

Integrating Legacy and Modern Geodetic Reference Frames in Kenya:

A Pathway for Harmonizing Arc 1960, WGS84 and KENREF

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Abstract

Kenya's geodetic infrastructure is presently fragmented across four historical coordinate systems, most notably the Arc 1960 datum on which the bulk of cadastral records still rely, and the geocentric Kenya Geodetic Reference Frame (KENREF), the national implementation of the African Geodetic Reference Frame (AFREF) tied to the International Terrestrial Reference Frame (ITRF). This paper reviews the origins and current state of both systems, evaluates the empirical Arc 1960-to-WGS84 transformation parameters presently in official and informal use, and examines the additional complication posed by active tectonics along the East African Rift System, which displaces KENREF stations by an average of approximately 35 mm per year. Drawing on this review, the paper argues that a World Geodetic System 1984 (WGS84) to KENREF transformation is fundamentally simpler than an Arc 1960 to KENREF transformation, because WGS84 and ITRF share a common geocentric origin, orientation and scale to within centimetres, whereas Arc 1960 carries both a large origin offset and undocumented internal network distortion. A hub-and-spoke integration methodology is proposed, together with recommendations for a nationally adopted, epoch-aware transformation standard.

Keywords: AFREF, KENREF, Arc 1960, WGS84, ITRF, geodetic datum, coordinate transformation, East African Rift System

1. Introduction

A uniform geodetic reference frame is the spatial backbone on which all georeferenced activity in a country ultimately depends — from cadastral surveying and land registration to infrastructure design, utility management and disaster response. Kenya, like most African states, inherited a patchwork of colonial-era triangulation networks rather than a single coherent system. Four coordinate systems remain in active or residual use: the Local Origin system, the Cassini-Soldner system (on the Clarke 1858 ellipsoid), the East African War System, and the Universal Transverse Mercator (UTM) system built on the Arc 1960 datum (Clarke 1880 (RGS) ellipsoid). Of these, Arc 1960/UTM is the most widely used for cadastral and topographic work today.

Since 2000, the African Geodetic Reference Frame (AFREF) project, coordinated by the United Nations Economic Commission for Africa (UNECA) through its Committee on Development Information — Geo-Information (CODI-GEO), has sought to unify the continent's national reference frames into a single, ITRF-aligned, geocentric system realized through a network of Continuously Operating Reference Stations (CORS). Kenya's national implementation, the Kenya Geodetic Reference Frame (KENREF), was designed around a Zero Order network of 25 stations approximately 200 km apart and a First Order network of 75

stations approximately 70 km apart, though only 18 Zero Order pillars have been constructed to date and their coordinates remain unpublished.

The practical question facing Kenyan surveyors, land administrators and GIS practitioners is how to reconcile decades of Arc 1960-based records with this emerging geocentric framework — and whether the widespread use of consumer and survey-grade GNSS receivers, which report positions natively in WGS84, offers a more tractable bridge to KENREF than a direct Arc 1960 transformation. This paper synthesizes findings from the AFREF founding documentation, two University of Nairobi studies on the evolution and tectonic stability of KENREF, and a review of published Arc 1960–WGS84 transformation parameters, to propose a practical integration pathway.

2. Background

2.1 AFREF: The Continental Framework

AFREF was conceived to give Africa a single, unified three-dimensional geodetic reference frame consistent with the ITRF, replacing dozens of national datums — some over a century old — that make cross-border planning, mapping and infrastructure development difficult. The project's design envisages a core CORS network with station spacing of roughly 500 km, integrated with the global International GNSS Service (IGS) network, densified nationally through each country's own GNSS networks and levelling connections, and complemented by a unified continental vertical datum and geoid model. Crucially, AFREF was designed to be planned, managed and executed by African institutions themselves, with technical support from the international geodetic community.

2.2 KENREF: Kenya's National Implementation

KENREF is Kenya's realization of AFREF. Its planned architecture layers a sparse Zero Order network over a denser First Order network, ultimately supporting a national CORS system. Development began in 2010, but only 18 of the planned 25 Zero Order pillars were built, largely because insecurity along the Kenya–Somalia and Kenya–Ethiopia borders prevented construction at some planned sites. The Survey of Kenya has separately installed 20 rooftop Tier-3 CORS stations. In parallel, at least eight private and parastatal organisations — including Kenya Power and Lighting Company (KPLC), Measurement Systems Limited (MUYA-CORS), and the Regional Centre for Mapping of Resources for Development (RCMRD) — operate their own independent CORS networks, none of which are centrally coordinated or systematically integrated with KENREF or the legacy network.

This lack of coordination, combined with the fact that KENREF's own Zero Order coordinates have not yet been officially published, means Kenya currently has no single authoritative, modern geodetic reference frame in production use — even though the geocentric infrastructure to support one already substantially exists.

3. The Legacy Datum Problem: Arc 1960

Arc 1960 is a local, non-geocentric datum defined on the Clarke 1880 (RGS) ellipsoid, established through classical triangulation carried out piecemeal between 1904 and 1983 by several different colonial and post-colonial authorities, principally the Anglo-German Boundary Commission and the Directorate of Overseas Surveys. Because these triangulation chains were observed independently, over different periods, and were never closed and adjusted as a single national network, Arc 1960 carries two distinct classes of error relative to a modern geocentric frame:

- A large, systematic origin offset — Arc 1960's origin is displaced from the Earth's centre of mass by on the order of 150–300 metres, reflecting the datum's local (non-geocentric) definition.
- Unquantified internal distortion — because the constituent triangulation chains were never adjusted as a whole, a surveyor moving across chain boundaries historically encountered measurable displacement; over 60% of the original triangulation pillars are now reported vandalised, making the extent of this distortion difficult to re-establish empirically today.

Both error sources matter when deciding how to transform Arc 1960 coordinates into a modern frame: the origin offset can be captured reasonably well by a simple similarity (Helmert) transformation, but the internal distortion generally cannot, and requires either a distortion (rubber-sheet) grid or a full network readjustment for high-accuracy work.

4. Existing Arc 1960 → WGS84 Transformation Parameters

Several official and semi-official transformation parameter sets already exist for Arc 1960 to WGS84, summarised in Table 1. None was derived using KENREF or other modern CORS data, and all pre-date the tectonic velocity information discussed in Section 5.

Parameter Set	ΔX (m)	ΔY (m)	ΔZ (m)	Basis	Reported Accuracy
EPSG:1284 (Kenya-specific)	-157	-2	-299	24 stations, military survey	~3–4 m
EPSG:1122 (Kenya + Tanzania mean)	-160	-6	-302	25 stations, military survey	~20 m
Lwangasi (1993), 7-parameter	-179.1	-39.7	-304.1	25 points, relates Arc 1960 to WGS 72	Scale error ~-0.3 ppm; rotations < 1" per axis

Table 1. Published Arc 1960 → WGS84 transformation parameter sets for Kenya.

In practice, Kenya's Ministry of Mining formally adopted the EPSG:1284 parameters (-157, -2, -299 m) for migrating mineral licence coordinates from Arc 1960 to WGS84, as gazetted in January 2015. However, this is a single national-scale similarity transformation; it does not, and cannot, correct for the local network distortion described in Section 3. The coexistence of at least three different parameter sets in circulation, with no single authoritative national standard tied to KENREF, mirrors the broader coordination problems already identified in the Kenyan geodetic literature.

5. The Tectonic Complication: Rift-Driven Displacement of KENREF

Kenya straddles the boundary between the Nubian and Somalian tectonic plates, separated by the East African Rift System (EARS), an actively widening divergent boundary. A 2021 study by Matara et al. compared KENREF Zero Order station coordinates observed in November 2012 against a second GNSS epoch observed in October 2019 at five stations spanning both plates (Kapenguria and Kilgoris on the Nubian plate; Maralal and Namanga on the Somalian plate; Eldama Ravine on the rift floor). The results are summarised in Table 2.

Station	Tectonic Setting	Annual 2D Displacement (mm/yr)	Period
RAVE (Eldama Ravine)	Rift floor	34.0	2012–2019
NAMA (Namanga)	Somalian plate	37.6	2012–2019
KILG (Kilgoris)	Nubian plate	31.1	2012–2019
MARA (Maralal)	Somalian plate	38.0	2012–2019

Table 2. Annual 2D displacement at selected KENREF Zero Order stations (Matara et al., 2021). The Kapenguria (KAPE) result is excluded here as the 2019 re-observation was made on a substitute mark, not the original pillar.

The average horizontal displacement across these stations is approximately 35 mm per year, consistent with IGS-derived velocities for nearby stations on both plates (Nubia average ~29.8 mm/yr; Somalia average ~29.2 mm/yr), and with an inferred inter-plate divergence rate of roughly 2.8 mm/yr across the rift. Because KENREF's Zero Order coordinates were fixed at their November 2012 observation epoch, any comparison with a current-epoch GNSS position — whether nominally “KENREF” or “WGS84” — accumulates a growing positional discrepancy purely from tectonic motion, independent of any datum transformation error. At 35 mm/yr, this discrepancy reaches roughly 35-50 cm over the decade since the KENREF zero epoch, a magnitude that is inconsequential for small-scale mapping but material for cadastral and engineering-grade survey work.

This finding motivates the recommendation, discussed further in Section 7, that any KENREF integration strategy include an explicit epoch and velocity model rather than treating KENREF coordinates as static.

6. WGS84 → KENREF: The Geocentric Advantage

KENREF, following AFREF's design intent, is a geocentric frame realized through GNSS observations and computed in ITRF2014. WGS84, the datum broadcast by the Global Positioning System, is likewise geocentric, and its successive realizations have been deliberately maintained in close alignment with ITRF: WGS84(G1674) is considered coincident with ITRF2008, and WGS84(G1762) compares with ITRF2008 and ITRF2014 to within about 1 cm RMS when compared at the same epoch. Realizations since G2139 (2018) are considered coincident with ITRF at the sub-centimetre level.

This stands in sharp contrast to Arc 1960, whose origin is offset from the geocentre by roughly 150–300 m before any consideration of internal network distortion. The practical implication is that a WGS84-to-KENREF transformation requires no large empirical shift, rotation or scale correction: the two frames

already share the same origin, orientation and scale to a very high degree of confidence. What remains is not a spatial transformation problem but a temporal one — reconciling the observation epoch of KENREF's fixed coordinates (2012.0) with the live epoch of a WGS84 GNSS observation, using a station velocity or plate-motion model of the kind developed in the tectonic displacement study reviewed in Section 5.

Table 3 summarises this contrast.

	Arc 1960 → KENREF	WGS84 → KENREF
Nature of the difference	Large origin offset plus undocumented internal network distortion	Near-zero systematic offset; primarily an epoch/time difference
Transformation type required	Empirical similarity (Helmert) transform, ideally supplemented by a distortion grid	Epoch propagation using a velocity / plate-motion model
Data required	Dual-observed common points across the surviving legacy network	A station velocity model (already partly available from KENREF tectonic studies)
Achievable accuracy	Meter-level without a distortion grid; better only with substantial new fieldwork	Centimetre-level if epoch is correctly handled

Table 3. Comparison of the Arc 1960 → KENREF and WGS84 → KENREF integration problems.

7. Proposed Integration Methodology

Combining the findings above, this paper proposes a hub-and-spoke integration strategy in which KENREF (as an ITRF-based geocentric frame) sits at the centre, with two distinct spokes: one to WGS84/GNSS, which is largely a matter of epoch management, and a separate, harder spoke to Arc 1960, which is a matter of empirical network calibration. The recommended steps are as follows.

7.1 Complete and publish KENREF

- Finalise and officially publish coordinates for the existing 18 Zero Order stations, explicitly stating the reference frame (ITRF2014) and observation epoch (2012.0).
- Prioritise reconstruction or replacement of the unbuilt Zero Order sites and progress the planned 75-station First Order densification.

7.2 Establish the WGS84 ↔ KENREF spoke (epoch management)

- Adopt a station velocity model — building on the Nubia/Somalia plate velocities already estimated in the KENREF tectonic displacement study — to propagate KENREF coordinates from the 2012.0 epoch to the epoch of any current GNSS observation, and vice versa.
- For applications tolerant of decimetre-level uncertainty (general GIS, small-scale mapping), treat WGS84 and KENREF coordinates as directly interchangeable, consistent with the sub-centimetre-to-centimetre agreement between recent WGS84 realizations and ITRF.

- For cadastral and engineering-grade work, apply the epoch correction before treating a GNSS position as a KENREF coordinate.

7.3 Establish the Arc 1960 ↔ KENREF spoke (empirical calibration)

- Identify surviving Arc 1960 triangulation and cadastral control points and re-observe them with GNSS tied to KENREF, prioritising areas with active cadastral or infrastructure activity.
- Fit a distortion (grid-based) transformation rather than relying solely on a single national similarity transformation, given the documented lack of a unified adjustment of the historical triangulation chains.
- Where possible, undertake a rigorous combined least-squares network adjustment incorporating both legacy triangulation observations and new GNSS baselines, following the approach used internationally for comparably distorted legacy datums.

7.4 Institutional coordination

- Designate a single official transformation standard — endorsed by the Survey of Kenya — to replace the multiple EPSG and academic parameter sets currently in informal, uncoordinated use.
- Bring private and parastatal CORS operators (KPLC, MUYA-CORS, RCMRD and others) into a coordinated national CORS framework integrated with KENREF, as recommended in the Kenyan geodetic literature, to avoid further duplication of infrastructure and further undocumented, mutually inconsistent local networks.
- Establish a single public platform for CORS and transformation metadata, addressing the current absence of any central portal for this information.

8. Discussion

The methodology above does not resolve the practical constraints that have delayed KENREF's completion — insecurity along parts of the northern border, inter-agency coordination failures, and the vandalism of legacy monuments — but it does clarify where effort is best spent. The WGS84 spoke is comparatively cheap: it requires a velocity model, much of which already exists in the research literature reviewed here, rather than a costly national field campaign. The Arc 1960 spoke is intrinsically more expensive, because it requires physically re-observing a deteriorating and incompletely documented legacy network. A pragmatic implication is that Kenya could realistically offer a reliable, centimetre-aware WGS84–KENREF relationship in the near term, while treating full Arc 1960 harmonisation as a longer-term, resource-intensive undertaking — conducted opportunistically wherever cadastral or infrastructure projects already require new fieldwork in areas with surviving legacy control.

A further implication concerns semi-dynamic datum design. Countries such as Israel and Taiwan, which similarly straddle active tectonic boundaries, have adopted semi-dynamic datums in which station coordinates are referred to a fixed epoch and updated only when the datum itself is redefined. Given the roughly 35 mm/yr displacement documented for KENREF stations, a comparable semi-dynamic design — rather than a purely static datum — would materially improve the long-term usability of KENREF for precise applications.

9. Conclusion

Kenya's path toward a unified, modern geodetic reference frame runs through two integration problems of very different character. Because KENREF and WGS84 are both geocentric frames aligned with ITRF to within centimetres, integrating GNSS-derived WGS84 positions into KENREF is primarily a matter of epoch and velocity management — a problem already substantially informed by existing tectonic displacement research on KENREF itself. Integrating the legacy Arc 1960 datum, by contrast, requires confronting a genuine origin offset and an internally distorted, incompletely documented historical network, and will require sustained fieldwork and a nationally coordinated transformation standard. Recognising this asymmetry allows resources and institutional attention to be targeted more effectively: complete and publish KENREF, formalise a velocity-aware WGS84–KENREF relationship in the near term, and pursue Arc 1960 harmonisation as a longer, deliberately resourced programme of legacy network recovery.

References

- CODI-GEO / UNECA (2005). Call for Participation in the Unification of African Reference Frames — The AFREF Project 2005–2010. United Nations Economic Commission for Africa, Committee on Development Information, Geo-Information Subcommittee.
- EPSG Geodetic Parameter Dataset. Arc 1960 to WGS 84 (1), EPSG:1122; Arc 1960 to WGS 84 (2), EPSG:1284; Arc 1960 / UTM zone 37N, EPSG:21097; Arc 1960 / UTM zone 37S, EPSG:21037; Arc 1960, EPSG:6210. Available at epsg.io / epsg.org.
- International GNSS Service / IERS (2013). ITRS and WGS84. Available at itrf.ign.fr.
- Kenya Mining Cadastre Portal. Conversion to WGS84 — Kenya Gazette Notice, 30 January 2015.
- Lwangasi, A.S. (1993). Datum Transformation Parameters for the Kenya Geodetic System. *Survey Review*, 32(247), 39–46.
- Matara, S.M., Siriba, D.N., Kiema, J.B.K. and Musyoka, S.M. (2021). Predicting Displacement Effects of Tectonic Movements on the Kenyan Geodetic Reference Frame Network (KENREF). FIG e-Working Week 2021, Virtually in the Netherlands, 21–25 June 2021.
- 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*, 24(1), 1–11.
- National Geodetic Survey (NGS) / Penn State GEOG 862. ITRF2014, WGS84 and NAD83 — comparison table of realizations and epochs.
- Wong, R., Rollins, C.M. and Minter, C.F. (2012). Recent Updates to the WGS 84 Reference Frame. *Proceedings of ION GNSS 2012*.