Evolution of the Kenyan Geodetic Reference Frame*

[1]S. M. Matara, [1]D. N. Siriba, [1]J. B. K. Kiema and [1]S. M. Musyoka
[1]Department of Geospatial and Space Technology, University of Nairobi, P.O. Box 30197 – 00100 Nairobi, Kenya

Matara, S. M., Siriba, D. N., Kiema, J. B. K and Musyoka, S. M. (2024), "Evolution of the Kenyan Geodetic Reference Frame", *Ghana Mining Journal*, Vol. 24, No. 1, pp. 1-11.

Abstract

A uniform geodetic reference frame forms the spatial foundation for the creation of a Land Information System (LIS), based on which related spatial data for transport, mineral resources, power transmission, telecommunication, etc., can be overlaid to aid in operations like design, construction, commissioning, and surveillance of the infrastructure. In essence, a geodetic reference frame permits spatial referencing of all land data to identifiable positions on the earth's surface. Further, a geodetic reference frame provides an effective language for interpreting and disseminating land information. Kenya does not have a uniform geodetic reference frame instead there is a patchwork of geodetic networks across the country established by different organizations to facilitate activities like the demarcation of international boundaries, as such, Kenya's geodetic network consists of many coordinate systems. This paper reviews the evolution of the Kenyan geodetic network, highlights various geodetic networks established in Kenya, and identifies challenges to the development of a modern uniform Geodetic Reference Frame for Kenya (KENREF). The installation of Continuously Operating Reference Stations (CORS) by the government and private entities is not centrally coordinated, which implies that Kenya may not realize a uniform modern geodetic reference frame soon.

Keywords: Geodetic reference frame, AFREF, KENREF, CORS, Harmonisation.

1 Introduction

A geodetic control network usually consists of stable, identifiable points with published datum values or coordinates derived from observations that tie the points together (Bossler, 1984). Conventionally, a control network is divided into two components; horizontal (X, Y) control and vertical (Z) control mainly because of technical limitations. The Global Navigation Satellite Systems (GNSS) provide the possibility to determine the coordinates of points on an integrated three-dimensional control network directly – thus ensuring a homogeneous geodetic control network. All major geodetic (triangulation) networks in Kenya were established by different organizations that include: the Anglo-German Boundary Commission (AGBC) and the Directorate of Overseas Surveys (DOS), all with different objectives. These networks use different datums and coordinate systems resulting in an inhomogeneous geodetic reference network.

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

The African Geodetic Reference Frame (AFREF) project that is being implemented locally as the Kenya Geodetic Reference Frame (KENREF) promises to achieve this goal of harmonisation. In spite of the availability of specifications, however, independent networks established by private companies that are based on Continuously Operating Reference Stations (CORS) are unlikely to solve this problem of inhomogeneous geodetic networks. It is therefore important to know more about these efforts. These efforts notwithstanding, there isn't comprehensive documentation of the Kenyan Geodetic Reference Frame that provides the history, challenges, and current efforts, which this paper aims to achieve.

The paper is organised into six sections; the next section gives an outline of the Kenyan geodetic network. Section 4 describes the geodetic datums used in Kenya while section 5 highlights the limitations of the existing geodetic reference frame in Kenya in its current state. Section 6 addresses the efforts that have been put in place to modernize the Kenyan Geodetic Reference Frame including the adoption of Continuously Operating Reference Stations (CORS). The paper concludes by proposing key issues to be addressed in order to realize a modern and uniform geodetic reference frame for Kenya.

2 Resources and Methods Used

To better understand the evolution, current status, and modernization of the Kenyan Geodetic Reference Frame, archival research and extensive literature review were conducted at the Kenya National

*Manuscript received April 11, 2023
Revised version accepted Dec 25, 2023
https://doi.org/10.4314/gm.v22i1.1

Archives and the Survey of Kenya Library where both pre- and post-independence documents on the Kenyan Geodetic Reference Frame are kept. Similarly, an online questionnaire survey was developed and sent to a number of surveyors working at the Survey of Kenya - Geodetic Section.

The author also interviewed individuals with extensive knowledge of the various stages that the Kenyan Geodetic Reference Frame has gone through to get to its present status.

In addition to the above data and information sources, the author also reviewed several papers focusing on the Kenyan Geodetic Reference Frame published in different journals as well as presented during local and international conferences.

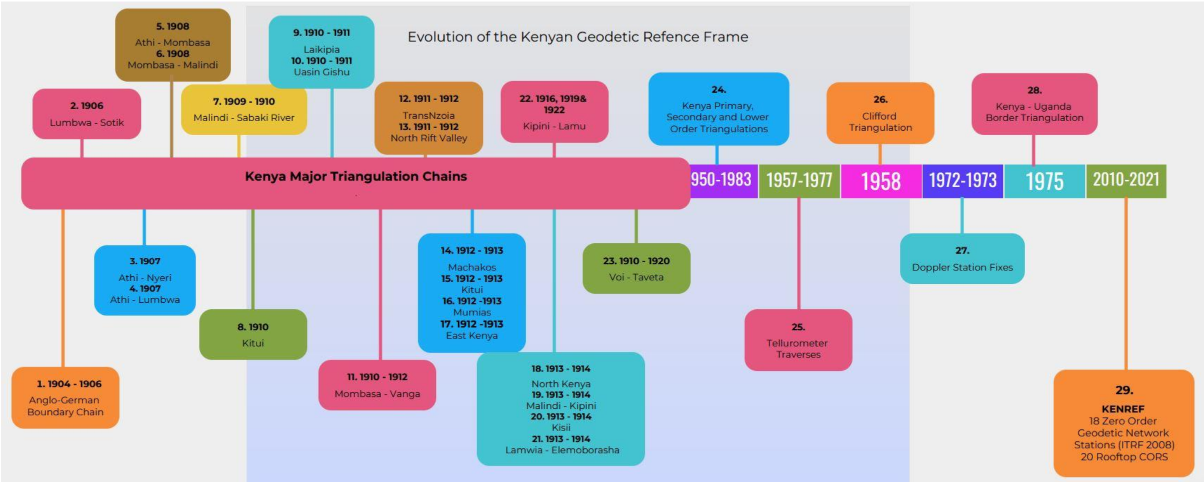

Fig.1 Evolution of the Kenyan Geodetic Reference Frame and a highlight of Kenya Major Triangulation Chains

3 Results and Discussion

3.1 A Historical Outline of the Kenyan Geodetic Network

This section gives an outline of the geodetic networks established and used in Kenya, the section starts off by highlighting details about the Kenya Major Triangulation Network mainly established by the Anglo-German Boundary Commission, details of the Clifford Triangulation and the Kenya – Uganda Border triangulations. Finally, some highlights of Kenya's Vertical Control network are given.

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

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, 2014). This was far away from the areas where surveys for land registration were required.

3.2 Kenya Major Triangulation

Kenya Major triangulation started in 1906 to extend control for title surveys and topographical mapping in the White Highland areas (Caukwell, 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. Fig. 2 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. Fig. 1 highlights the evolution of the Kenyan Geodetic Reference Frame and in particular names of various Kenya Major Triangulation chains and the period during which these chains were observed.

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.

Fig. 1 summarizes the evolution of the Kenyan Geodetic Reference Frame into three phases; Phase I (pre-independence)– The Kenya Major System mainly established by the AGBC, Phase II (post-independence) Kenya Primary, Secondary, and Lower order Triangulations done by the Directorate of Overseas Surveys (DOS) and finally Phase III (Modernisation) carried out by the Survey of Kenya.

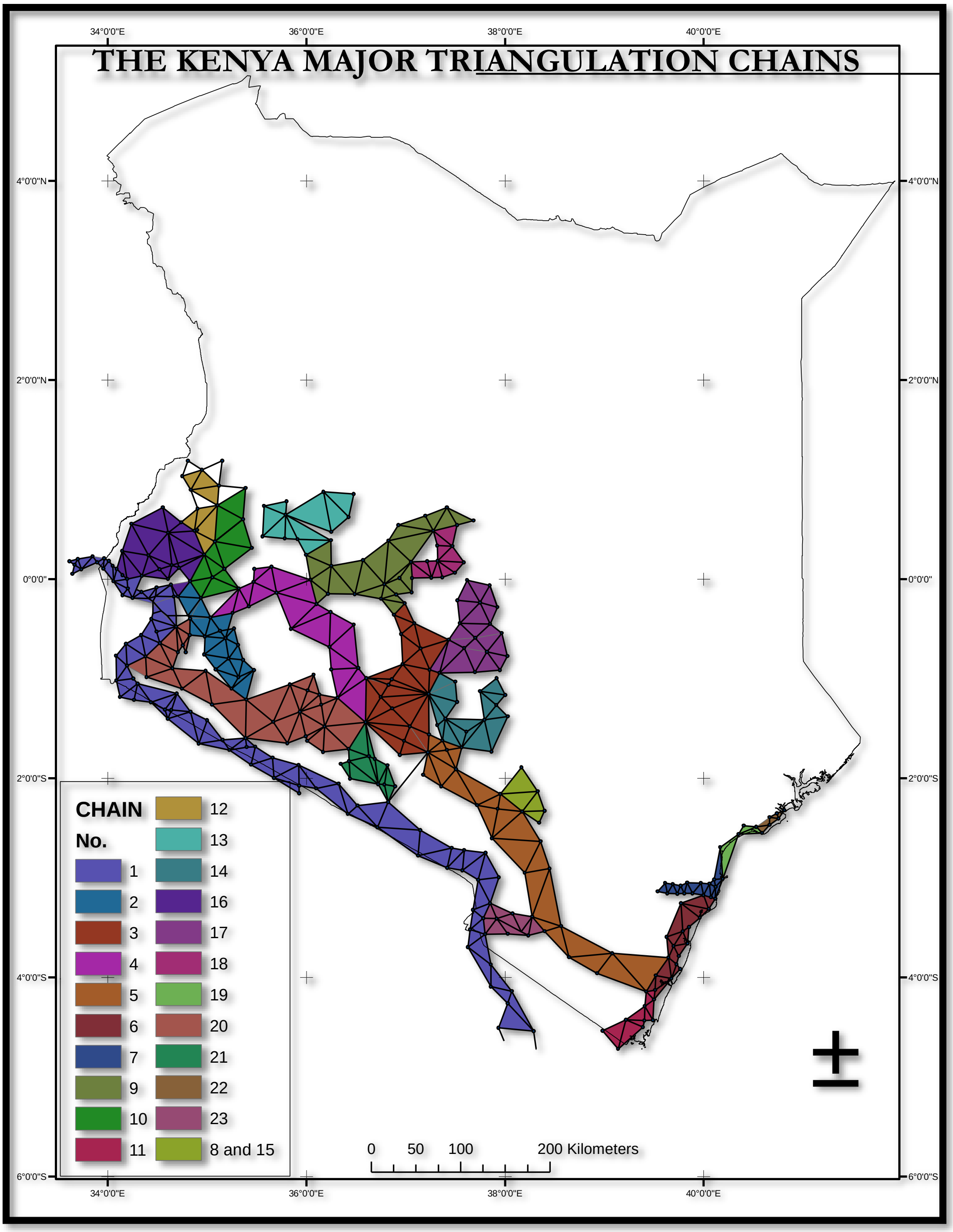

Fig. 2 Kenya Major Triangulation Network (Caukwell, 1977

3.2.1 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 the dismissal of all staff below the rank of District Surveyor (Caukwell, 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 the tertiary breakdown of the network for cadastral purposes in very limited areas.

3.2.2 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 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 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 1957 after the invention of the Tellurometer.

3.2.3 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 (Humphries *et al.*,1958). 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 (Lwanga, 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 3.2.2 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 and Wright, 2008).

3.2.4 Doppler Station Fixes

The Survey of Kenya, the Defence 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 Fig. 3 in red.

3.3 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 Fig. 3.

3.4 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, (Sturman *et al.*, 2008). See Fig. 3.

3.5 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 1.65 feet below the previously established datum in (a) above.

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, 1979).

Double levelling for the Nairobi – Kisumu line with its adjoining circuits was completed by end of 1959 and connections were 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 habour 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, 1979). See Fig. 3, the levelling loops are shown in colour blue.

4 Geodetic Datums used in Kenya

A datum is any conventional framework to which observations are related or a reference surface to which the horizontal and vertical coordinates of points are referred (Lwangasi, 1993). The reference surface may be a geoid which is a natural surface or an ellipsoid 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) Clarke 1880 spheroid is used.

4.1 Coordinate Systems for Mapping in Kenya

This section presents the four coordinate systems used for mapping in Kenya.

4.1.1 The Local Origin Coordinate System

This coordinate system covers a small area or region on the earth's surface. It is offset from the geo-center, which in most cases is the origin of 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 value. The scale of the system was obtained by measuring a baseline 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, 1977).

4.1.2 Cassini-Soldner Coordinate System

The origins of this coordinate system are the intersections between the equator and the odd meridians. The odd meridians served as the central meridian for each 2º belt which extends one degree to east and west. For example, the Central meridians can be 35ºE, 37ºE, 39ºE, etc., with belt limits extending from 34ºE to 36ºE, 36ºE to 38ºE, 38ºE to 40ºE 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 coordinates and up to today most surveys in urban and former white highlands are based on this system.

4.1.3 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 the 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 1.

Table 1: 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 coordinates being; Eastings +400 000 meters and Northings +4,500,000 meters. The scale factor at the central meridian was 1999/2000 approximately equal to 0.9995 with the reference spheroid being Clarke 1880. The Coordinates in this system have been converted to the Universal Transverse Mercator system.

4.1.4 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 meter.

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

4.2 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, 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 4.1.

iv) Height data across the country is inconsistent because 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 Modernisation 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, 2005). AFREF implementation is at the national level through National Mapping Agencies, Universities in Africa, and International Agencies and Organizations.

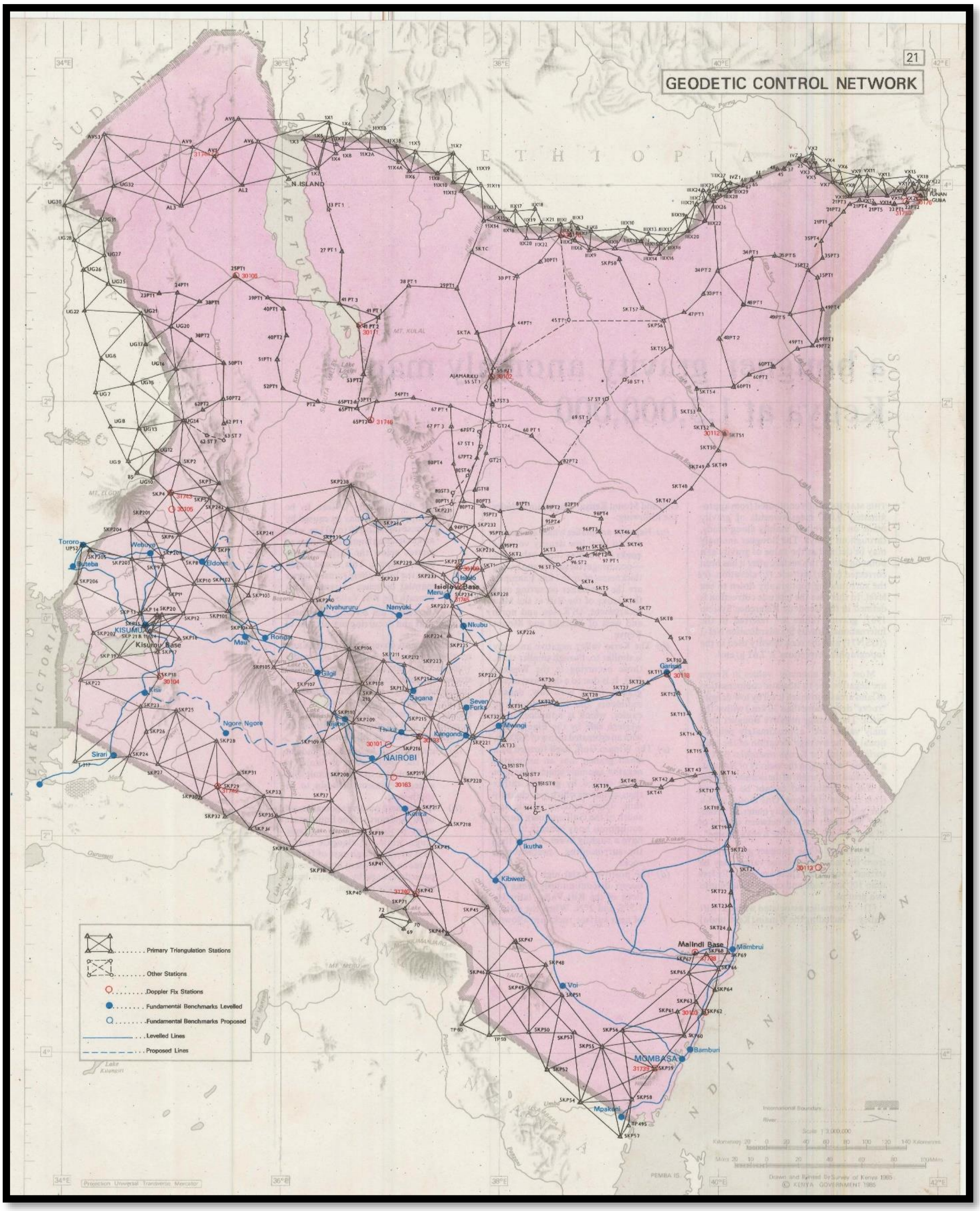

Fig. 3 Kenya's Geodetic Network (Kenya National Geodetic Report, 1985)

5.2 Kenya Geodetic Reference Frame (KENREF)

The 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 centre based in Nairobi (Owino, 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 *et al.*, 2013). The Survey of Kenya (SoK) has installed a total of 20 Roof Top - Tier 3 CORS as shown in Fig. 4.

Fig. 4 is a map of Kenya showing;

1. KENREF pillars which are passive and whose coordinates are not integrated with those of the legacy network and have not been officially published by the National Mapping Agency,
2. International GNSS Service (IGS) CORS network stations in Kenya,
3. Survey of Kenya (SoK) Rooftop CORS which are yet to be commissioned,
4. Kenya Power and Lighting Company (KPLC) CORS and finally
5. MUYA CORS.

5.3 Private CORS in Kenya

We have eight different organizations that own and operate independent CORS in Kenya as elaborated in Table 2 below and shown in Fig. 4 above.

Table 2 Privately Owned and Operated CORs in Kenya

No.	Organization	No. 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 (Fig. 4), to improve the accuracy of data in support of geospatial data management for its utilities (Thiong'o, 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 Fig. 4) 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 Geodetic Reference Frame for Kenya

A number of issues have been identified to be hampering the full implementation of the modernized geodetic reference frame (KENREF).

i. Work done towards the realization of KENREF is neither complete nor documented for reference.

ii. Lack of cooperation among ministries and state agencies whose service delivery directly relies on a uniform and modern geodetic reference frame.

iii. 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.

iv. Vandalism of the legacy geodetic network pillars

v. Some private CORS, Survey of Kenya rooftop CORS, and Zero order KENREF network pillars have been installed within a radius of less than 10 kilometers resulting in duplication of effort pointing towards network design weaknesses.

vi. Installation of CORS by private entities is not coordinated, this has led to an in-homogeneous network and duplication of effort.

vii. Design and implementation of the modernized KENREF network does not integrate with the legacy network making it difficult to utilize legacy data.

viii. There is no single common public platform/portal where users can access information on existing CORS both private and public and from where they can access data/information on the Kenyan Geodetic Network.

6 Conclusions and Recommendations

6.1 Conclusions

There isn't comprehensive documentation of the history of the Kenyan Geodetic Reference Frame. However, this paper has documented the history of the Kenyan Geodetic Network; highlighting the various geodetic networks established, the proposed KENREF Network, and the private CORS networks. The paper has also highlighted the key challenges to the modernization of KENREF.

It should form a basis for further work among them analyzing the stability of geodetic network stations, harmonisation of the legacy networks, and development of a central portal for sharing data and information on existing public and private CORS.

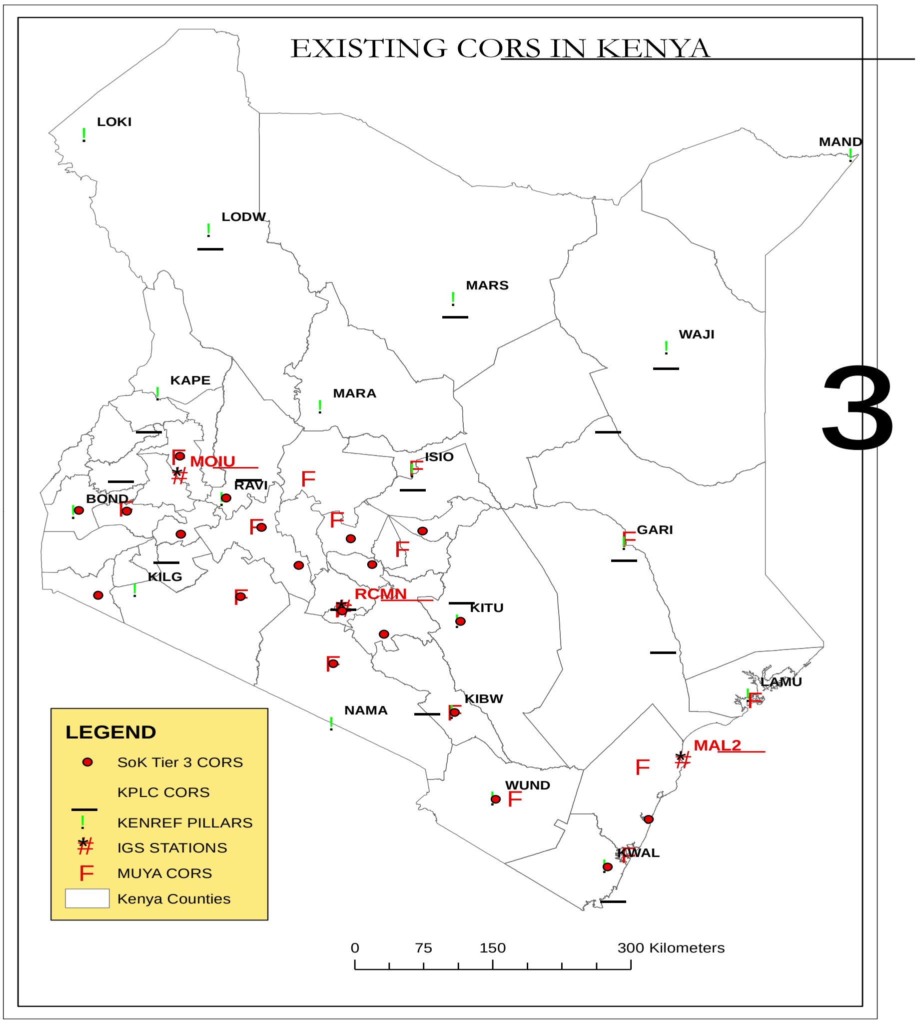

Fig. 4 Distribution of CORS in Kenya

6.2 Recommendations

The Kenyan geodetic network in its current state cannot sustain Kenya's development agenda and therefore it is recommended as follows; that both public and private players involved in the establishment of CORS should collaborate so that the CORS currently being established are integrated with others established at regional and international level for the realization and maintenance of a uniform regional and continental geodetic reference frame.

It is recommended that the Ministry of Lands, Public Works, Housing and Urban Development through the Survey Department should establish a mechanism for continuous monitoring and modernizing of the existing geodetic reference system. Similarly, the Survey Department should take up the role of coordinating the installation and operation of CORS through Public Private

Partnerships (PPP) in the country to avoid duplication of effort by private players and ensure consistency of the public and private networks.

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. The National government should support and finance the Survey of Kenya in its efforts to establish a modern geodetic reference frame tied to ITRF and negotiate with the British government to share any records of geodetic surveys carried out in Kenya during the colonial period because this will greatly enhance the efforts of Survey of Kenya to integrate the current geodetic network with the legacy networks. Legislation regarding National Geodetic monuments should be revised with a view to protect geodetic reference network stations against vandalism.

Finally, Kenya's vertical datum was developed using classical levelling techniques by the Survey of Kenya independent of the horizontal datum (Siriba, 2020). In the ongoing efforts to establish KENREF, the vertical datum should be an integral component of the 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.

Acknowledgements

We acknowledge and appreciate the Director of Survey and Survey of Kenya staff based in the Geodetic Section and Survey of Kenya Library for allowing us to access the library and responding to our questions. We also appreciate various licensed land surveyors that were intervied when writing this paper.

References

Bossler, J.D. (1984), "*Standards and Specifications for Geodetic Control Networks", Federal Geodetic Control Committee - Rockville, Maryland September 1984.*

Caukwell, R. A. (1977), "Cadastral Survey in Kenya and its Role in the Development of the Country", *Unpublished MSc. Surveying Thesis Report,* University of Nairobi.

Humphries G. J. and Brazier H. H. (1958), *First-Order Traversing with The Tellurometer*, Empire Survey Review, 14:109, 290-298, DOI: 10.1179/sre.1958.14.109.290

Lilje, C., Jivall, L., Munene, C. and Koskei, A. (2013), Processing and Analysis of the KENREF 2012 Campaign (Version 1.0)

Lwanga, C.M. (2012), "Documentation of the Kenyan Geodetic Network" *Unpublished BSc Project Report*, Technical University of Kenya.

Lwangasi, A.S. (1993), *Datum Transformation Parameters for the Kenya Geodetic System,* Survey Review, 32:247, 39-46, DOI: 10.1179/sre.1993.32.247.39

Mugnier, C. (2014), *Geodetic Report of Kenya*. ResearchGate, 1, 1–12. https://www.researchgate.net/publication/258509444_Geodetic_Report_of_Kenya.

Muya CORs by Measurement Systems Limited, accessed on 8th April 2022 (https://muya-cors.com/services/set)

Neilan, R.(2005), IGS Central Bureau, JPL MS 238-540; AFREF 2005 October/November Meeting Summary. http://igscb.jpl.nasa.gov

Nyadimo S.A. (1979), "*Primary Levelling in Kenya with particular reference to the need for a common East African Height Datum*". Conference of Commonwealth Surveyors 1979 paper No. C.1.

Owino B.N. (2013), Kenya Country Report to the 26th International Cartographic Conference held in Dresden Germany; 25th – 30th August, 2013.Available at https://icaci.org/files/documents/national_reports/2011-2015/Kenya_2011-2013.pdf

Siriba, D.N. (2020), "*Renewing Kenya's Vertical Datum as an Integral Part of KENREF through the Definition of a Local Geoid Model"*. Surveyor's Journal (Second Edition 2020) by Institution of Surveyors of Kenya.

Sturman, B. and Wright, A. (2008), *"The History of Tellurometer"* FIG Working Week 2008 - Stockholm, Sweden 14-19 June 2008

Thiong'o, P.N. (2019), Continuously Operating Reference Stations (CORS): Transformation between KPLC CORS System and the Kenya National Geodetic System, *Unpublished MSc GIS Project Report*, University of Nairobi.

Authors

Mr Sammy Mwangi MATARA, holds a Bachelor's Degree in Geospatial Engineering from the University of Nairobi (2009), and a Second Level Spatializing Master in Navigation and Related Applications from Politecnico di Torino, Italy (2014). Currently he is a Tutorial Fellow at the Department of Geospatial and Space Technology, University of Nairobi where he is also carrying out his PhD research. His research interest is in the field of GNSS and Engineering Survey. Mr. Matara is also a Licensed Land surveyor and a Full Member of the Institution of Surveyors of Kenya.

Dr-Ing. David Nyangau SIRIBA, is a senior lecturer in the Department of Geospatial and Space Technology, University of Nairobi His current reseacrh interests are in Geodetic Infrastructure Modernization, Spatial Data Infrastructures, Land Administration Domain Modelling, and on various aspects on Volunteered Geographic Information System (VGI). He is a Licensed Land Surveyor, a Full Member of the Institution of Surveyors of Kenya and currently serves as a member of the Land Surveyors' Board (Kenya)

Dr-Ing. Sammy Mulei MUSYOKA, is a Licensed Land Surveyor, a Full Member of the Institution of Surveyors of Kenya and a senior lecturer in the Department of Geospatial and Space Technology, University of Nairobi.

Prof-Ing. John Bosco Kyalo KIEMA, is an Associate Professor in the Department of Geospatial and Space Technology, University of Nairobi and also a former Director of Technical Services at the Regional Centre for Mapping of Resources for Development (RCMRD).