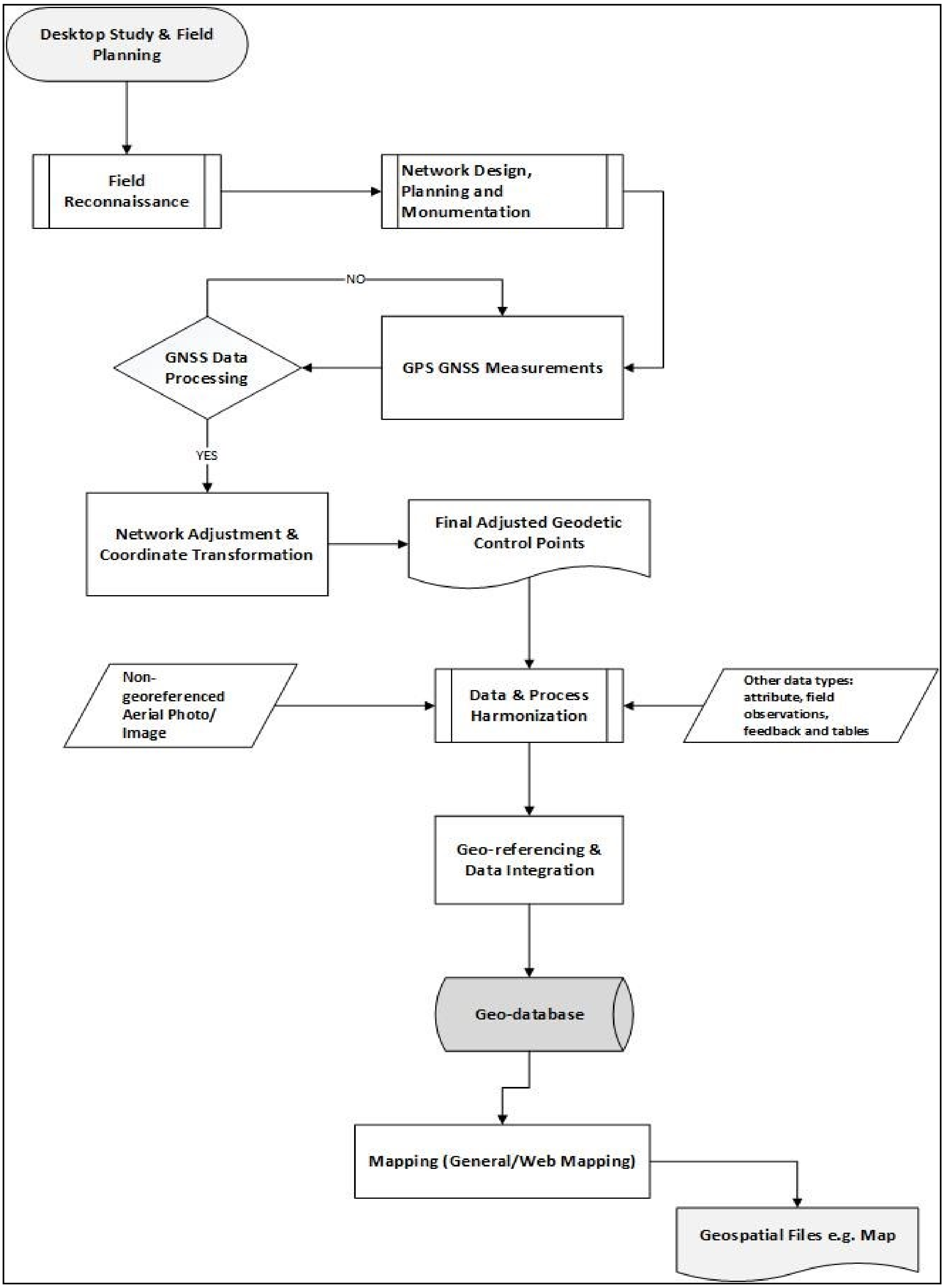

Figure 2: Research methodology flow Diagram

Equipment and materials used at this stage included a set of Global Navigation Satellite System equipment for measurements, Kenya Geodetic Control Network map Series SK81F Kenya at a scale of 1:1,000,000, Triangulation Cards with UTM, Arc 1960 Coordinates, Control pillar information and a 1:50,000 topographic maps of the area. Plotting of the existing geodetic control points on the topographic maps was done to facilitate reconnaissance and thereafter a reconnaissance survey of the study area was carried out. Design of new geodetic control point locations was then carried out. Preference of locations was given to areas considered safe to avoid destruction of the new control points. Establishment of monuments for the selected locations of new points was thereafter undertaken.

Field measurement on the established monuments was carried out followed by data processing. Teams of research assistants were sent out to conduct field work. These comprised five teams. Each team was provided with the necessary equipment including a set of GNSS equipment comprising of Leica GPS Base and Receivers, tripods, external batteries, a digital camera, and a vehicle. In each session of the field measurement, each team conducted GNSS measurement at the new control points and other survey marks using an agreed and pretested common procedure of GNSS measurements. Each session was accorded ample time for data logging to ensure accurate observations. The data collected was thereafter processed in two stages. The first stage was the pre-processing which involved data conversion into Rinex Format, error checks, confirming data completeness and preparing for data processing. In the second stage, Leica Geo-Office Version 8.3, a GNSS data processing and network adjustment software, was used to process, and analyse the data. An evaluation of the Leica Geo-Office along with others has been carried out (Siniša *et al*, 2015). The results of their study that compared geodetic processing software, including Leica GeoOffice, showed that the resulting baseline error differences are insignificant relative to the typical accuracies set for establishment of Control networks.

Network Adjustment and Coordinate Transformation

Data processing then set the stage for network adjustment and coordinates transformation**.** All the baselines in the network were adjusted using Leica Geo-Office software to provide the final coordinates of the new geodetic control points. Adjustment also ensured quality evaluation of both the field observations and the final coordinates. The transformation parameters were obtained by occupying a number of control stations that had their coordinates in local coordinate system. The transformation parameters between Universal Transverse Mercator (UTM), Arc 1960 and World Geodetic System (WGS 84) system were then calculated. Finally, the baseline data was transformed using the obtained transformation parameters and subsequently final UTM Coordinates of the new geodetic control points obtained.

RESULTS

The results of the reconnaissance survey are summarized in Table 1. Four existing national geodetic control pillars were found intact. Their coordinate information as provided by Survey of Kenya is as shown in the table.

Table 1: Existing national geodetic control points in study area (Source: SOK)

Point	Name	UTM Zone	1:50,000 Topo	Northing (m)	Easting (m)	Ortho. Hgt (m)	Order
SKP 211	Nyeri	37	120/4	9954810.146	266508.302	2182.380	1st
120S1	Rakasa	37	120/4	9963932.073	269718.833	2031.780	2nd
120S2	Kiadongoro	37	120/4	9949485.060	261852.810	2225.970	2nd
135S10	Gitaima	37	135	9923934.280	759535.630	2068.590	2nd

From the field measurements, processed and adjusted data, a total of fifty two (52) geodetic control stations were established in the study area and their final adjusted coordinate information recorded as shown in Table 2. The resulting final adjusted coordinates had a maximum standard deviation of 2cm and 5cm on horizontal and vertical coordinates respectively and the general loop misclosure of less than one part per million. In addition, nine (9) control points were also conveniently established to allow geospatial activities and engineering surveying purposes in the study area.

Table 1: Final Adjusted UTM Grid (Clarke 1880, Arc 1960, Zone 37 South) coordinates of the new geodetic control points

	Point	Status	Easting (m)	sdE (m)	Northing (m)	sdN (m)	Orth Hgt (m)	sdOrt Hgt (m)

1	A	Adjusted	286712.159	0.011	9961214.884	0.012	1860.227	0.041
2	B	Adjusted	286103.714	0.012	9960889.509	0.012	1837.181	0.042
3	CHAKA	Adjusted	277335.979	0.011	9960743.144	0.011	1758.611	0.041
4	CHIN	Adjusted	266402.269	0.013	9933696.290	0.013	2032.333	0.044
5	DEKUT5	Adjusted	272693.643	0.011	9956706.388	0.011	1779.511	0.041
6	DKUT	Adjusted	272861.245	0.011	9956561.795	0.011	1773.102	0.041
7	DeKUT10	Adjusted	272635.758	0.011	9956966.664	0.012	1784.699	0.041
8	DeKUT2	Adjusted	273023.401	0.011	9956379.697	0.011	1774.256	0.041
9	DeKUT3	Adjusted	273118.081	0.011	9956287.817	0.011	1770.657	0.040
10	DeKUT4	Adjusted	272990.034	0.011	9956217.094	0.012	1777.741	0.041
11	DeKUT7	Adjusted	272903.575	0.011	9956825.260	0.011	1780.936	0.041
12	DeKUT8	Adjusted	272848.131	0.012	9956892.370	0.012	1782.847	0.041
13	DeKUT9	Adjusted	272689.262	0.011	9956898.092	0.012	1787.526	0.041
14	GATH	Adjusted	265073.605	0.014	9945980.119	0.014	2069.391	0.045
15	GIAT	Adjusted	274911.760	0.014	9942658.374	0.013	1834.242	0.045
16	GKI	Adjusted	305038.464	0.012	9947521.458	0.012	1675.891	0.042
17	IRUR	Adjusted	281088.240	0.013	9933638.851	0.013	1716.159	0.044
18	ITUN	Adjusted	297857.260	0.013	9954209.968	0.012	1941.607	0.043
19	KAGI	Adjusted	305552.162	0.013	9930894.738	0.013	1234.379	0.044
20	KAGU	Adjusted	308925.831	0.012	9935247.867	0.012	1273.586	0.042
21	KAIR	Adjusted	264813.484	0.014	9941349.471	0.013	2043.562	0.045
22	KANG	Adjusted	295429.175	0.012	9944400.475	0.013	1653.657	0.043
23	KARA	Adjusted	291733.266	0.012	9946814.504	0.012	1754.627	0.042
24	KARI	Adjusted	263956.817	0.013	9936553.072	0.013	2066.933	0.044
25	KARIA	Adjusted	311691.226	0.013	9940281.866	0.013	1348.152	0.045
26	KARO	Adjusted	288128.449	0.012	9944353.089	0.012	1717.908	0.042
27	KBGT	Adjusted	298395.114	0.012	9937772.879	0.012	1375.841	0.042
28	KBR	Adjusted	310460.772	0.012	9946635.982	0.012	1577.183	0.042
29	KDC	Adjusted	310121.000	0.014	9926608.390	0.013	1187.745	0.045
30	KHC	Adjusted	294436.743	0.013	9928236.675	0.013	1387.400	0.045
31	KIAN	Adjusted	316371.073	0.013	9945638.221	0.013	1498.359	0.044
32	KIRI	Adjusted	271813.546	0.013	9934071.100	0.013	1868.145	0.044
33	KPPI	Adjusted	299793.397	0.013	9932189.717	0.013	1242.877	0.043
34	KPS	Adjusted	307013.790	0.013	9926896.915	0.013	1199.761	0.045
35	KRG	Adjusted	308667.340	0.013	9944043.434	0.013	1512.642	0.045
36	KRIO	Adjusted	300172.248	0.012	9946448.993	0.012	1619.299	0.042
37	KRTU	Adjusted	293204.215	0.013	9957401.316	0.012	1993.777	0.043
38	KUTU	Adjusted	313560.041	0.013	9937475.097	0.013	1289.305	0.045
39	KWV	Adjusted	304782.106	0.014	9925344.771	0.014	1155.464	0.046
40	MAKA	Adjusted	311527.850	0.014	9917164.324	0.014	1160.184	0.046
41	MARU	Adjusted	282469.528	0.012	9949971.995	0.012	1626.743	0.042
42	MIHU	Adjusted	286370.773	0.013	9937402.436	0.013	1708.000	0.044
43	MIIR	Adjusted	295483.915	0.012	9947011.877	0.012	1743.123	0.042
44	MKN	Adjusted	307989.409	0.014	9916181.419	0.014	1153.285	0.046
45	MTU	Adjusted	304964.896	0.012	9943115.698	0.012	1498.125	0.042

46	MUTH	Adjusted	267408.831	0.015	9950277.029	0.014	1968.794	0.047
47	MUTI	Adjusted	313257.693	0.014	9919808.675	0.014	1146.778	0.046
48	MWDC	Adjusted	287020.524	0.012	9947845.819	0.012	1772.726	0.042
49	MWEI	Adjusted	266519.470	0.011	9963935.330	0.011	1962.603	0.041
50	NDIA	Adjusted	276564.655	0.013	9937647.386	0.013	1822.446	0.044
51	NDUN	Adjusted	286078.582	0.011	9959173.219	0.012	1845.210	0.041
52	NGO	Adjusted	306791.554	0.014	9920774.340	0.014	1152.214	0.046
53	NGOR	Adjusted	284060.979	0.013	9939534.313	0.013	1734.916	0.043
54	NYAN	Adjusted	317197.678	0.013	9933838.208	0.013	1238.185	0.045
55	OTHA	Adjusted	270817.313	0.013	9938118.225	0.013	1876.070	0.044
56	RC2	Adjusted	272943.320	0.011	9956273.795	0.011	1790.861	0.041
57	RURI	Adjusted	272866.773	0.015	9951414.988	0.014	1777.271	0.047
58	RWAM	Adjusted	316584.935	0.013	9941842.083	0.013	1392.834	0.044
59	SAMS	Adjusted	317863.541	0.013	9938775.160	0.013	1337.541	0.045
60	SUP	Adjusted	300055.413	0.015	9927071.049	0.015	1198.779	0.048
61	WANG	Adjusted	318861.489	0.015	9923765.066	0.014	1146.914	0.048

Coordinate Transformation

A three dimensional transformation was performed using the Molodensky-Badekas model that derived ten (10) transformation parameters that would allow transformation of coordinates from WGS 84 to UTM system (Lwangasi, 1993).

$$\begin{pmatrix} X_R \\ Y_R \\ Z_R \end{pmatrix} = M * \begin{pmatrix} 1 & R_Z & -R_Y \\ R_Z & 1 & R_X \\ -R_Y & -R_X & 1 \end{pmatrix} * \begin{pmatrix} X_S & - & X_P \\ Y_S & - & Y_P \\ Z_S & - & Z_P \end{pmatrix} + \begin{pmatrix} X_P \\ Y_P \\ Z_P \end{pmatrix} + \begin{pmatrix} dX \\ dY \\ dZ \end{pmatrix}$$

Where;

(dX, dY, dZ) : Translation vector,

(R_X, R_Y, R_Z): Rotations to be applied to the coordinate reference frame,

(X_P, Y_P, Z_P): Coordinates of point about which the coordinate reference is rotated,

M: The scale factor

The parameters derived, their respective magnitudes and accuracy estimates are summarized in Table 3.

Table 3: Transformation parameters between WGS84 and UTM

	Parameter	Magnitude	Accuracy estimate
1.	Shift dX	158.7351m	0.0305 rms

2.	Shift dY	2.1067m	0.0305 rms
3.	Shift dZ	297.6477m	0.0305 rms
4.	Rotation about X	-4.40526" (Seconds)	0.6652 " (Seconds)
5.	Rotation about Y	4.79097" (Seconds)	0.8152 " (Seconds)
6.	Rotation about Z	18.28060" (Seconds)	0.4690 " (Seconds)
7.	Scale	-2.9178m	1.3073 ppm
8.	X_P	5094671.7799 m	
9.	Y_P	3840165.4725 m	
10.	Z_P	-49016.0584 m	

Sample Application of the Established Geodetic Control in GIS Mapping

To explore the utility of the extended geodetic control network for GIS mapping applications, a satellite image covering part of central Kenya and within the study area was geo-referenced using the newly established geodetic control points. Rubber sheeting method of georeferencing was used for geo-referencing the image into a geo referenced map (Figure 3) that was later digitized to develop a GIS geo-database.

The procedure adopted in developing the GIS Geodatabase and the map in order to explore the utility of the extended geodetic control network for GIS mapping applications involved the following key stages: Adding data layers into ArcGIS, defining the general and symbology properties for layers, drawing layers based on attribute fields, labeling layers based on their attribute fields, evaluating data frame properties especially in order to ensure appropriate coordinate system, and creating a layout for graphic export of the map. The resulting map is shown in Figure 4.

Figure 3: Geo-referenced satellite image using the resulting geodetic control point values

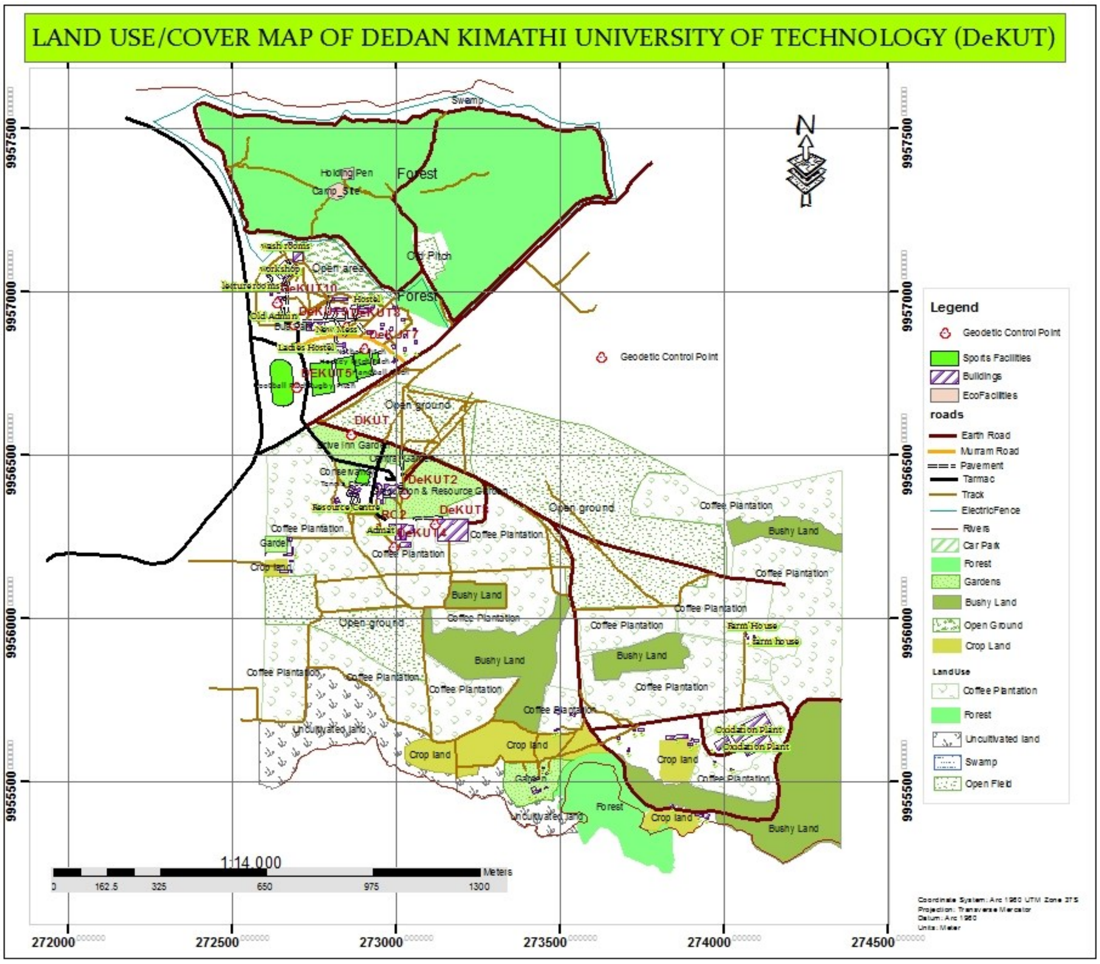

Figure 4: Map developed to demonstrate utility of geodetic control network extension

CONCLUSION

In this study, and from the GNSS field measurements, data processing, and adjustment, a total of fifty two (52) geodetic control points or stations were established in the study area and their final adjusted coordinates derived. The resulting final adjusted coordinates had a maximum standard deviation of 1cm and 1.5cm on horizontal and vertical coordinates respectively, and a general loop misclosure of less than one part per million. The newly established geodetic control network is connected to the existing network whose control points were used as reference. In addition to this, nine (9) control points were also suitably established to be used for geospatial applications. The application of the newly established control points in geo-referencing of satellite imagery, a common feature in remote sensing and GIS applications, was also demonstrated.

From the results, the quality of the established control point positions was high, and the study demonstrates efficient extension of geodetic control networks using modern satellite positioning systems and efficient computational techniques in situations such as the ones currently prevailing in central Kenya. The same may be replicated in other parts of the country thus re-establishing the geodetic network that are largely destroyed throughout.

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