

A Review of the History and Development of the Kenyan Geodetic Reference Frame

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Key Words — AFREF, KENREF, geodetic reference frame, Harmonization.

SUMMARY

All major triangulation networks in Kenya were established by different organizations such as the Anglo German Boundary Commission (AGBC) and the Directorate of Overseas Surveys (DOS), all with different objectives. Moreover, these networks use different datums and coordinate systems resulting in an inhomogeneous geodetic reference network.

In addition, all efforts to create a unified reference frame within the country have not been realized. For example, the African Doppler Survey (ADOS) project that ended in 1986 did not achieve the objective of harmonization because of technical challenges.

Although the African Geodetic Reference frame (AFREF) project that is being implemented locally as the Kenya Geodetic Reference Frame (KENREF) promises to achieve this goal, and despite the availability of specifications, independent networks of Continuously Operating Reference Stations (CORS) established by private companies are unlikely to solve the problem of an inhomogeneous geodetic network.

The aim of this paper is therefore to review the historical development of the Kenyan Geodetic network as a basis for any eventual harmonization of the legacy network with KENREF.

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1. INTRODUCTION

A geodetic control network also referred to as a reference network or control network is a set of physical points that often form triangles which are measured precisely by either terrestrial surveying techniques or satellite geodetic techniques. A geodetic control network consists of stable, identifiable points with published datum values or coordinates derived from observations that tie the points together (Bossler, J.D., (1984)). Conventionally, a control network is divided into two components; horizontal (X-Y) control and vertical (Z) control mainly because of technical limitations. Though Global Navigation Satellite Systems provide the possibility to compute coordinates of points on an integrated three-dimensional control network directly.

Kenya's geodetic network consists of many systems of coordinates. The term "system" here refers to either the datum/reference surface or the projection used to represent geographic coordinates on the plane. Geodetic control networks are needed to facilitate activities such as; mapping, boundary demarcation, urban planning and management, implementation of engineering projects, hydrographic mapping, environmental management, earthquake hazard assessment, space research among others.

2. A HISTORICAL REVIEW OF THE KENYA GEODETIC NETWORK

At the beginning of the 20th century the Anglo German Boundary Commission (AGBC) of 1893 that consisted of Belgians, Portuguese, British and Germans was established to carry out delimitation of boundaries of colonies in Central and East Africa (Mugnier, C., (2014)).

The delimitation of interterritorial boundaries needed geodetic control points as a basis, but none existed at that time. The colonial powers thus established and observed triangulation networks along the agreed boundaries. The triangulation networks established were not well conditioned insofar as geodetic requirements are concerned and were rather shaped by the boundaries.

The first triangulation network to be observed by the AGBC in East Africa was between Kenya and Tanganyika (current Tanzania) between 1892 and 1893. The second triangulation network was done by the Anglo German Boundary Commission of 1902-1906.

2.1 Kenya Major Triangulation

By 1906 only two major triangulation chains established by the AGBC existed, these chains were along the Kenya - Tanzania boundary and the edge of Lake Victoria (Mugnier, C. (2014)). This was far away from the areas where surveys for land registration were required. Kenya

Major triangulation started in 1906 to extend control for title surveys and topographical mapping in the White Highland areas (Caukwell, R.A. (1977)).

Kenya major system was based on Cassini Soldner Projection calculated from origins at the intersections of odd-numbered-degree meridians (as central meridian) with the equator as the reference latitude and extending over successive zones of two degrees of longitude and referenced to Clark 1858 Ellipsoid. Figure 1 shows the extent of this network. Kenya Major derived its datum from AGBC of 1902 at *Kisumu* where a base existed and its latitude at *Athi River*. The longitude was derived at *Elemoborasha*. After this initial work, several other triangulation chains were conducted between 1906 and 1922, see Table 1.

The common points between Kenya Major triangulation network and the AGBC chains enabled re-computation of AGBC 1902-1906 triangulation based on Kenya major sections. The purpose was to generate co-ordinates consistent with Kenya Major triangulation data.

The Kenya Major System was never closed and adjusted as a whole. Consequently, a surveyor working across the triangulation chains would encounter a substantial displacement. To carry out subdivision or re-establishment surveys, it became necessary to know which triangulation chain had controlled the original cadastral survey.

Table 1: The Kenya Major Triangulation Chains (Source: Caukwell R.A., (1977))

Series No.	Series Name	Year Observed
1	Anglo-German Boundary Chain	1904 - 1906
2	Lumbwa - Sotik	1906
3	Athi - Nyeri	1907
4	Athi - Lumbwa	1907
5	Athi - Mombasa	1908
6	Mombasa - Malindi	1908
7	Malindi – Sabaki River	1909 - 1910
8	Kitui	1910
9	Laikipia	1910 - 1911
10	Uasin-Gishu	1910 - 1911
11	Mombasa - Vanga	1910 - 1912
12	TransNzoia	1911 - 1912
13	North Rift Valley	1911 - 1912
14	Machakos	1912 - 1913
15	Kitui	1912 - 1913
16	Mumias	1912 - 1913
17	East Kenya	1912 - 1913
18	North Kenya	1913 - 1914
19	Malindi - Kipini	1913 - 1914
20	Kisii	1913 - 1914
21	Lamwia -Elemoborasha	1913 - 1914
22	Kipini - Lamu	1916, 1919 & 1922

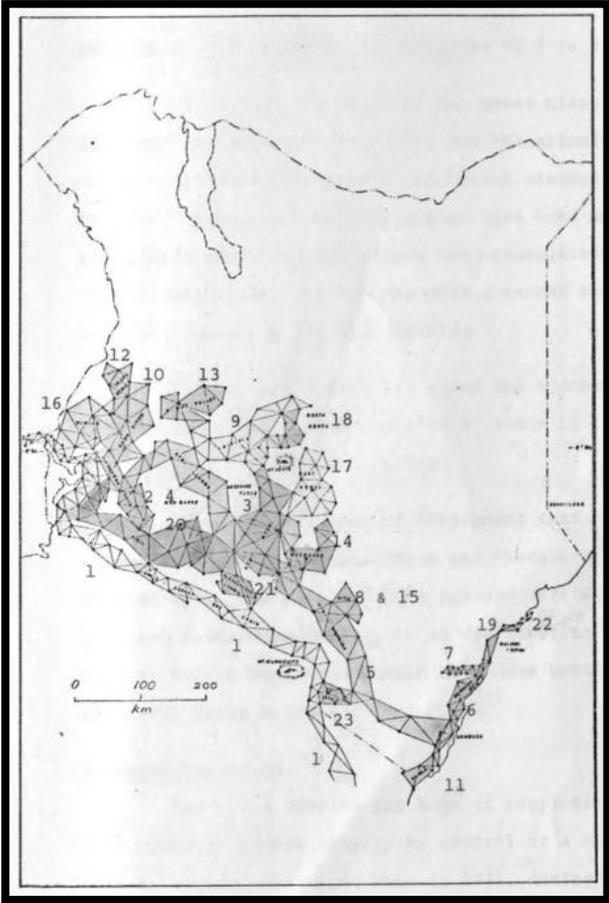


Figure 1: Kenya Major Triangulation Network (Caukwell R.A., (1977)).

2.1.1 Extension of The Kenya Major Triangulation

Kenya Major Triangulation was implemented between 1906 and 1914. Due to the world economic recession in 1921, no further extension of control took place as a result of the collapsing of the Trigonometrical and Topographic Sections of the Survey Department and dismissal of all staff below the rank of District Surveyor (Caukwell R.A., (1977)). The next major extension of control by triangulation resumed between 1939 and 1941 due to the need by the military to use maps. A number of extensions were executed and referred to as the East African War System. The only triangulation conducted from 1921 until 1950 was tertiary breakdown for cadastral purposes in very limited areas.

2.1.2 The Kenya Primary, Secondary and Lower Order Triangulations

The British Government provided survey and mapping services in its colonies through the Directorate of Overseas Surveys (DOS). The DOS executed survey missions in Kenya between

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1950 and 1983 during which they established the present Kenya primary, secondary and lower order triangulation networks and also observed traverses. The DOS coordinates were computed using Universal Transverse Mercator (UTM) projection and Clarke 1880 as the reference ellipsoid and these are the controls that are used for all new cadastral surveys in Kenya to date.

A whole new network was observed as an integral part of the East and Central African primary coverage, with three new measured bases in Kenya, and tied to the Arc of the 30th Meridian in western Uganda. This triangulation included the primary traverse from north of *Mount Kenya* down the *Tana River* valley to *Malindi* which was planned in 1908 to close the Kenya Major network, but was not executed until 1958 after the invention of the Tellurometer.

2.1.3 Tellurometer Traverses

For these surveys, traverse distances were measured using the Tellurometer. This exercise was done with the help of the British Survey Squadron and Major Norland in three epochs.

The first epoch was carried out in 1972 headed by Captain Robinson for the Provision of Horizontal and altimeter height control for the 1:100,000 topographical sheets east of *Lake Turkana*. The second was implemented in 1974 east of *Lake Turkana* but at an enlarged scale with the help of Bilby Towers. The third campaign was again carried out east of *Lake Turkana* but with an expanded team between December 1976 and February 1977, the aim was to complete the geodetic loop from each end of the chain. This team was led by *Captain Bruce Burton* and *Professor G.O. Wayumba* was part of this team (*Lwanga C. M., (2012)*).

For the three epochs executed by tellurometer the purpose was to connect the old triangulation chain with the Clifford triangulation along the Kenya – Ethiopia border. Another Tellurometer traverse chain running from *Isiolo – Marsabit – Sololo – Moyale – Wajir – Harba Sweni – Kula Mawe* and back to *Isiolo* was carried out between 1976 and 1977.

As earlier mentioned in section 2.2.2 the *Tana River Valley* first order precise traverse running from the base at *Malindi* and closing at the *Isiolo* base, following the road from *Malindi* northwards through *Garsen, Garissa* and *Garba Tula* was also observed by Tellurometer in 1957 by the United Kingdom (UK) Directorate of Colonial Surveys in 28 days although the same triangulation traverse had been planned to last two and a half years (*Sturman et al. (2008)*).

2.1.4 Doppler Station Fixes

The Survey of Kenya, the Defense Mapping Agency of the USA and the Directorate of Military of the UK first carried out Doppler observations in Kenya in 1972 and 1973. The objective of this joint exercise was to; evaluate the accuracy of the primary controls, provide geodetic control in remote and un-surveyed areas of the country, strengthen the triangulation network with precise positions at optimal spacing and contribute to the development of a single well-fitting Datum for the African continent. Doppler positioning using precise ephemeris fixed fifteen (15) stations distributed across the country. See Figure 2 in red.

2.2 Clifford Triangulation

This control network was established in 1958, the campaign was led by Major Clifford. The main objective of establishing this control network was to map the Kenya – Ethiopia boundary. This triangulation network was based on the East Africa War System. See Figure 2.

2.3 The Kenya – Uganda Border Triangulation

This was carried out in 1975 with the objective of mapping the Kenya – Uganda boundary. This survey was done by Tellurometer traverses (Lwanga, C. M., (2012)). See Figure 2.

2.4 Kenya's Vertical Control

Before establishing the Primary Levelling Network in Kenya (1949 - 1958) all the triangulation networks in the country which were observed between 1906 and 1914 for cadastral and topographical surveys had trigonometrical heights derived from:

- (a) The original Uganda Railway Datum based on an assumed Mean Low Water Ordinary Spring Tides at Kilindini, Mombasa. This is the height datum that was used for the original railway survey from Mombasa to Kisumu around 1900 and
- (b) The New Kenya – Uganda Railway Datum based on more accurate measurements of Mean Low Water Ordinary Spring Tides at Kilindini. This revised datum was found to be 1.65feet below the previously established datum in (a) above.

Except for engineering levels related to rail roads, no levelling network had been established in Kenya before 1949. To establish a uniform system of reduced heights all over the country primary levelling was initiated in 1949. This network was designed to cover routes along railways and main roads connecting towns in Kenya and extending into the neighbouring Uganda and Tanzania. By 1952, approximately 2,000 Kilometers of levelling circuits had been observed and provisional height values determined for 1,290 benchmarks (Nyadimo S.A. (1979)).

Double levelling for the *Nairobi – Kisumu* line with its adjoining circuits was completed by end of 1959 and connections made to three tide gauges along Lake Victoria. Between 1965 – 1966, *Kisumu – Buteba* and *Mombasa – Lungalunga* lines were also levelled making it possible to establish provisional relationship between the three East African Datums.

The primary Levelling Network was referred to the Mean Sea Level (MSL) values deduced from the 1932 – 1933 records of the tide gauge at *Kilindini* in *Mombasa*, this therefore means that Kenya's height Datum is the Mean Sea Level (MSL) referred to a tide gauge installed at *Kilindini* harbour in *Mombasa*. Except for the *Webuye – Kisumu – Sirari* line that was levelled between 1970 – 1971, no work has been done to extend the primary levelling network in the country. (Nyadimo S.A. (1979)). See figure 2, the levelling loops are shown in colour blue.

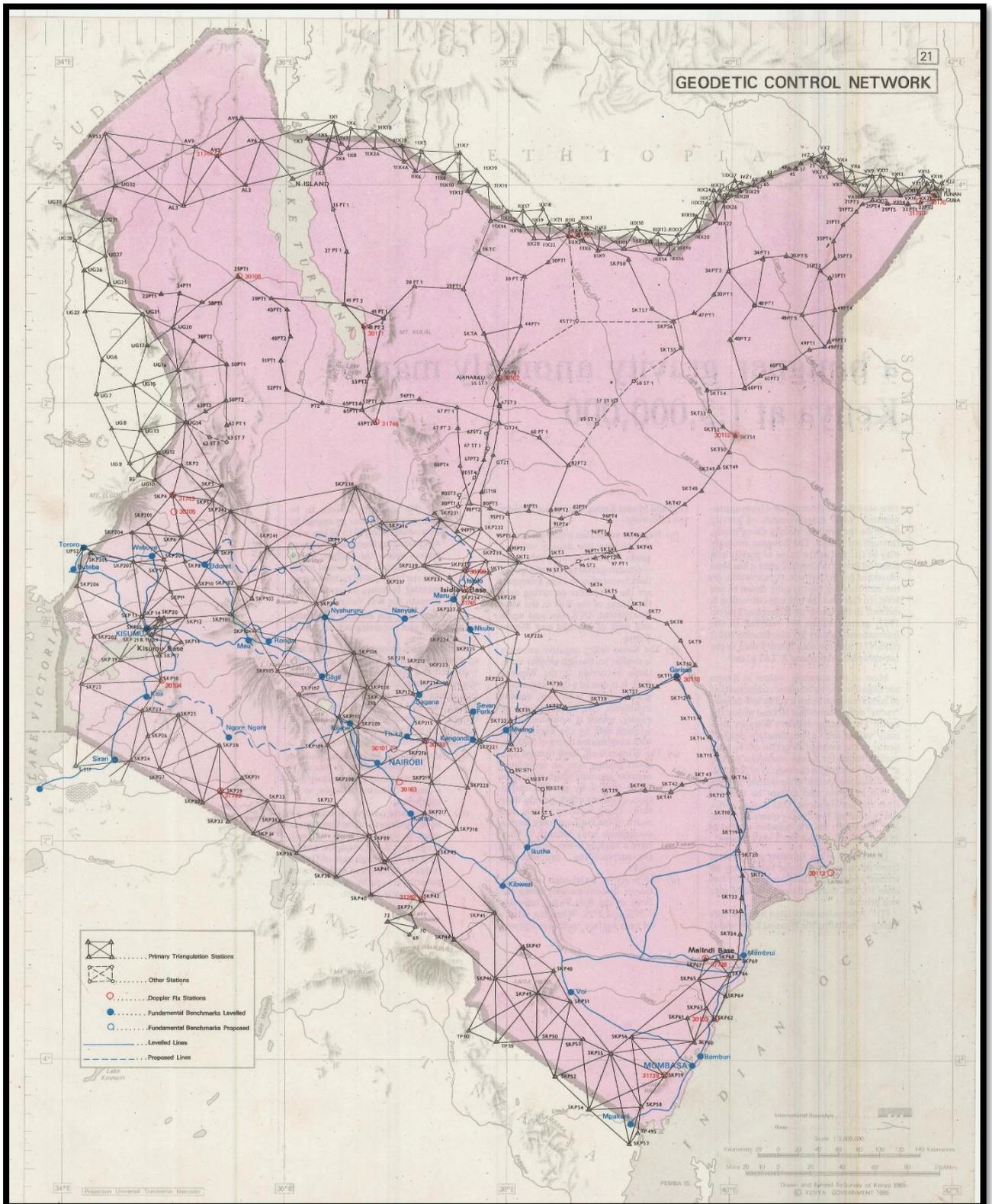


Figure 2: Kenya's Geodetic Network (Kenya National Geodetic Report, (1985))

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3.0 GEODETIC DATUMS USED IN KENYA

A datum is any conventional framework onto which observations are related or a reference surface to which the horizontal and vertical coordinates of points are referred (Lwangasi, A.S., (1993)). The reference surface may be the geoid which is a natural surface or an ellipsoid /spheroid which is an artificial entity.

We have two categories of ellipsoids:

- i. A geocentric ellipsoid e.g., WGS 1984 ellipsoid that is used for worldwide applications or
- ii. A regional or local ellipsoid e.g., Clarke 1880 ellipsoid for continental or national level (horizontal) geodetic networks.

Two reference ellipsoids are used for coordinate computation in Kenya:

- (a.) For Cassini-Soldner projection **Clarke 1858 spheroid** is used while,
- (b.) For Universal Transverse Mercator projection (UTM) **Clarke1880 spheroid** is used.

3.1 Co-ordinate Systems for Mapping in Kenya

Four co-ordinate systems are used for mapping in Kenya: -

i) The Local Origin Coordinate System

This coordinate system covers a small area or region on the earth surface. It is offset from the geo-center, which in most cases is the origin for global coordinates. In Kenya this system was used in areas that were not covered by the Kenya Major Triangulation network.

Surveys based on a local origin were scattered all over the newly alienated areas in the country and did not have a specific datum. As an example, cadastral surveys for land parcels that were close to the Uganda Railway line were tied to the Centre-line of the railway as a base and referenced by compass measurements to telegraphic posts which were numbered and existed along the Railway corridor all the way from Mombasa to Kisumu. Local origin surveys are captured in the Survey Act and referred to as “isolated” surveys.

The Local Origin Coordinate systems had orthogonal coordinate axes (X, Y) with the Y axis oriented approximately to the North via astronomic Azimuth determination e.g., by sun azimuth method or by campus bearings. The origin of the system was assigned a value of (0, 0) as coordinates or any other arbitrary figure. The scale of the system was obtained by measuring a base-line with a cadastral band (180m) long. Some of the areas where the Local Origin System was used for cadastral surveying included; Londiani, Naivasha, and Molo. In 1903, the Chief Surveyor observed that this situation was not tenable as such isolated surveys would soon result in boundary conflicts. The Chief Surveyor therefore recommended for the establishment of a proper triangulation network to control such surveys, this led to the Kenya Major Triangulation Network that was established starting from 1904 (Caukwell R.A., (1977)).

ii) Cassini-Soldner Coordinate System

The origins of this co-ordinate system are the intersections between the equator and the odd meridians. The odd meridians served as the central meridian for each 2° belt which extends one degree to east and west. For example, the Central meridians can be 35°E, 37°E, 39°E etc., with belt limits extending from 34°E to 36°E, 36°E to 38°E, 38°E to 40°E etc. The reference ellipsoid used is Clarke 1858 and the unit of measurement is the British foot.

Before 1950, nearly all triangulation networks were based on this system. Cadastral surveys in Kenya were also based on this system of co-ordinates and up to today most surveys in urban and former white highlands are based on this system.

iii) The East African War System of Coordinates

The war system was introduced as a military system for East Africa with the extended triangulation to Kenya Major Triangulation north of and around Mt. Kenya being based on this system. The main objective of the East Africa war system was to unify the coordinate system for the British Commonwealth territories in the South, East and Central Africa to avoid discontinuity in topographical mapping and grid references across territorial boundaries. It was also thought that the same system could have been used for cadastral surveys.

Coordinates for this system are based on Transverse Mercator projection of 5° wide belts. Belts were designated C, D, E, etc. and Kenya is covered by Belts H and J as illustrated in Table 2.

Table 2: Zones/Belts of the East Africa War System.

Belt H	Western Limit	35° E
	Central Meridian	37° 30' E
	Eastern Limit	40° E
Belt J	Western Limit	40° E
	Central Meridian	42° 30' E
	Eastern Limit	45° E

The origin for this coordinate system was the intersection of the Equator and the Central meridian, with false co-ordinates being; Eastings +400 000 meters and Northings +4,500,000 meters. The scale factor at the central meridian was 1999/2000 approximately equals 0.9995 with the reference spheroid being Clarke 1880. The Co-ordinates in this system have been converted to the Universal Transverse Mercator system.

iv) The Universal Transverse Mercator (UTM) Coordinate System

This coordinate system was introduced in Kenya in 1950 by the Directorate of Overseas Surveys (DOS), when the DOS began implementing control survey work in Kenya. The system used Clarke 1880 spheroid initially but was later recomputed based on the modified Clarke 1880 spheroid. Kenya is covered by four UTM Zones 36M, 36N, 37M and 37N. The unit of measurement used by this coordinate system is the international metre.

The survey department has converted the coordinates of all control points in the country to this co-ordinate reference system.

4. LIMITATIONS OF THE EXISTING GEODETIC REFERENCE FRAME IN KENYA

Since 1892, several major triangulation networks were observed and computed by different organizations both local and international for specific purposes. Each organization chose the coordinate system that was suitable for its needs, resulting in different coordinate systems. For each network, the readily available datum was adopted leading to many datums for both planimetric and vertical control (Mugnier, C., (2014)). Based on this historical background, a number of limitations of the existing network can be listed;

- i) The existing geodetic reference frame in the country is disjointed and inhomogeneous.
- ii) Over 60% of the old triangulation pillars have been vandalized
- iii) Existing cadastral survey records in the country are in four different coordinate systems as discussed in section 3.1.
- iv) Height data across the country is inconsistent because of it is derived from different datums.
- v) There is inadequate information and data on geodetic surveys carried out before 1950 because these records were taken away by the executing agencies.

5. MODERNIZATION OF THE KENYAN GEODETIC REFERENCE FRAME

5.1 Introduction

All the 54 countries in Africa have their own geodetic reference frames based on different ellipsoids and datums as is the case in Kenya. To make it easier to co-ordinate planning and development activities across the African continent a uniform 3D geodetic reference frame for Africa aligned to the International Terrestrial Reference System (ITRS) and its realization, the International Terrestrial Reference Frame (ITRF) was initiated by the United Nations Economic Commission for Africa (UNECA) in the year 2000 as the African Geodetic Reference Frame (AFREF) project. AFREF is based on a network of permanent geodetic GNSS receivers (Neilan, R., (2005)). AFREF implementation is at national level through National Mapping Agencies, Universities in Africa and International Agencies and Organizations.

5.2 Kenya Geodetic Reference Frame (KENREF)

The modernized Kenya Geodetic Reference Frame (KENREF) which is tied to AFREF was designed to include a Zero Order Geodetic Network consisting of twenty-five (25) reference stations approximately 200 km apart and a First Order Geodetic Network consisting of seventy-five (75) reference stations approximately 70 km apart. Based on the two networks, a Continuous Operating Reference Stations (CORS) Network was to be gradually set up with its control center based in Nairobi (Owino, B.N., (2013)).

Development of KENREF started in 2010 with the construction of 18 Zero order network station pillars instead of 25 as earlier planned because of insecurity in some locations where the pillars were to be constructed along the Kenya – Somalia and Kenya – Ethiopia boundary (Lilje, C. et al, (2013)). The Survey of Kenya (SoK) has installed a total of 20 Roof Top - Tier 3 CORS as shown in Figure 3.

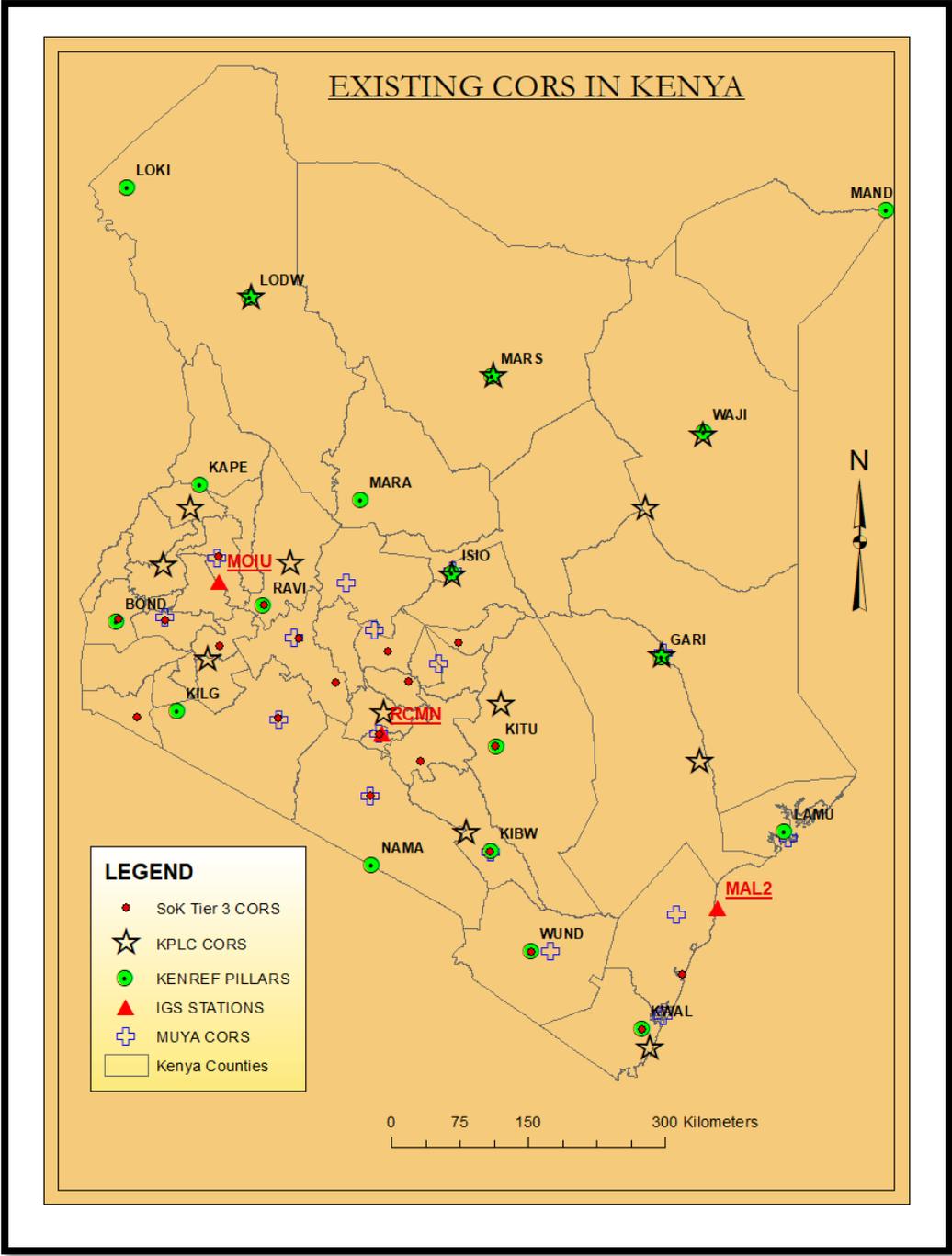


Figure 3: A Map showing the Distribution of CORS in Kenya

5.3 Private CORS in Kenya

Currently eight different organizations own and operate their independent CORS in Kenya as elaborated in Table 4.

Table 4: Privately Owned and Operated CORS in Kenya

No.	Organization	Number of CORS
1.	Kenya Power and Lighting Company (KPLC) CORS	15
2.	Measurement Systems Limited (Muya CORS)	16
3.	Oakar Services Limited	1
4.	Optron (Pty) Limited	1
5.	Geoid Technologies Limited	1
6.	Africa Geonetworks Limited	6
7.	Jospam Solutions Limited	3
8	Regional Centre for Mapping of Resources for Development (RCMRD)	3

KPLC (a government agency) operates 15 CORS distributed across the country (figure 3), to improve the accuracy of data in support of geospatial data management for its utilities (Thiong'o, P.N., (2019)). KPLC CORS have NOT been integrated with the existing legacy Kenyan Geodetic Network as well as the proposed KENREF network. Measurement Systems Limited manages a private CORS network called MUYA-CORS (see figure 3) which has been integrated with the legacy geodetic network and currently there are efforts to integrate this network with the KENREF Network. (<https://muya-cors.com/services/set>)

5.4 Challenges in Achieving a Modernized Geodetic Reference Frame for Kenya

Four main issues have been identified to be hampering the full roll out/implementation of the modernized geodetic reference frame (KENREF).

- i. Lack of political will in support of a modernized geodetic reference frame
- ii. Inadequate funding for the Ministry of Lands and Physical Planning to facilitate the roll out of KENREF
- iii. Lack of cooperation among ministries and state agencies whose service delivery directly rely on a uniform and modern geodetic reference frame.
- iv. Inadequate data/information on some existing control networks in the country as a result of poor record keeping and documentation makes it difficult to integrate the modernized geodetic reference frame with the legacy networks.

6. CONCLUSION AND RECOMMENDATIONS

The Kenyan geodetic network in its current state cannot sustain Kenya's development agenda and therefore it is recommended as follows:

- 1) Both public and private players involved in the establishment of CORS should cooperate so that the CORS currently being established are integrated with others established at regional and international level for the realization and maintenance of regional and international geodetic reference frame.
- 2) The Ministry of Lands and Physical planning through the Survey of Kenya should establish a mechanism for continuous monitoring and modernizing of the geodetic reference system;
- 3) The Ministry of Lands and Physical Planning should take up the role of coordination of installation and operation of CORS through Public Private Partnerships (PPP) in the country to avoid duplication of effort by private players and ensuring consistency of the public and private networks
- 4) It is also recommended that during GNSS campaigns, legacy network stations should be incorporated in the data collection missions to enable the computation of transformation parameters between KENREF and the legacy networks.
- 5) There is need for advocacy to gain political will that will support and finance the Survey of Kenya in its efforts to establish a modern geodetic reference frame tied to ITRF.
- 6) There is need for the Kenyan government to negotiate with the British government, so that records of geodetic surveys carried out in Kenya during the colonial times are returned; this will greatly enhance the efforts of Survey of Kenya to integrate the current geodetic network with the legacy networks.
- 7) Legislation regarding National Geodetic monuments should be revised with a view to protect geodetic reference network stations against vandalism.
- 8) Kenya's geodetic vertical datum was constructed using classical levelling techniques by the Survey of Kenya independent of the horizontal datum (Siriba, D.N., (2020)). In the ongoing efforts to establish KENREF, the vertical datum should be an integral component of new reference datum. Since KENREF is expected to be part of the ITRF, equally, the vertical datum should be part of the global height reference, which is the Geoid.

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BIOGRAPHICAL NOTES

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