

Impact of Geomagnetic Parameter of Declination for Accurate Positioning, Navigation, and Orientation in Nigeria

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Abstract

The Earth's magnetic declination, a key parameter of the geomagnetic field, has long provided a fundamental reference for navigation, orientation, and geospatial positioning. Owing to temporal and spatial variations in the geomagnetic field, periodic model updates are essential for maintaining positional accuracy and geophysical consistency. This study modelled the spatiotemporal variability of magnetic declination across Nigeria over 15 years (2010-2025) to enhance geomagnetic referencing for sustainable navigation and mapping systems. The study employed a quantitative geoscientific methodology. The study integrated International Geomagnetic Reference Field (IGRF-14) Gauss coefficients using MATLAB programming to compute magnetic field elements and generate declination models at a 1:50,000 scale. Analytical outputs revealed significant regional variations, with the North-West, South-South, and South-East zones recording the highest declination changes of 2.40°, 2.10°, and 2.00°, respectively. Conversely, the North-Central, North-East, and South-West zones exhibited relatively lower variations of 0.70°, 1.20°, and 1.70°, respectively. A comparative assessment between declination values from the developed model and those derived from the global geomagnetic calculator revealed minimal discrepancies (−0.009480 to −0.001340), with root mean square errors ranging from 0.00470 to 0.00670. These findings underscore the importance of the magnitude of secular variations of magnetic declination across Nigeria. The variability of these values provides a veritable basis to support geospatial infrastructure development, accurate navigation, and calibration of inertial systems. Regular updates of isogonic maps and geomagnetic parameters are therefore recommended to strengthen national geospatial frameworks, enhance disaster preparedness, and promote SDG-aligned geoscience innovations that underpin resilient infrastructure and sustainable urban development.

Keywords

Magnetic Declination, Geomagnetic Field Modeling, IGRF-14, Spatiotemporal Variability, Geospatial Analysis, Sustainable Development Goals (SDGs)

1. Introduction

Accurate knowledge of the Earth's magnetic declination (the angle between magnetic meridian and true meridian) is essential for many surveying, navigation, and orientation tasks because instruments and human procedures that reference magnetic north must be converted to true bearing for mapping, geodetic control, and safe navigation (NOAA, IGRF/WMM). The geomagnetic field is not static: it exhibits continuous secular variation driven by core processes, episodic disturbances from space weather (storms and sub-storms), and regional superposed ionospheric and crustal contributions that can produce measurable spatial and temporal changes in declination over years to decades (IGRF/WMM; [1]). These changes matter in practice; even a decadal change of a fraction of a degree can produce meter-level orientation and mapping errors when long baselines, precision azimuths, or sensor fusion (magnetometer + GNSS/INS) are used in surveying, marine/aeronautical operations, and cadastral mapping [2].

In West Africa and Nigeria specifically, regional studies have documented pronounced spatial and temporal variability in geomagnetic components, including enhancements associated with equatorial electrojet and solar-quiet currents, as well as storm-time excursions that affect the horizontal field magnitude and direction [3] [4]. Such variability implies that a single, static declination correction (a map printed value) rapidly becomes outdated for tasks needing sub-degree azimuth precision, and that operational systems should rely on regularly updated geomagnetic models (IGRF/WMM) or locally observed time series for corrections. For low-latitude environments like Nigeria, where the dip equator, equatorial electrojet, and rapid secular shifts can all influence declination behaviour. The risk of orientation error is amplified relative to mid-latitude.

Beyond orientation error for traditional compasses, geomagnetic variability can indirectly affect GNSS-based positioning through ionospheric disturbances that degrade signal propagation (increased TEC variability, scintillation) and through degraded sensor fusion when magnetic heading is used to initialise or constrain inertial navigation systems. Recent studies emphasize that GNSS/INS integration and air/sea navigation systems must explicitly account for both secular changes (by updating models like WMM/IGRF) and transient geomagnetic/ionospheric events to preserve the integrity and reliability of the combined solution [5] [6]. Thus, a national assessment spanning 2010-2025 offers practical value: it quantifies how declination evolved across Nigeria during a period of both secular change and recent model updates (WMM releases), and it informs surveying, mapping, maritime, and aviation stakeholders about the magnitude and spatial pattern of

azimuthal risk. This paper, therefore, aims to characterise the spatial-temporal variability of magnetic declination across Nigeria from 2010 through 2025 using regional observations and the global reference model and quantify the impact of observed declination changes on common geodetic and navigation tasks (survey, GNSS/INS heading initialization, and map projection alignment).

Study Area

Nigeria occupies a total area of approximately 923,769 square kilometers, comprising 909,890 km² of land and 13,879 km² of water [7] [8]. It has 36 states with the federal capital territory, Abuja, as shown in **Figure 1**. It is situated in West Africa, bounded by latitudes 4°N to 14°N and longitudes 2°E to 15°E, encompassing a diverse geomagnetic environment influenced by equatorial electrojet dynamics and crustal magnetic anomalies. A uniform geographic grid (1° × 1° resolution) was defined to cover the national territory for sampling and analysis. It shares land borders with Benin (773 km) to the west, Cameroon (1690 km) to the east, Niger (1497 km) to the north, and Chad (87 km) to the northeast [9]. Nigeria's coastline spans 853 kilometers along the Gulf of Guinea. Its territorial sea extends 12 nautical miles (nm), with an Exclusive Economic Zone (EEZ) of 200 nm, and a continental shelf depth of approximately 200 meters, as defined by international maritime law [10] [11]. The country's lowest elevation point is at sea level along the Atlantic Ocean, while its highest point is Chappal Waddi, rising to 2419 meters above sea level in the southeastern Adamawa Highlands [12]. Geologically, Nigeria is composed of three major lithological regions. These geological formations not only shape the landscape but also influence natural resource distribution, seismic behavior, and geomagnetic variability across the country [13].

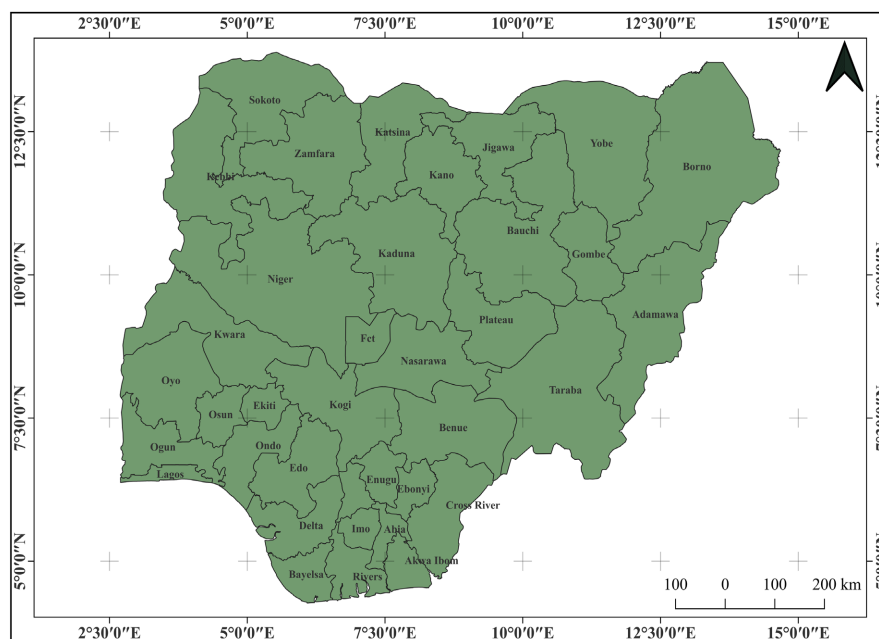


Figure 1. A map of the study area. (Source: NIMASA)

This study is limited to the extraction and application of geomagnetic field parameters over Nigeria using spherical harmonic coefficients from the International Geomagnetic Reference Field model (IGRF-14) [14]. The research focuses on modeling and analyzing the temporal variation, specifically the secular variation, of declination from 2010 to 2025 at annual intervals.

2. Materials and Methods

2.1 Data Source

The study primarily relied on satellite-derived geomagnetic datasets and geodetic station data to model magnetic declination over Nigeria. The Software tools used were MATLAB for mathematical modeling and harmonic computations. QGIS (v3.x) as shown in **Table 1**. The International Geomagnetic Reference Field (IGRF-14), developed by the International Association of Geomagnetism and Aeronomy (IAGA) [14], and the World Magnetic Model (WMM 2024) repositories provided the spherical harmonic coefficients, which served as the fundamental inputs for computing the magnetic field components necessary to derive magnetic declination at defined spatial locations. Magnetic field coefficients for the epochs 2010-2015, 2015-2020, and 2020-2025 were obtained from the National Oceanic and Atmospheric Administration (NOAA) repository. **Table 2** shows IGRF14 coefficients up to degree and order 4. Similarly, the spherical harmonic coefficients were extracted for epochs spanning 2010 to 2025, at 1-year intervals, covering the spatial extent of Nigeria (Latitudes 4°N - 14°N, Longitudes 2°E - 15°E). These data enabled a 15-year spatiotemporal trend analysis of geomagnetic field variations across Nigeria. We deployed 55 primary geodetic station coordinates, which were sourced from the Office of the Surveyor General of the Federation (OSGOF), as shown in **Table 3**. The primary use of the 55 geodetic points is for the Root Mean Square Error (RMSE) calculation. The process for this calculation involves determining the difference between the observed declination values at these geodetic points and the declination values predicted by a model. This difference is calculated for each geodetic point, squared, and then averaged across all points. Finally, the square root of this average is taken to obtain the RMSE value, which quantifies the overall accuracy of the model in predicting declination values at the geodetic points. Additionally, 1:50,000-scale map sheet centre coordinates of Nigeria [15] were employed to provide spatial referencing for magnetic field interpolation and mapping.

The parameter computation involved the use of MATLAB; the magnetic field parameter of declination (D) was computed from the spherical harmonic coefficients at multiple grid points across the country. The secular variation for each element was calculated by evaluating temporal changes in values from one year to the next. The processed data were imported into Quantum Geographic Information System (QGIS) software for spatial visualization. Gridded data were interpolated using the Inverse Distance Weighting (IDW) and kriging techniques to generate smoothed surfaces of isogonic lines. The resulting maps for each epoch

and parameter were validated for consistency with global WMM datasets and cartographic standards. Using Quantum Geographic Information System (QGIS), the study developed and visualized an updated isogonic map to support navigation, mapping, and geospatial applications across Nigeria. The Software tools used were MATLAB for mathematical modeling and harmonic computations. QGIS (v3.x) as shown in **Table 3**.

Table 1. International geomagnetic reference field (IGRF-14) spherical harmonic coefficients of degree n , order m .

n	m	g_n^m	h_n^m	dgnm	dhnm
1	0	-29350.00	0.00	12.60	0.00
1	1	-1410.30	4545.50	10.00	-21.50
2	0	-2556.20	0.00	-11.20	0.00
2	1	2950.90	-3133.60	-5.30	-27.30
2	2	1648.70	-814.20	-8.30	-11.10
3	0	1360.90	0.00	-1.50	0.00
3	1	-2404.20	-56.90	-4.40	3.80
3	2	1243.80	237.60	0.40	-0.20
3	3	453.40	-549.60	-15.60	-3.90
4	0	8799.60	0.00	-1.70	0.00
4	1	94.70	278.60	-2.30	-1.30
4	2	55.80	-134.00	-5.80	4.10
4	3	-281.10	212.00	5.40	1.60
4	4	12.00	-375.40	-6.80	-4.10

British Geological Survey (BGS) website.

Table 2. Excerpt of primary geodetic stations' coordinates and height above the ellipsoid.

S/No.	Station Id	Latitude (Degrees Decimal)	Longitude (Degrees Decimal)	Altitude (m)
1	A10	9.3195	12.2299	287.036.
2	A24	10.6038	11.3397	624.625
3	A16	10.1249	12.3759	786.604
4	A39	11.2889	10.4174	495.499
5	C21	6.9687	9.2468	344.608
6	C16	6.1371	9.0267	628.430
7	C32	7.7582	10.1205	391.825
8	CFL56	11.8532	13.1164	357.405
9	CFH66	6.1731	6.7501	57.368
10	CFA 33/A	6.6269	3.3231	70.412

Continued

11	D29	11.388	5.2173	526.7924
12	D17	10.7607	4.5602	350.1121
13	E10	9.1908	10.4399	332.7233
14	H4	7.4627	8.6032	362.903
15	H5	7.5121	8.9717	300.431
16	H11	8.2477	8.8032	259.5107
17	L10	7.2044	3.3449	197.892
18	L18	8.5369	4.558	430.3807
19	L16	7.9041	4.4038	523.7774
20	M606	5.122	8.3388	105.326
21	N25	8.9988	8.0874	591.959
22	N102	9.6391	6.5587	471.778

[15].

Table 3. Software and hardware.

S/N	Software	Hardware
1	QGIS 3.22	Core i3 Lenovo Laptop (8.00Gb + 8.00Gb). CPH2363_11 OPPO Reno71.
2	MATLAB. R2023b 23.2	Core i3 Lenovo Laptop (8.00Gb + 8.00Gb).
3	Microsoft Excel 2013	Core i3 Lenovo Laptop (8.00Gb + 8.00Gb).
4	Google Earth professional	Core i3 Lenovo Laptop (8.00Gb + 8.00Gb).

Table 4. Excerpt of geodetic position and height above the ellipsoid at 1:50,000 resolution.

S/No	Location	Latitude (Degrees Decimal)	Longitude (Degrees Decimal)	Altitude (m)
1	Kurdula	13.875	4.125	272.5
2		13.875	4.375	296.25
3		13.625	4.125	294.75
4		13.625	4.375	253.25
5	Matsena	13.375	10.125	360.50
6		13.375	10.375	355.25
7		13.125	10.125	354.00
8		13.125	10.375	349.00
9	Kubli	10.3750	4.1250	253.00
10		10.3750	4.3750	176.50
11		10.1250	4.1250	273.25
12		10.1250	4.3750	165.75
13	Lokoja	7.875	6.625	179.75

Continued

14	7.875	6.875	40.50
15	7.625	6.625	116.00
16	7.625	6.875	243.00

[15].

For spatial analysis, interpolation, and map design, and Python scripting (where applicable): For batch processing of data inputs and outputs. The geodetic coordinates and ellipsoidal heights computed at a 1:50,000 resolution, as shown in **Table 4**, define the reference network employed for the magnetic declination analysis.

The Earth's geomagnetic field can be mathematically represented using spherical harmonic expansion, a method that decomposes the field into a series of orthogonal basis functions over a sphere. According to [16], and further refined in the IGRF-13 model by [14], the geomagnetic field vector $B(r, \theta, \lambda)$ at a given point in spherical coordinates, where r is the radial distance from Earth's center, θ is the colatitude (measured from the North Pole), and λ is the longitude is expressed as:

$$B(r, \theta, \lambda) = \sum_{n=1}^{\infty} \sum_{m=0}^n [g_n^m \cos(m\lambda) + h_n^m \sin(m\lambda)] p_n^m(\cos \theta) \quad (1)$$

where: $B(r, \theta, \lambda)$ is the magnetic vector at spherical coordinates (r, θ, λ) , g_n^m and h_n^m are the spherical harmonic coefficients representing the radial and tangential components of the magnetic field, p_n^m are the associated Legendre functions of degree n and order m , r is the radial distance from the Earth's center θ is the colatitude (angle from the North pole), and λ is the longitude. These coefficients are derived through inversion techniques using observational data from satellite missions (e.g., Swarm), ground-based observatories, and airborne or marine magnetic surveys. Estimation of the coefficients typically employs least squares fitting combined with regularization methods to stabilize the inversion in the presence of noise and data gaps [17] [18].

2.2. Determination of Magnetic Field Component

The geomagnetic field components B_r , B_θ and B_ϕ in spherical coordinates (radius vector r , colatitude θ and longitude ϕ are represented by spherical harmonics given by the mathematical formulation [19], given as;

$$B_r = \frac{-\partial V}{\partial r} = -\sum_{N=1}^N \sum_{m=0}^n \left(\frac{a}{r}\right)^{n+2} (g_n^m(t) \cos(m\phi) + h_n^m(t) \sin(m\phi)) p_n^m(\cos \theta) \quad (2)$$

$$B_\theta = \frac{-\partial V}{r \partial \theta} = -\sum_{N=1}^N \sum_{m=0}^n \left(\frac{a}{r}\right)^{n+2} (g_n^m(t) \cos(m\phi) + h_n^m(t) \sin(m\phi)) \frac{\partial p_n^m(\cos \theta)}{\partial \theta} \quad (3)$$

$$\begin{aligned}
 B_\phi &= \frac{-\partial V}{r \sin \theta \partial \phi} \\
 &= \frac{1}{\sin \theta} \sum_{N=1}^N \sum_{m=0}^n \left(\frac{a}{r}\right)^{n+2} m \left(g_n^m(t) \sin(m\phi) - h_n^m(t) \cos(m\phi) \right) P_n^m(\cos \theta)
 \end{aligned} \tag{4}$$

2.3. Magnetic Declination (D)

Magnetic declination, also known as magnetic variation, is the horizontal angle between the geographic north (true north) and the magnetic north (the direction a compass needle points). It is mathematically defined by [19] as given:

$$D = \tan^{-1} \left(\frac{B_\phi}{B_\theta} \right) \tag{5}$$

where B_ϕ and B_θ are the northward and eastward components of the magnetic field, respectively. Equation (5) was used to compute the magnetic declination, essential for calibrating the compass needle in drone survey, aerospace navigation control, marine chart course, as well as mapping mineral deposits

2.4. Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) was used to validate the value of magnetic declination from the evaluation of thirty-nine (55) geodetic stations distributed across Nigeria. It was critical for evaluating the accuracy of the results of magnetic declination generated using MATLAB GUI. RMSE provided a quantitative measure of how closely a model's predictions align with observed values as represented in the IGRF14. The study assessed magnetic declination by comparing values produced with the MATLAB GUI against those derived using the geomagnetic calculator. This helps ensure the model's stability and reliability, particularly for navigational, geophysical, and geospatial applications.

The RMSE is mathematically defined [17] [19]-[21] given as:

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_{\text{Developed}} - y_{\text{Geomag 7}})^2} \tag{6}$$

where:

$y_{\text{Developed}}$ is the Developed Model value of magnetic field component declination;

$y_{\text{Geomag 7}}$ is the Geomagnetic Calculator value from the IGRF-14 Model from NOAA;

n is the total number of data points.

The difference $y_{\text{Developed}} - y_{\text{Geomag 7}}$ is the residual or error for each data point.

Squaring the residuals and taking the mean ensures that both positive and negative errors are considered equally. The square root returns the error to the original unit of measurement, making RMSE easier to interpret.

3. Result

The results obtained in this study show a non-uniform variation of the magnetic field parameters across the Zones in Nigeria.

Figure 2 represent time scale variability of the magnetic field across Nigeria from 2010 to 2025 at 5 years epoch with the black polygon describing the territorial boundary of Nigeria, the blue line represents the two major rivers (Niger and Benue) in Nigeria, with the following continuous line representing Isogonic line, 2010 (green), 2015 (cyan), 2020 (purple) and red (2025).

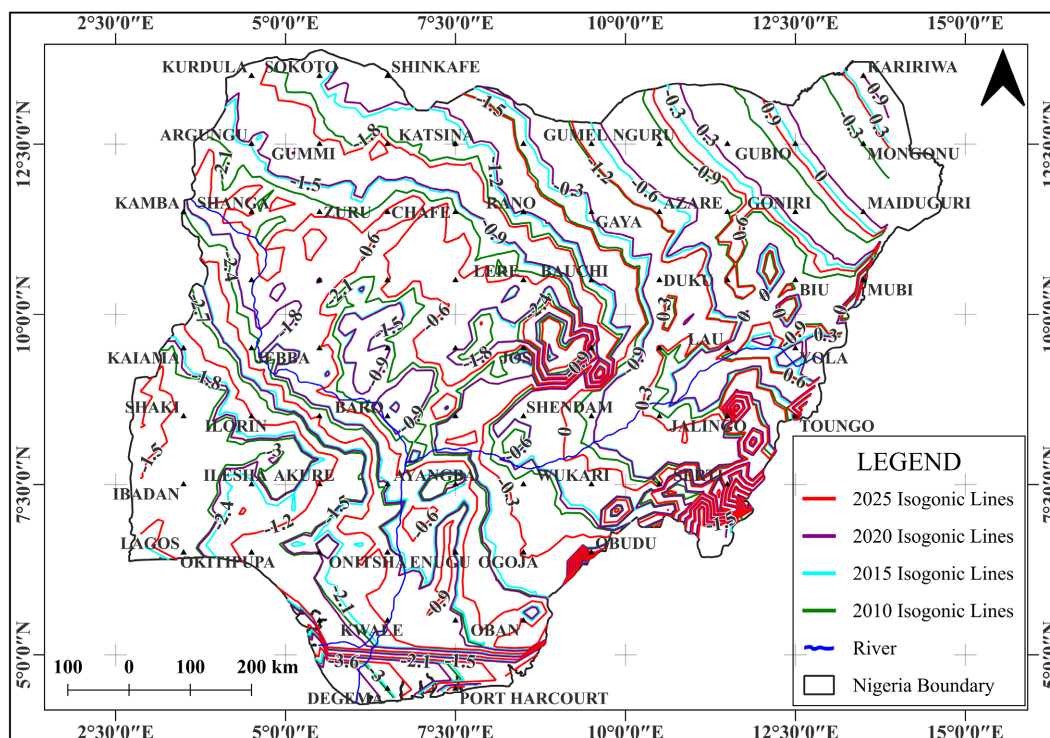


Figure 2. Isogonic time scale, spatial and secular distribution map across Nigeria. Author (2025).

Table 5 displays the epochal declination values observed in various zones across Nigeria. These values were determined by calculating the average declination for the years 2010, 2015, 2020, and 2025 in each zone. The results are presented in columns 2 to 5 of **Table 5**. Additionally, column 6 shows the total change in declination for each zone from 2010 to 2025, while column 7 describes the direction of the change. In the same vein, **Table 6** shows a track of magnetic declination variability across zones in Nigeria as a consequence of the analysis from the Isogonic map in **Figure 2**. The zones in Nigeria were evaluated at an epoch of 5 years (2010, 2015, 2020, and 2025), which shows clear evidence of non-uniform magnetic declination change.

Table 6 examines three areas in Nigeria that show a high degree of concentration of magnetic declination as observed in **Figure 2**.

Positional implication of neglecting magnetic declination correction at varying distances, as shown in **Table 7**. The magnitude of error is a function of the degree of change in declination and the distance covered.

The differential between the generated magnetic declination results using MATLAB GUI and their respective RMSE range from -0.00948° to -0.00134° and

0.0047° to 0.0067° as shown in **Table 8**. This was necessary to compare the MATLAB GUI program with a standard geomagnetic result from IGRF.

Table 5. Temporal analysis of mean magnetic declination by zone in Nigeria at five-year epoch (2010-2025).

Zone	2010 Mean Declination	2015 Mean Declination	2020 Mean declination	2025 Mean Declination	Variation (ΔH) 2010-2025	Trend Description
North-West	-1.5°	-0.6°	+0.2°	+0.9°	2.4°	Significant increase towards the east of the true north
North-East	+0.3°	+0.5°	+0.8°	+1.0°	0.7°	Minimal variation over the 15-year epoch
North-Central	~0.2°	+0.3°	+0.7°	+1.0°	1.2°	Clear eastern drift of the true meridian
South-West	~2.0°	-1.3°	-0.8°	~0.3°	1.7°	Strong eastward movement towards the true meridian
South-East	~1.5°	-0.5°	-0.2°	+0.5°	2.0°	Significant movement across zero declination
South-South	-3.6°	-2.7°	-2.0°	-1.5°	2.1°	Significant eastward drift towards the true meridian

Author, 2025.

Table 6. Key areas with high isogonic line concentration and declination variation.

Location	Declination Trend	Zone	Status by 2025
Lat. (6.7° - 9.2°N), Long. (10.2° - 12.2°E)	-0.2° to +1.2°	Northcentral/Northeast	1.4°
Lat. (4.8° - 5.2°N), Long. (5.3° - 8.9°E)	-3.6° to -1.5°	South-South/South-West	2.1°
Lat. (8.9° - 10.5°N), Long. (8.5° - 10.0°E)	-0.3° to +1.0°	Central Nigeria	1.3°

Author, 2025.

Table 7. Positional implications of neglecting magnetic declination correction at varying distances (100 - 10000) m.

From Station	Zone	True Brg (°)	D (°)	Magnetic Brg (°)	Implication for Neglecting Declination Correction			
					100 (m)	1000 (m)	5000 (m)	10,000 (m)
CFA33A	South-West	114.2	-1.48	112.76	2.58 m	25.83 m	129.15 m	258.30 m
ZVS3003	South-South	56.71	-0.89	55.89	1.57 m	15.71 m	78.54 m	157.08 m
U78	South East	48.24	-1.01	47.24	1.75 m	17.45 m	87.27 m	174.53 m
CFL56	North East	272.11	0.91	273.02	1.59 m	15.88 m	79.41 m	158.82 m
R43	North-West	94.01	-0.56	93.45	0.98 m	9.77 m	48.87 m	97.74 m
N102	North Central	148.28	-0.59	147.65	0.59 m	5.84 m	29.17 m	58.33 m

Author, 2025.

Table 8. Specimen of the comparative analysis of the geomagnetic calculator version 7.0 derived declination values at the 55 primary geodetic stations in Nigeria and the declination values obtained at the same station using the MATLAB GUI program developed in this study (d.d represents degree decimal).

S/N	Station Id	Dec. From Geo. Cal. (d.d)	Dec. From Dev. Model (d.d)	Diff. in Dec. (degree decimal)	Root Mean Square Error (RMSE)
1	A10	0.04177	0.049447	-0.00768	0.005428
2	A24	-0.43095	-0.4243	-0.00665	0,004702
3	A16	-0.52284	-0.51534	-0.0075	0.005303
4	A39	-0.3431	-0.33551	-0.00759	0.005367
5	C21	-1.00682	-0.99939	-0.00743	0.005254
6	C16	-1.57334	-1.566	-0.00734	0.005190
7	C32	-0.75648	-0.74719	-0.00929	0.006569
8	CFL56	0.42147	0.43005	-0.00858	0.006067
9	CFH66	-1.34585	-1.3371	-0.00875	0.006187
10	CFA33/A	-2.11406	-2.1055	-0.00856	0.006053
11	D29	-1.43638	-1.4282	-0.00818	0.005784
12	D17	-1.4394	-1.4317	-0.0077	0.005445
13	E10	-0.39949	-0.39113	-0.00836	0.005911
14	H4	-1.09333	-1.0848	-0.00853	0.006032
15	H5	-0.92044	-0.91127	-0.00917	0.006484
16	H11	-0.78615	-0.77712	-0.00903	0.006385
17	L10	-2.15855	-2.1502	-0.00835	0.005904
18	L18	-1.91992	-1.9118	-0.00812	0.005742
19	L16	-2.18991	-2.1811	-0.00881	0.006230
20	M606	-1.22088	-1.2114	-0.00948	0.006703
21	N25	-1.26606	-1.2581	-0.00796	0.005629
22	N102	-1.33843	-1.3292	-0.00923	0.006527
23	N120	-1.20839	-1.2009	-0.00749	0.005296
24	N127	-1.31874	-1.3103	-0.00844	0.005968
25	N10	-2.02693	-2.0185	-0.00843	0.005961
26	R28	-0.87174	-0.86441	-0.00733	0.005183
27	R36	-0.84615	-0.8377	-0.00845	0.005975
28	R16	-1.13118	-1.1234	-0.00778	0.005501
29	R43	-1.13223	-1.1242	-0.00803	0.005678
30	U70	-1.55779	-1.5488	-0.00899	0.006357
31	U73	-2.05171	-2.0427	-0.00901	0.006371
32	U81	-1.50114	-1.4927	-0.00844	0.005968
33	U78	-1.59359	-1.5849	-0.00869	0.006145

Continued

34	ZVS3003	-1.50214	-1.4938	-0.00834	0.005897
35	C008	-1.43245	-1.4234	-0.00905	0.006399
36	L40	-1.33698	-1.3284	-0.00858	0.006067
37	CBL10	-1.67786	-1.6689	-0.00896	0.006336
38	L8	-2.29215	-2.2827	-0.00945	0.006682
39	N133	-0.94432	-0.93596	-0.00836	0.005911
40	L18	-1.9737	-1.9767	0.003	0.002121
41	U13	-1.4788	-1.4832	0.0044	0.003111
42	D13	-1.4638	-1.4659	0.0021	0.001485
43	L03	-2.1823	-2.1861	0.0038	0.002687
44	D06	-1.6061	-1.6097	0.0036	0.002546
45	K01	-0.61206	-0.61458	0.00252	0.001782
46	N09	-1.9678	-1.9697	0.0019	0.001344
47	C014	-1.0032	-1.0063	0.0031	0.002192
48	N123A	-1.3605	-1.3643	0.0038	0.002687
49	L040	-1.1106	-1.1143	0.0037	0.002616
50	N032	-1.5801	-1.5822	0.0021	0.001485
51	N025	-1.2549	1.2582	0.0033	0.002333
52	A001	0.18538	0.18311	0.00227	0.001605
53	U72	-2.0843	-2.0885	0.0042	0.002970
54	C036	-0.7358	-0.73884	0.00304	0.002150
55	A21	-0.56892	-0.57286	0.00394	0.002786

4. Discussion

In **Figure 2**, Isogonic maps from different epochs were superimposed on each other, and it shows that the lines shift eastward over time, which indicates a gradual change in magnetic declination. This is a well-known global geophysical phenomenon due to the dynamic nature of the Earth's magnetic field. In 2010, the -0.5° (westward) line passed through north central Nigeria (Nasarawa). By 2025, that same -0.5° W line has shifted eastward toward the northeastern state (Borno, Maiduguri). Some areas, particularly in the southeast and south-south zones, show significant compression or crowding of Isogonic lines, indicating rapid variation in declination between epochs. Coordinate systems aligned to the magnetic meridian (older local maps, cadastral plan, or compass-based layout) become obsolete over time, except corrected for declination drift. Cadastral boundaries, engineering design, and infrastructure alignments made using the 2010 magnetic north could now be misaligned by over 1 to 2 degrees in regions like south-south. Compass-based navigation charts must be updated frequently to prevent course deviations. Ships entering Lagos or Port Harcourt ports using old charts risk nav-

igational misalignment. Aircraft flight path, runway alignments, and approach pattern (especially in manual or backup navigation systems) depend heavily on accurate magnetic headings. While GNSS provides true north, many field devices (handheld GPS units, mobile apps) use magnetic meridian overlays. Software and GIS systems must incorporate temporal declination models for historical corrections and accurate orientation. For drone-based mapping, yaw alignment and compass calibration must consider up-to-date local declination values.

Table 5 shows the temporal analysis of locational variation in declination across Nigeria from 2010 to 2025. In the northwest, magnetic declination exhibits a gradual change toward a positive value from -1.5° in 2010 to $+0.9^\circ$ in 2025, with changes from 2010 to 2015 as the highest. Total displacement from 2010 to 2025 is 2.4° . Old (Legacy) maps need updating for modern compass usage. Declination range fairly stable in the northeast from $+0.5^\circ$ to $+1.2^\circ$ (2010-2025) with minimal variation of $+0.7^\circ$ over 15 years. Low magnetic drift makes this region ideal for long-time mapping (minimum calibration needed for inertia navigation systems such as drone survey, UAVs, and Aerospace systems). In north-central, magnetic declination drifts from about -0.20 to $+1.0^\circ$ from 2010 to 2025. This shows a clear eastward drift of magnetic declination of $+1.2^\circ$. Such a change necessitates frequent compass calibration, and magnetic applications need time-tagged magnetic correction. A total of $+1.7^\circ$ variation of strong eastward movement of declination shift from -2.0° (2010) to -0.3° (2025) is experienced in the southwest. Older maps may show significant azimuth misalignment. Marine navigation near the Lagos coast must be updated for safe heading. South-east shows a magnetic declination variation from around -1.5° in 2010 to $+0.5^\circ$ in 2025 with a total of 2.0° across the epoch. This shows a rapid movement across zero declination that can affect alignment tools. Maps made a decade apart can differ by 2.0° in orientation. The south-south declination evolution from -3.6° (2010) to -1.5° (2025) indicates a slower eastward drift compared to the other zones. It has displaced a total of $+2.1^\circ$ declination variation over 15 years. Persistent westward declination can cause directional errors in surveying if neglected. This can greatly affect marine navigation charts, oil rig positioning from compass-based inertia navigation systems, and GPS signal interference.

Table 6 shows an analysis of some three areas of concern in the Isogonic time series map of Nigeria in **Figure 2**. Location ranging from Lat. ($6.7^\circ - 9.2^\circ\text{N}$), Long. ($10.2^\circ - 12.2^\circ\text{E}$), lies in North-central to North-eastern Nigeria covering Nasarawa, Benue, Taraba, part of Adamawa, and Plateau States. 2010 declination is slightly negative (West of the true meridian), $-0.2^\circ - 0.3^\circ$. In 2015, it shifted towards zero, becoming slightly positive in the eastern parts. From 2020 to 2025, the region experiences a steady increase to around $+0.5^\circ$ to $+1.2^\circ$ in 2025. This region is experiencing a west-to-east migration of the zero Isogonic line. Magnetic declination here is increasing over time, moving from westward deviation to eastward. For mapping, aerospace/drone navigation, epoch-specific declination is needed for calibration to avoid misalignment and inaccuracy. Lat. ($4.8^\circ - 5.2^\circ\text{N}$), Long.

(5.3° - 8.9° E) lies in the coastal and low belt of south-south and part of south-west Nigeria (Delta, Bayelsa, Rivers, Edo, and part of Ondo). The 2010 declination is strongly negative from -3.6° to -2.5° . From 2015 to 2020, it became less negative, improving to -2.0° . In 2025, still negative, but closer to -1.5° , suggesting a slow eastward drift. This region is the slowest in the decline and recovery. The negative declination remains, though it is decreasing steadily. Compass ready may still have a strong westward bias. Marine navigation, geophysical exploration, mapping, and GIS applications in this region need a robust magnetic model due to persistent negative declination. The region around Lat. (8.9° - 10.5° N), Long. (8.5° - 10.0° E) covers central Nigeria, including Kaduna, Bauchi, Plateau, and Nasarawa States. In 2010, the declination is near 0° , slightly negative, crosses into positive territory with a declination range from $+0.3^{\circ}$ to $+0.5^{\circ}$ in 2015. From 2020 to 2025, it reaches $+1.0^{\circ}$ and slightly more in some areas. This region is central to the Isogonic transition from west to east declination. It exhibits a balance and steady increase and is one of the earliest regions in the country to cross over into positive values. Surveying and geospatial reference systems require regular declination updates to avoid angular discrepancies in land partitioning and boundary demarcation. Aircraft instruments need compass correction to reflect the ongoing eastward drift. These three sections are experiencing a high variability in magnetic declination, and the implications are huge if not corrected.

Table 7 illustrates the impact of neglecting to apply declination corrections to our compass and inertial devices for navigation, orientation, positioning, and geospatial applications. Westward declination (negative values) shows that the magnetic meridian is west of the true meridian. Eastward declination (positive values) implies that the magnetic meridian is east of the true meridian. Also, declination values are small (-1.48° to $+0.91^{\circ}$), but their impact increase with distance. At 100 m, the error ranges from 0.59 m to 2.58 m, which is negligible for certain geospatial applications such as navigation and rescue operations. At 1000 m (1 km), the error increases to 5.84 m to 25.83 m, making small inaccuracies noticeable in surveying and mapping. At 5000 m (5 km), the error ranges between 29.17m and 129.15 m, which is significant for mapping, navigation, and aviation. At 10,000 m (10 km), the error escalates up to 258.3 m, meaning a location could be misplaced by over 250 m (approximately 0.250 km) if declination correction is not applied. Errors beyond 1 km become significant for surveying and mapping, and at 5km, they exceed 50 m, making geospatial data unreliable without correction for declination. Sailors, pilots, and other compass-based navigation systems must apply declination correction to avoid misalignment of the flight path or maritime chart. Because at 10 km, a shift of 258m in location can cause major displacement in navigation. In all, at every one degree (1°) and hundred meters (100 m), a positional shift of 1.75 m is expected. Precision targeting, reconnaissance, and artillery positioning require declination correction to avoid off-target errors in military campaigns. Positional accuracy of satellite imagery and geospatial databases also depends on declination corrections. This neglect of declination correction can

cause a delay in time, which often results in economic setback.

The differential and RMSE between the generated magnetic declination using MATLAB GUI and the geomag 7.0 calculator developed by the National Oceanic and Atmospheric Administration show minimal deviation, indicating a high degree of accuracy of the obtained results of magnetic declination across Nigeria.

5. Conclusions

This study provided a comprehensive evaluation of the spatiotemporal variations in the geomagnetic field parameter of declination over Nigeria for the 15 years (2010-2025). The results reveal a significant regional disparity in magnetic field behavior, with the North-West (2.40°), South-South (2.10°), and South-East (2.00°) exhibiting the highest declination changes, while the North-East (0.70°), North-Central (1.20°), and South-West (1.70°) recorded comparatively lower variations. These findings underscore the dynamic nature of the Earth's geomagnetic field and its direct influence on geospatial positioning, navigation, and orientation systems [17] [22]. The observed secular variations highlight the necessity of regularly updating geomagnetic models and isogonic maps to maintain the accuracy of navigation, surveying, and georeferencing applications. Such updates are particularly critical for regions with higher rates of magnetic field change, specifically the North-West, South-South, and South-East zones, where uncorrected declination could compromise positional accuracy in geospatial and infrastructural projects. From a sustainability perspective, the study aligns with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities) by supporting the development of reliable geospatial infrastructure that enhances safety and efficiency in transportation, aviation, and marine navigation. Moreover, it contributes to SDG 13 (Climate Action) through the continuous monitoring of Earth system dynamics, which provides essential data for environmental modeling and disaster preparedness [23] [24]. The contribution of geomagnetic monitoring and analysis involves the relationship between geomagnetic field variations and climate change. This information can be used to improve climate models and predictions, leading to a better understanding and forecasting of climate change impacts. In addition, the Earth's geomagnetic field can influence atmospheric and oceanic circulation patterns, which in turn can affect regional and global climate dynamics. By understanding and anticipating these changes, appropriate measures can be taken to enhance the resilience of critical infrastructure and reduce the potential risks associated with extreme weather events and other climate-related phenomena.

In conclusion, the integration of geomagnetic monitoring into Nigeria's geospatial data infrastructure and urban planning frameworks will strengthen spatial flexibility, enhance national positioning services, and ensure that the country remains aligned with global standards for sustainable geoscientific and technological development.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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