Orientation and Frequency Analysis of Topographic Lineaments in the Miringa Volcanic Zone of the Biu Plateau Region, Borno State, Nigeria

Yakubu Mohammed1*, Ashe Kalli Gazali1, John Onu Odihi2 and Mohammed Mala Daura2

1Department of Geology, University of Maiduguri, Nigeria. 2Department of Geography, University of Maiduguri, Nigeria.

Authors’ contributions

This work was carried out in collaboration among all authors. Author YM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AKG, JOO and MMD managed the analyses of the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2020/v24i830244

Editor(s): (1) Kaveh Ostad-Ali-Askari, Islamic Azad University, Iran.

Reviewers: (1) Tarek Awad Seleem, Suez Canal University, Egypt. (2) R. B. Golekar, Science College, Guhagar, India.

Complete Peer review History: http://www.sdiarticle4.com/review-history/62377

Original Research Article

Received 05 September 2020
Accepted 11 November 2020
Published 02 December 2020

ABSTRACT

The aim of present study is to spatially analyze the topographic lineaments of tectonic origin in the Miringa Volcanic Zone located in the northwestern part of the Biu Plateau. To achieve such aim, SRTM of spatial resolution 12.5 m was utilized. The lineaments were automatically extracted by using PCI GEOMARTICA software version 10. This was followed by field work for ground thrusting and to establish field relationships. ArcGis 10.5 software version was used for spatial analysis of lineaments while Rockworks version 16 was used in creating the Rossace used in lineament trend analysis and other related statistical variables associated with the lineaments of the study area. 2036 linear structures were identified in the area with a total length of 30,193.85 m. The maximum length of lineament recorded in the study area is 150 m while the minimum is 3.68 m. Field work revealed that most of the lineaments in the area developed from the weathering of contacts between successive volcanic beds in areas overlaid by the highly dissected plateaus, escarpment...
slopes and denudation hills. Trend analysis of lineaments of the study area indicates that the direction of lineaments tend to lie in the North-east to southwest direction (Azimuth 45°-225°) which has same direction with major drainage system and most of the volcanoes of the area. This signifies the presence of a major fissure trending in the north-east to south-west direction as the primary tectonic structure of the area. Subsequent exogenic processes exploited this structure leading to the formation of other micro-lineaments that trend along the same direction.

**Keywords:** Biu plateau; geomorphology; miringa and tectonic lineaments.

1. INTRODUCTION

Surface manifestations of structurally controlled features such as joints, faults, dykes, lithological contacts, linear valleys, linear ridges, linear slope breaks and other displaced rock structures mostly developed along weak zones generally referred to as lineaments Arlegui and Soriano [1]: Hubbard et al. [2]. Lineaments analysis of topographic features is a well-established field of study in geomorphology Mohammed et al. [3,4]. Lineaments have been defined as extended mappable linear or curvilinear features on the surface of the earth whose parts align in straight or nearly straight relationships that may be the expression of folds, fractures or faults in the subsurface (Őlen 2004). Aldharab et al. [5] stated that linear and curvilinear features on the earth’s surface expressed as “lineaments” represent zones of weaknesses or structural displacement Tirēn [6]. These features are structurally controlled and developed along joints, faults, dykes, lithological contacts and other displaced rock structures mostly developed along weak zones Arulbalaji et al. [7]. It reflects a general surface manifestation of underground fractures with inherent characteristics of porosity and permeability of the subsurface materials Tariq et al. [8]; Rajavani et al. 2017). They can be mapped at various scales, from local to regional which provides great utility to the various fields of geosciences. Earth scientists have been interested in linear features on the earth crust since the early period of earth observations Őlegen, [9] and Escamilla [10]. This is because these features can give a clue for explorations of Ore, Crude oil, groundwater and other underground resources. They are also important in engineering constructions and environmental management. A number of studies have demonstrated the usefulness of the knowledge about lineaments of an area in various fields of geosciences such as mapping of geomorphic structures, geotectonics, morphodynamics and exploration of minerals, seismicity analysis, landslides, and soil erosion Saleem [11]; Semere and Woldai [12]. Developments in remote sensing and Geographic Information System (GIS) technologies and their applications in lineament analysis have increased over the last decade. This is due to its ability to analyze lineaments from local to regional level at different scales with vast applicability in the field and other fields of geosciences Arulbalaji et al. [7]. The availability of free satellite images, advancements in digital image processing and lineament extraction technique have made satellite data the most important data sources for the extraction of lineaments Chaaboni et al. [13]; Rajaveni et al. [14]. The Mirlinga Volcanic zone displays a unique geologic, geomorphic and structural characteristic. Although lineament analysis has long been applied in structural and tectonic studies, there is yet no documented study involving the application of remote sensing and GIS technologies in analyzing the lineaments of the Mirlinga Volcanic Zone despite the complex nature of the terrain and the benefits that could be derived from it. The spatial analysis of lineament in the area using a synthesis of field and satellite data provides a pool of information with vast applicability that would provide us the opportunity of understanding the tectonic evolution of the area. Also the generated data could be utilized in assessing the hydrology, volcanic structures, tectonics and mineral prospects of the area.

1.1 The Study Area

The Miringa Volcanic Zone is part of the Biu Plateau located to the northwestern part of the plateau covering an area of about 613.42 km² (Fig. 1). The presence of pyroclastic material and different rock compositions in the area as compared to other parts of the Biu plateau region make researchers such as Turner [15] and Islam [16] to demarcate the area and name it the Miringa Volcanic Zone. The various forms of volcanic structures in the area indicate variations in viscosity of the basaltic lavas as well as differences in time, places and mode of extrusion Mohammed et al. [3,4]. This presents a different and unique geologic and geomorphic
characteristics from the larger Biu Plateau region hence its treatment as a different entity.

1.2 Geologic Setting

The Biu plateau is a highland area in northeastern Nigeria covering an area of about 2635.12 km². The plateau lies between the Upper Benue Basin to the south and the Chad Basin to the north. The volcanic plateau is characterized by many spectacular geomorphic features which make the area very unique compared to its surrounding. It is characterized by series of volcanic cones, volcanic lava flow ridges, volcanic scalp slopes, craters, crater lakes and crater rims Abdullahi et al. [17,18]. The plateau is a part of the Tertiary-Recent volcanic province of Nigeria and Cameroon, and like the Adamawa Plateau of Cameroon, it lies away from the Gulf of Guinea Islands, through the Cameroon Mountain and the Bamenda volcanic district towards the Lake Chad. Some researchers considered the Biu Plateau as the end of the North-North West (NNW) branch of the continental sector of the Cameroon volcanic line Tuner 1978; Lee et al. [19]. According to Abdullahi [17,18] over 80 volcanoes have been identified in the area. The basalts in the study area are generally alkaline olivine basalts. They show little variation in mineralogical characters and petrography, which could be attributed to their mode of origin or source materials Mohammed, et al. [3,4].

![Map showing the study area](https://example.com/map.png)

**Fig. 1.** Map showing the study area. Insert are maps of Nigeria and Borno state showing the location of Miringa volcanic zone

*Source: Extracted from Open Street Map (OPS) Data 2019*
1.3 Geomorphic Setting

Generally, the study area has an altitude range of about 300-900 m above sea level. The Digital elevation map of the Miringa volcanic zone (Fig. 2) indicates the lowest value to be 500 m with the highest value being 950 m. A number of volcanic cones rise above the terrain, some appear well preserved while others have their outer slopes developing free face, talus slope and pediment characteristics of the back-wearing process of normal erosion. These have made the study area to have different degrees of elevations. The current landscape according to Mohammed et al, 2017 is essentially the result of differential weathering arising from the action of different erosive agents on a juxta-position of highly varied products of volcanicity over space and time. These products as previously mentioned range from the hardest of lavas to the softest of ashes, through intermediate products of cinders and conglomerates. The most resistant of these products remain as crags while the soft ones are worn away creating a landscape that is rough, craggy and rugged in outline. Abdullahi [17,18] and Mohammed et al. [3,4] stated that the plateau is characterized by series of volcanic cones, volcanic lava flow ridges, volcanic scarp slopes, craters, crater lakes and breached crater rims. Within the plains, there are many low scarps and occasional larger escarpments which mark the end of individual flows. Boulder screes and mud flows are also associated with some flow escarpments. In the west, south and southeast the plateau is bounded by a strongly dissected major terminal escarpment rising through 150-300 m. The boundary in the northeast is less spectacular, and in some places is marked only by a discernible low scarp of 3-6 m in height. The north plains, which extend northeastwards from this low scarp, consist of gently sloping basalt plains with a range of relief which seldom exceeds 3-6 m Abdullahi, [17,18].

2. METHODOLOGY

The data used for this study are geological map of the area, Landsat ETM+ image and shuttle Radar Topographic Mission (SRTM) 12.5 m resolution data of the area downloaded from the United States Geological survey (USGS) website. Field mapping was carried out for the purpose of ground truthing and measurement of some lineament characteristics. The acquired image was digitally enhanced using band-ratio techniques, contrast stretching, directional edge and enhancement filters. The lineament of the study area was extracted from the satellite imagery automatically using the PCI GEOMARTICA version 10 Software. This presents many advantages including its ability to extract the lineament which are not recognized by the human eyes, less time in processing operations when compared to the manual method and the production of uniform approach to different images. The extracted linear features were further screened for non-geomorphic linear features such as roads, fence etcetera. Rockworks version 16 was used in creating the Rossace used in lineament trend analysis and other related statistical variables associated with the lineaments of the study area. Lineament density map of the area was produced using the line density tool in spatial analyst extension of ArcGIS 10.5 software version.

3. RESULTS AND DISCUSSION

Two lineament characteristics were evaluated in this paper; orientation and density analysis.
Lineament distribution can be characterized by a density map Thannoun [20]; Saleem [21]. Lineament density can be expressed in variable ways, in this study; it is applied in calculating the frequency of lineaments per unit area (square meter). It shows the concentration of lineaments over the area. Lineaments analysis of the Miringa Volcanic Zone was carried out and the result indicated that lineaments are meager in the area (Fig. 3). This can be attributed to the nature of geologic materials in the area which is subjected to monolithic tectonic event since eruption (Lar et al. 2013). Bulk of the identified lineaments in the area consists of Joints and lineations which are fractures in rocks without movement along the surfaces. Although most of the joints are secondary rock structures, some are primary formed at the time the lava crystallized. Joint types in the area include columnar and sheet joints which hardly exceed five meters. From the geomorphic point of view, Valleys controlled by faulting and jointing, hill ranges and ridges, displacements and abrupt truncation of rocks are lineaments formed as a result of exogenic processes.

There are about 2036 linear structures in the area with a total length of 30,193.85 m. The maximum length of lineament recorded in the study area is 150 m while the minimum is 3.68 m. Most lineaments in the area are observed to have developed from the weathering of contacts between successive volcanic beds. A greater percentage of the lineaments are concentrated in the southwestern part of the study area with the central and other parts of the area having meager amounts of lineaments. From the lineament density map produced, a marked increase of lineament concentration can be observed in the western and southeastern portions of the study area. These are areas overlaid by the highly dissected plateaus, escarpment slopes and denudation hills as major land forms. The intense actions of fluvial activity in these landforms resulting from differential slope range results to the development of faults. The faults mostly developed along lava flow contacts and when enhanced by other physical and chemical processes results to the formations of some major valleys in the area (Plate 1A&B).

Lineament density of the study area was reclassified into four categories as very low (0 - 0.9), low (0.9 – 1.79), moderate (1.8 - 2.69) and relatively high (2.7 – 3.58) as shown on Fig. 4. It is acknowledged that an area with high lineament density reflects high degree of rock fracturing, shearing, intensive deformation and enhanced permeability. Also these areas are associated with high groundwater yield and minerals especially associated with hydrothermal activities Prahakaran and Raj [22] and Mohammed et al, [23].

Topographic and tectonic structures are oriented in different directions. According to Aldharab et al, 2018 it is possible to combine the various orientations into a single rose diagram with angles ranging from 1-180°. Accordingly, the Rose diagrams are used in analyzing the directional distribution of lineaments based on the distribution of its frequency to the orientation trend. Trend analysis of lineaments of the study area indicates that the major part of the lineaments tend to lie in the North-east to southwest direction (Azimuth 45°E-225°W). A Rose diagram showing the direction of all lineaments in the study area is shown in

Plate 1. A&B Field occurrences of some linear structures in the field
Fig. 3. Lineaments of the Miringa Volcanic zone

Fig. 5. When compared with the direction of major drainages of the study area, most of the lineaments have the same orientation with the major drainage system which also has the same orientation with most of the volcanoes of the area. This clearly revealed that the major tectonic event that occurred during the Neogene was the partial melting of the asthenosphere which resulted in the formation of fissures and dykes. The fissures and dykes have a major trend of northeast-southwest orientation as observed from the formed volcanoes. Further endogenic and exogenic activities exploit these primary tectonic structures in developing the observed topographic expressions.
Fig. 4. Lineament density contour map of the Miringa Volcanic
4. CONCLUSION

As surface manifestation of underground features, lineaments give a clue of the tectonic imprint of an area. Generally the Miringa Volcanic Zone has been found to have few lineaments which clearly revealed that the basalts of the area were extruded through a linear vent. These vent which according to Carter et al. [24] and Turner [15] developed as a result of a local uplift. This view was reinforced by the result of this research whose findings revealed the presence of a major lineament trending in the north-east to south-west direction. Volcanoes and major drainages of the area are also aligned to this direction. The occurrence of lineaments trending in the other directions is manifestations of smaller dykes and vents developed along the central vent. Subsequent lineaments developed as a result of exogenic processes exploiting the primary structures forming linear structures in the form of rills, rivers, valleys, faults and other erosional structures. Also, eroded lava contacts have been found to constitute a larger percentage of micro lineaments in the area.
COMPETING INTERESTS
Authors have declared that no competing interests exist.

REFERENCES
1. Arlegui LE, Soriano MA. Characterizing Lineaments from satellite Images and Field Studies in the Central Ibro Basin, Northeast Spain. International Journal of Remote Sensing; 1998.
2. Hubbard BE, Mark TJ, Thompson AI. Lineament analysis of mineral areas of interest in Afghanistan. Open File Report 2012-1048, United States Geological Survey. 2012;28.
3. Mohammed B, Mustafa H, Osman A, Mohammed M, Abdulaziz A. Analysis of lineaments within the Wajid Group, SW Saudi Arabia, and their Tectonic Significance. Arabian Journal Geosciences. 2017;10(106):1-17 DOI: 10.1007/s12517-017-2860-0
4. Mohammed Y, Daura MM, Abdullahi J, Usman UA. Origin, geomorphology and petrogenesis of the Biu Plateau, Borno State, Northeastern Nigeria: An Overview. Maiduguri Journal of Arts and Social Sciences (MAJAS). 2017;14:143-152.
5. Aldharab SH, Ali AS, Ikbal J, Ghereb AS. Spatial analysis of lineaments and their tectonic significance using Landsat Imagery in Alarasah Area, Southeastern Central Yemen. Journal of Geography, Environment and Earth Science International. 2018;18(2):1-13.
6. Tirēn S. Lineament interpretation short review and methodology. A Research Conducted for the Swedish Radiation Safety Authority. Report No. 2010;2013:33.
7. Arubalaji P, Padmalal D, Sreelash K. GIS and AHP techniques based delineation of groundwater potential zones: A Case Study from Southern Western Chats, India. Scientific Reports. 2019;9:2082. Available: https://doi.org/10.1038/s41598-019-38567-x.
8. Tariq I, Rahiman H, Jarg RP. Analysis of lineaments and their relationship to neogene fracturing. SE Viti Levu, Fiji. GSA Bulletin. 2016;120(11/12):1544–1555. DOI: 10.1130/B26264.
9. Ölgen KM. Determining Lineaments and Geomorphic Features Using Landsat 5-TM Data on the Lower Barkilyan Plain, Western Turkey. Åegean Geographical Journal. 2004;13:47-57.
10. Escamilla-Casaa J, Schulz J. Tectonic interpretation of topographic lineaments in the SEA Coast region of New Hampshire, U.S.A. Geofisca International. 2016;55(1):17-37.
11. Saleem TA. Structural analysis and tectonic evolution of Southwestern Sinai, Egypt. Ph.D. Thesis, Suez Canal University, Suez. Ismailia; 2005.
12. Semere S, Woldai G. Lineament characterization and their tectonic significance using Landsat TM data and field studies in the central highlands of Eritrea. Journal of African Earth Sciences. 2006;46:371–378. DOI:10.1016/j.jafrearsci.2006.06.007
13. Chaaboni R, Bauziz S, Perresson H, Wolfgang J. Lineament analysis of South Jenein Area (South Tunisia) using remote sensing data and geographic information system. The Egyptian Journal Remote Sensing and Space Sciences. 2012;15:197-206.
14. Rajaveni SP, Brindha K, Elango L. Geological and geomorphological controls on groundwater occurrence in a Hard Rock Region. Applied Water Science. 2017;7:1377-1389. DOI 10.1007/s13201-015-0327-6.
15. Islam MR. Petrographic studies of biu plateau Northern Nigeria. Annals of Borno Journal of Geology. 1986;3:215-226.
16. Abdullahi J. Analysis of Volcanic Craters and their Socio-economic Importance on the Biu Plateau, North-eastern Nigeria. Unpublished Ph.D. Thesis, Geography Department.University of Maiduguri. 2015;154.
17. Abdullahi J, Odihi JO, Wannah BB. Analysis of morphology of volcanic craters on the Biu Plateau, Borno State, Nigeria. Journal of Geography, Environment and Earth Science International. 2015;3(1):1-10.
18. Lee DC, Halliday AN, Fitton JG, Poli G. Isotopic variations with distance and time in the volcanic islands of the cameroon line- evidence for a mantle plume origin. Earth and planetary Science Letters. 1994;123(14):119-138.
19. Thannoun GR. Automatic extraction and geospatial analysis of lineaments and their
Tectonic Significance in Some Areas of Northern Iraq Using Remote Sensing Techniques and GIS. International Journal of Enhanced research in Science Technology and Engineering. 2013;2(2):1-11.

21. Saleem AT. Analysis and tectonic implication of DEM-Derived Structural Lineaments, Sinai Peninsula, Egypt. International Journal of Geosciences; 2013.

22. Prabhakaran A, Raj JK. Mapping and analysis of tectonic lineaments of Pachamalai Hills, Tamil Nadu, India Using Geospatial Technology. Geology, Ecology and Landscapes. 2018;2(2):81-103.

23. Mohammed Y, Wulo IB, Abdullahi J, Gazali AK, Lawan AZ. Geomorphometric and terrain characteristics of the Nigerian Section of the Chad Basin (Bornu Basin) Northeastern Nigeria. Journal of Geography and Geology. 2019;11(4):1-12.

24. Carter JD, Barber W, Tait EA, Jones GP. The geology of parts of adamawa, bauchi and borno provinces in Northern Nigeria. Geological Survey of Nigeria. Bulletin. 1963;30:99.

© 2020 Mohammed et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/62377