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ESTIMATION OF LOCAL EARTHQUAKE MAGNITUDE FROM MACROSEISMIC INTENSITY DATA AT IGBOGENE, BAYELSA STATE, NIGERIA.

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Abstract
Nigeria is situated on a stable crust, yet it has experienced several earth tremors from 1933 to 2024. Some of these tremors went unrecorded due to the lack of monitoring seismic stations. Therefore, this study aims to determine the location parameters for the June 10, 20216 earth tremor, which was widely felt in parts of Bayelsa and Rivers States (with attendant damage to infrastructure) but was not recorded by any seismic stations. The method involves the acquisition of Macroseismic Intensity data using structured questionnaires and administered to residents (such as technicians, artisans, farmers, traders, students, health workers, academicians, and other professionals from other sectors) of the affected communities; as well as visual observations to estimate the damage caused by the tremor. The results revealed that the tremor's epicenter was located at Igbogene, a border town between Rivers and Bayelsa States, with intensities III-V on the Modified Mercalli scale, and estimated magnitudes of 3.0-3.6 on the Richter scale. We also established that the significant damage to structures in the affected communities was due to soil amplification, given the relatively small magnitude of the event. This study has addressed the research gap regarding the location and magnitude of an earthquake that seismic stations could not record. The findings are significant as they will be applied in similar situations in the future, thereby improving our understanding of Nigeria's seismicity and seismotectonic context.
Keywords: *Nigeria, seismicity, Igbogene, Earth Tremor, Macroseismic Intensity, Location, Magnitude*

Introduction

Nigeria, located in West Africa, has experienced a number of low to medium magnitude earth tremors between 1933 and 2021 (Kadiri *et al*., 2019). On June 10, 2016, an earth tremor occurred at the boundary between Rivers and Bayelsa states. This tremor caused varying levels of damage to facilities, including buildings and roads. Prior to the June 10, 2016, event, tremors had been observed in other communities within the region covered in this study. The most recent tremors before the June 10 event occurred in 2015 and 2006. The absence of seismic monitoring equipment in the region and the lack of historical earthquake records have posed significant challenges to understanding the seismic activities in the area.

In situations where acquiring information about an earthquake is impossible, collecting seismic intensity data, which is based on the observed impacts of the event on structures and the environment, becomes essential. This was the case during the 2016 earthquake in Igbogene. Thus, the primary source for estimating the magnitude of such seismic disturbances in regions with insufficient instrumental data is the analysis of the macroseismic intensity dataset. Although this intensity data provides valuable insights, estimating local earthquake magnitudes requires the use of well-established attenuation relationships that are specific to the region being studied.

In general, strain failure along faults, especially in regions of high seismicity or with tectonic activities, results in earthquakes (Lay. and Wallace, 1995). Although Nigeria is not seismically active like African countries such as Ethiopia, Malawi, Tazania, Southern Ghana, Algeria, Morrocco, Namibia, South Africa, etc., it became imperative to adopt all available approaches to better understand the pockets of tremors observed in the country, especially between 2009 and 2021 (Kadiri, *et al*., 2019).

According to Nwajide and Reijers (1996), the study area is located within the Niger Delta basin, which is one of the major basins of the Benue Trough. Short (1967) proposed that three depositional cycles occurred in the southern Nigerian sedimentary basins. The first cycle, associated with Albian-Coniacian tectonism, was confined to the Benue Trough. The second phase unfolded during the Campanian period, leading to the formation of the Anambra Basin and Afikpo Syncline. The third phase resulted from the tectonic separation between the first and second cycles, ultimately contributing to the formation of the Niger Delta, as noted by Kogbe (1976).

Hockey and Jonas (1964), and Kogbe (1974) posited that the Campanian sediments began with a short marine transgression followed by regression, which in Southeastern Nigeria deposited the Nkporo Shale and its lateral equivalent Enugu Shale and Owelli Sandstone. The sea hot shallower and Mamu Formation was deposited followed by the continental sequence of Ajali Sandstone. This was followed by a return to marine condition of Nsukka Formation. In a related development, Hazel (1950) and Orajaka (1972) were of the view that Ajali Sandstone has iron occurrence between the two units. They believed that the ironstone was derived from the overlaying ferruginous Nsukka Formation and was further described by Ibe And Adiuku-Brown (2000) as marking the transition between Ajali Formation and the Nsukka Formation.

The estimation of earthquake magnitude is a critical aspect of understanding and preparing for seismic hazards in any region. In Nigeria, the lack of a dense network of seismic stations makes it challenging to accurately locate some earthquakes and determine their magnitudes. One method of addressing this issue is through estimating earthquake magnitude, using information collected through questionnaires. The motivation for this study, therefore, is to implement macroseismic intensity data to estimate the magnitude and other critical parameters of the June 10, 2016, earth tremor that occurred in Bayelsa state.

Seismicity of Nigeria

Nigeria is not typically recognized as a seismically active region on the African continent. Unlike areas such as California or Japan, which are known for their earthquakes, Nigeria has been experiencing an increase in both the frequency and magnitude of earthquakes in recent years. One of the challenges in studying and monitoring earthquakes in Nigeria is the limited network of seismometers available. Consequently, earthquake magnitudes are often estimated using macroseismic intensity data, which reflects the observable effects of an earthquake on the ground and buildings. This method involves gathering reports from witnesses and assessing the damage caused by the earthquake to determine its magnitude. In the Igbogene area, located at the boundary between the river and Bayelsa in Nigeria, there have been reports of earthquakes in the past. However, the absence of a seismometer network in the region makes it challenging to accurately measure the magnitude of these events. Consequently, estimating local earthquake magnitudes from macroseismic intensity data in Igbogene is essential for understanding and preparing for seismic hazards in the area.

Although global seismicity maps (USGS, 2011) generally indicate that the West African region—and Nigeria in particular—has an aseismic nature. However, historical evidence suggests that earthquakes have occurred in some parts of Nigeria (Ambraseys and Adams, 1986; Onuoha, 1988; Ajakaiye *et al*., 1988; Adepelumi, 2009; Kadiri *et al*., 2029). The majority of the tremors reported in Nigeria are historical (Akpan and Yakubu, 2010; Kadiri *et al*., 2011; Eze *et al*., 2011). Many earthquakes that are felt in Nigeria have epicenters located outside of the country (Onuoha, 1988). Based on past events, Nigeria is not earthquake-free, and there is a possibility that the country could experience a devastating earthquake before 2025 (Adepelumi, 2009; Onuoha, 1988).

Historical and recently recorded events have mainly occurred in the south-western and north-central (Ajakaiye *et al*., 1988; Kadiri *et al*., 2011, Fig. 1.12) and north-eastern parts of Nigeria.
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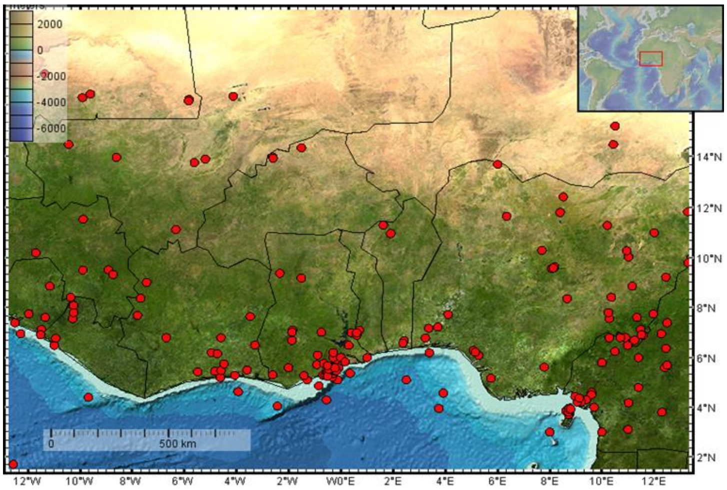

Fig. 1: Seismicity map of West Africa showing recent and historical events in Nigeria

Network of Seismic Stations in Nigeria

Since 2006, when the Nigerian National Network of Seismographic Stations was established and operated by the Centre for Geodesy and Geodynamics (CGG), under the National Space Research and Development Agency (NASRDA), the network has grown from five seismic stations to 14 in 2024. Figure 1.2 shows the current locations of the seismic stations, which include Toro in Bauchi State, Kaduna in Kaduna State, Minna in Niger State, Saki in Oyo State, Ile-Ife in Osun State, Akure in Ondo State, Abuja in the Federal Capital Territory, Awka, Abakaliki, Nsukka in Anambra, Ebonyi and Enugu States respectively.

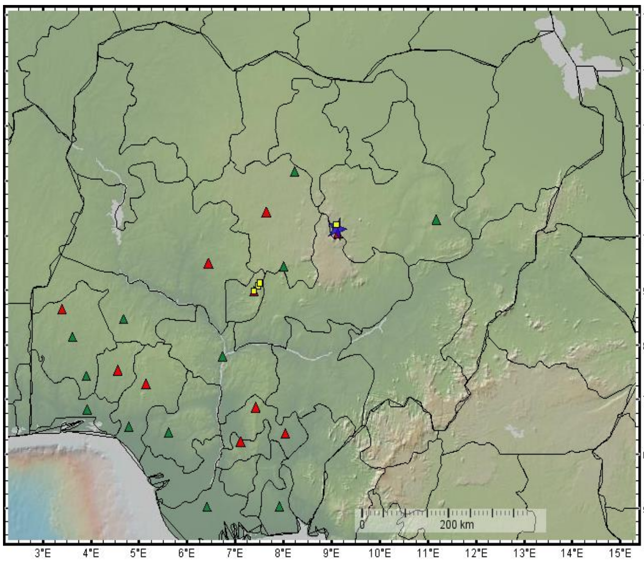

Fig. 1.2: Map of Nigeria showing the locations of operational seismic stations (Red triangles) and blue triangles (Green triangles). The yellow Squares are locations of the Global Positioning Systems antenna.

Figures 1.3-1.6 display various structures located at the Awka and Akure seismic stations. The seismic stations at Nsukka, Awka, and Ile-Ife share similar structures to those found in Awka. In contrast, the stations in Abuja, Saki, and Kaduna have facilities and designs that are comparable to those at Akure.

Fig. 1.3: Seismic station in Awka constructed in 2008 showing building, vault of about 4 meters deep, and platform for the sensor.

Fig. 1.4: Seismic station recently constructed in Akure established in 2024

Guralp Centimus Broadband Sensor were installed in Akure seismic station in 2024

Fig. 1.5: Guralp Centimus Sensor installed in Akure

Fig. 1.6: Some installed facilities at Akure Seismic Station

The seismic network in Nigeria is primarily established to monitor seismic activity and assess seismic hazards. It records local, regional, and distant (teleseismic) earthquakes. Additionally, this network serves as a foundation for data exchange, research, and collaboration. It is also a crucial component of Nigeria's comprehensive National Geohazard monitoring scheme.

Regional Geologic Setting

The geological setting of South-Eastern and parts of South-South Nigeria is characterized by various regional studies conducted in the past. These studies primarily examined the geology and stratigraphy of the Southern Nigeria, driven by the exploration for oil, coal, and mineral resources. Initial geological investigations took place between 1903 and 1913 under the supervision of the mineral survey of southern Nigeria, which was directed by the Imperial Institute. The southern part of Nigeria features outcrops of the eastern Eocene rocks, specifically classified as the Ameki Group. This group includes the Ameki Formation, Nanka sands, and the Nsugbe Sandstone. Several authors, such as Tattam (1944), Simpson (1955), Reyment (1969), Adegoke (1969), and Nwajide (1979), have provided descriptions of the Formation within the study area. Regional correlation indicates that the Paleocene succession extends southward into the oil-rich Niger Delta, where the Imo Formation and Ameki Formation are equivalent to the hydrocarbon-generating Akata Formation and the reservoir lithofacies of the Agbada Formation and Benin Formation, respectively. Additionally, it has been noted by Short and Stauble (1967), Avbovbo (1978), and Nwajide (1979) that the Nanka sandstone is laterally equivalent to the Ameki Formation. The geological characteristics of southern Nigeria have been extensively documented by Reyment (1965), Simpson (1954), and Murat (1972). The region is dominated by CretaceousTertiary sediments, which constitute the lower Benue Trough, Anambra Basin, and the Tertiary Niger Delta Basin. The region encompassing Igbogene, situated on the boundary between Rivers and Bayelsa states, exhibits a complex tectonic setting. Nigeria lies within the West African Rift System, a zone of active tectonic deformation that extends from the Gulf of Guinea to the Red Sea. The rift system is characterized by extensional tectonics, resulting in the formation of normal faults and grabens. The geology of the area primarily comprises sedimentary rocks, including sandstones, shales, and siltstones, which are part of the Niger Delta Basin. The Niger Delta Basin is a prolific hydrocarbon province, formed by sediment deposition from the Niger River and its tributaries. The basin is influenced by the Atlantic Ocean, as well as the tectonic forces associated with the West African Rift System. The region's geological structure and composition play a crucial role in the attenuation of ground motion during earthquakes. Understanding the regional geology is essential in developing accurate attenuation relationships between seismic intensity and earthquake magnitude. By analyzing the geological characteristics and previous studies conducted in similar regions, we can estimate local earthquake magnitudes at Igbogene based on macro seismic intensity data.

The evolutionary basins of southern Nigeria are believed to have originated from three major tectonic phases. These sedimentary basins have also been influenced by transgression and regression of ancient sea water. The first tectonic phase of the Albian age gave rise to Benue Trough with northeast-trending faults. This is discovered in the Benin Flank, in the west and east of the Calabar Flank by a Northwest and Southeast trending fault.

The second tectonic phase commenced in the Santonian, resulting in folding, faulting, and uplifting of the Albian sediments of Benue Trough. The Albian shale was referred to as the Asu River Group. The Anambra basin was then formed and filled in two sedimentary phases or events (Figure 1.7). The third phase of tectonism began in the late Eocene and was recognized in the Northeastern and Eastern parts of the basin. The structures associated with this phase were uncertain. The phase also led to the formation of the Niger Delta, Kogbe (1976).

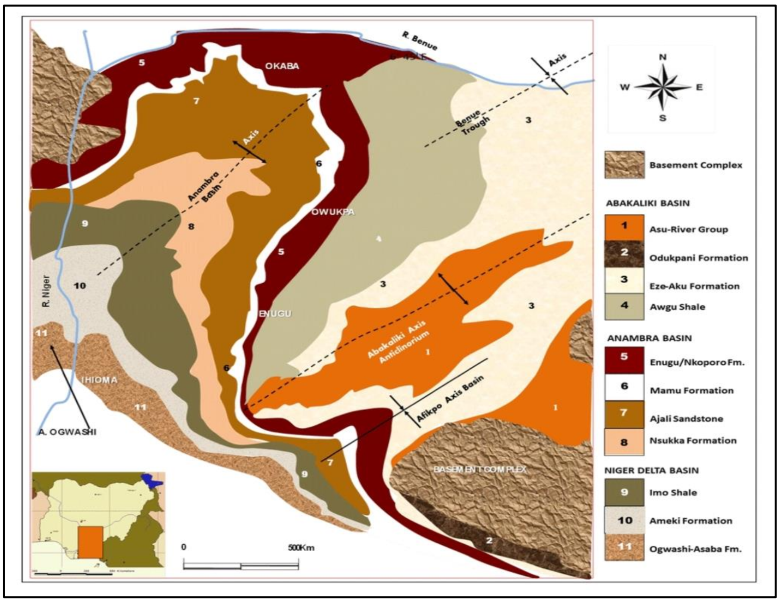

Fig. 1.7: Map of Southeastern Nigeria Sedimentary Basins Showing Surface Geologic Formations in Abakaliki Basin, Anambra Basin and Up-Dip Niger Delta Basin (After Akande et al. 2007; Dim et al. 2017).

A hiatus occurred between the Santonian and the mid Campanian, after which there was a transgression which occurred during the Campanian-Maastrichtian, which gave rise to the deposition of the Nkporo Shale (Lateral equivalent of the Enugu Shale) and is overlain by Mamu Formation, the Ajali Sandstone and Nsukka Formation. Imo shale (Paleocene) overlies the Nsukka Formation (Nwajide, 1990). It comprises clayey shale with occasional ironstone and thin sandstone in which carbonized plant remains may occur (Kogbe, 1989). The Ajali Sandstone and the Nsukka Formation, two lithostratigraphic units found in the study are were called the false-bedded sandstone and the upper coal measure, respectively.

Local Geological Setting of the Study Area

From the field observation, the lithostratigraphy units found in the area belong to Ajali Sandstone (Upper Maastrichtian) and the Nsukka Formation (Upper Maastrichtian to Danian). The Ajali Sandstone consists of white but sometimes iron-stained, friable, and medium to coarse-grained, cross-bedded, highly porous, and permeable aquiferous units. The Nsukka Formation is younger than the Ajali Sandstone and therefore lies conformably above it. The lithostratigraphic units are described based on field studies of outcrops. The sand of Nsukka Formation is highly ferruginized which is described by Ibe and Adiuku-Brown (2000) as marking the transition between Ajali Formation and the Nsukka Formation.

Nanka Sand

The Nanka Formation underlies the eastern part of the study area. It consists of a series of sand shale intercalations and highly fossiliferous greyish-green sandy clay with white clays (Reyment, 1965). Nanka sand is found in Okpuno-Awka, Amanuke and Urum. It has a similar texture and whitish colour to Ajali Sand. The most complex of erosion sites are underlain by poorly consolidated Nanka Sand. Nanka Sands forms hills filing and concave-shaped sand depressions in Imo shale. It is a regressive, shallow marine deposit influenced by the late Eocene tectonic episode of positive movement. Since Nanka Sand is underlain by aquitard shale, the major underground water reservoirs are found within it. The dry bulk density of Nanka Sand is the highest of all the geological formations and is significantly different from coastal sand and Ajali sand. It is not significantly different from Nanka Sand. The dry bulk density increases with depth.

Tectonic Evolution

Generally, the evolutionary basins of Southern Nigeria are believed to have originated from three major tectonic phases. These sedimentary basins have also been influenced by transgression and regression of ancient sea waters. The first tectonic phase of the Albian age gave rise to the Benue Trough with a northeast-trending fault. This is discovered in the Benin Flank, in the west and east of the Calabar Flank by Northwest and Southeast trending faults. The second tectonic phase commenced in the Santonian, resulting in the folding, faulting, and uplifting of the Albian sediments of the Benue Trough. These Albian Shales were referred to as the Asu River Group. The Anambra Basin was then formed and filled in two sedimentary phases or events.

The third phase of tectonism began in the late Eocene and was recognized in the North eastern and Eastern parts of the basin. The structures associated with this phase were uncertain. The phase also led to the formation of the Niger Delta, Kogbe (1976).

The Benue Trough was filled by the Conician time. The structural inversion of the trough led to the subsidence of the Anambra Basin and Afikpo Synclines on the west and Southeast respectively. These basins received sediments from the Campanian to the Palaeocene.
Benkhelil (1989) proposed a model in which transcurrent movements were considered to be the basic tectonic mechanism in the formation and subsequent evolution of the Benue Trough. This is the RRF model in which he noted the presence of the three Atlantic transform faults striking the Benue Trough, suggesting that the trough is a complex pull-apart basin formed by the transcurrent movement along these faults. The RRF model is consistent with alkaline magmatism in the trough and gives a good explanation for the Santonian compressive phase (Benkhelil and Robineau, 1983).

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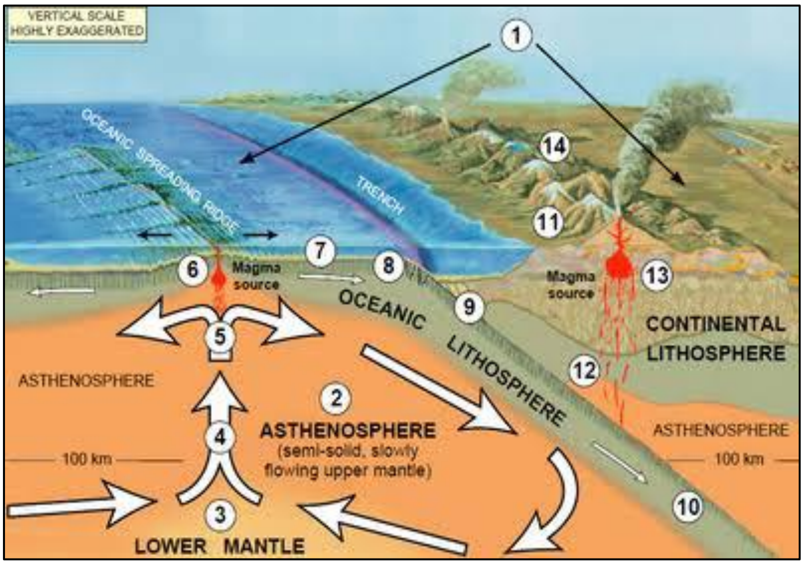


Fig. 1.8: Formation of Tectonics (Modified Image) Courtesy: https://www.researchgate.net

Stratigraphic settings of Niger Delta Basin

The stratigraphic sequence of the Niger Delta comprises three broad lithostratigraphic units namely;

(1) A continental shallow massive sand sequence – the Benin Formation

(2) A coastal marine sequence of alternating sands and shales – the Agbada Formation

(3) A basal marine shale unit- the Akata Formation (Obaje, 2009). The Akata Formation consists of clays and shales with minor sand intercalations. The sediments were deposited in prodelta environments. The sand percentage here is generally less than 30%.

The Agbada Formation consists of alternating sand and shales representing sediments of the transitional environment comprising the lower delta plain (mangrove swamps, floodplain, and marsh) and the coastal barrier and fluviomarine realms. The sand percentage within the Agbada Formation varies from 30 to 70%, which results from the large number of depositional offlap cycles. A complete cycle generally consists of thin fossiliferous transgressive marine sand, followed by an offlap sequence which commences with marine shale and continues with laminated fluviomarine sediments, followed by barriers and/or fluviatile sediments terminated by another transgression (Weber, 1972; Ejedawe, 1989).

The Benin Formation is characterized by high sand percentage (70–100%) and forms the top layer of the Niger Delta depositional sequence. The massive sands were deposited in a continental environment comprising the fluvial realms (braided and meandering systems) of the upper delta plain (Figure 1.9).

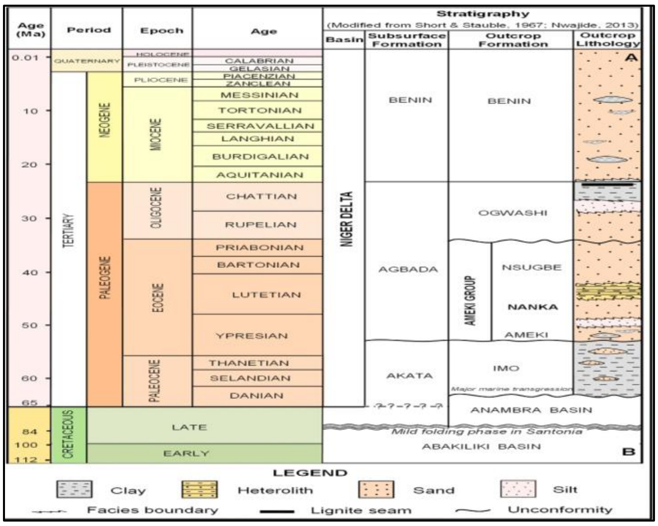


Fig 1.9: Modified Chronostratigraphic succession of the Cenozoic Niger Delta Basin outcropping in Southeastern Nigeria overlying the upper Cretacious Anambra Basin. Courtesy: ***https://www.researchgate.net***

Topography, Drainage, Vegetation, and Climate of the Study Area

Igbogene is a town located in the boundary between Rivers and Bayelsa State, Nigeria. The town's geographical coordinates are 5° 1' 54" North and 6° 24' 1" East. The elevation of Umuchukwu Community is not explicitly mentioned in the search results, but the village is situated near Ikarama, Ikibiri, Ikolo, and Jackbiri. Figures 1.10 and 1.11 show the topography and drainage maps of Igbogene area.

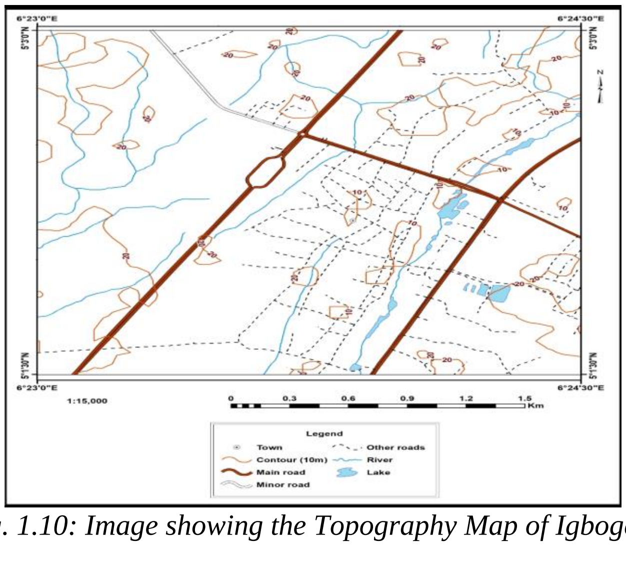


Fig. 1.10: Image showing the Topography Map of Igbogene

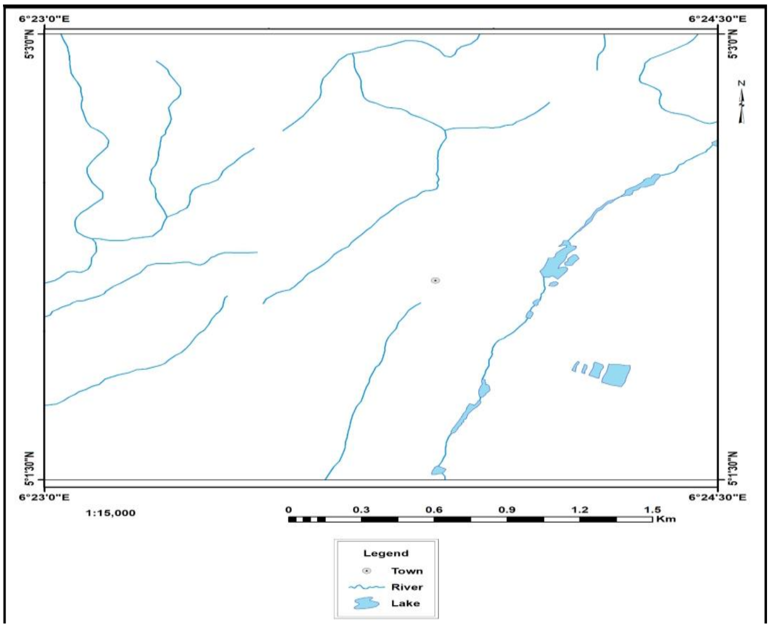


Fig. 1.11: Drainage Map of Igbogene

The vegetation of Igbogene (Figure 1.12) is a mix of rainforest and savanna, reflecting the transition between these two ecological zones. The area is characterized by rolling hills, streams, and rivers, which provide a diversity of habitats for a variety of plant species. In areas with higher rainfall and more fertile soils, the vegetation is dominated by rainforest species. These include tall trees such as iroko (Milicia excelsa), teak (Tectona grandis), and mahogany (Khaya senegalensis). These trees provide canopy cover, shelter for wildlife, and timber for construction.

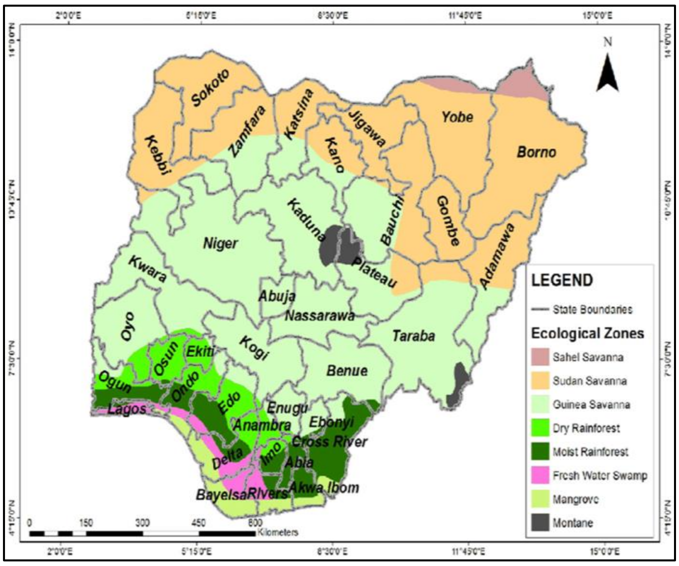


Fig 1.12: Map of Nigeria showing natural vegetation (Google image, 2013)

Igbogene Community experiences a tropical wet and dry climate. The average annual rainfall is around 1,400mm, with most of the rain falling between April and October. The dry season is from November to March, and temperatures are generally higher during this time.

The map (Figure 1.13) shows that Umuchukwu Community has a humid subtropical climate with hot and humid summers and mild winters. The average temperature in the summer is around 29°C, and the average temperature in the winter is around 24°C. Rainfall is abundant, and most of it falls during the summer months.

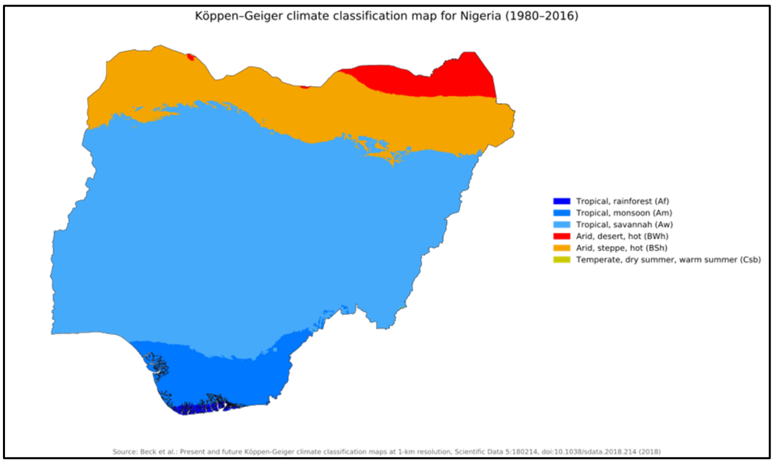


Fig 1.13: Climatic belts of Nigeria (modified by Rudolf Geiger, 1981)

Methodology

Location and Accessibility of the study area

Igbogene is a town located on the boundary between Rivers and Bayelsa States in Nigeria. It is situated near the towns of Ikarama, Ikibiri, Ikolo, and Jackbiri (Figure 1.13). The geographical coordinates of Igbogene are 5° 1' 54" North and 6° 24' 1" East. The Igbogene community is approximately 47.4 kilometers (27.8 miles) from Yenagoa, the capital of Bayelsa State.

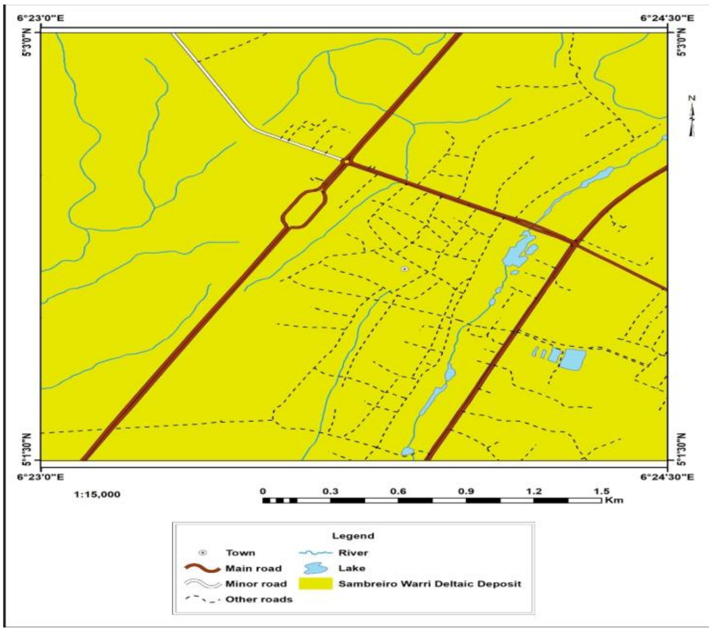


Fig. 1.13: Image Showing the Location Map of Igbogene

Igbogene is accessible by road in major cities in Nigeria. The most direct route Via Near major road to Igbogene is 2hours.2minutes (107.1km) (Figure 1.14).

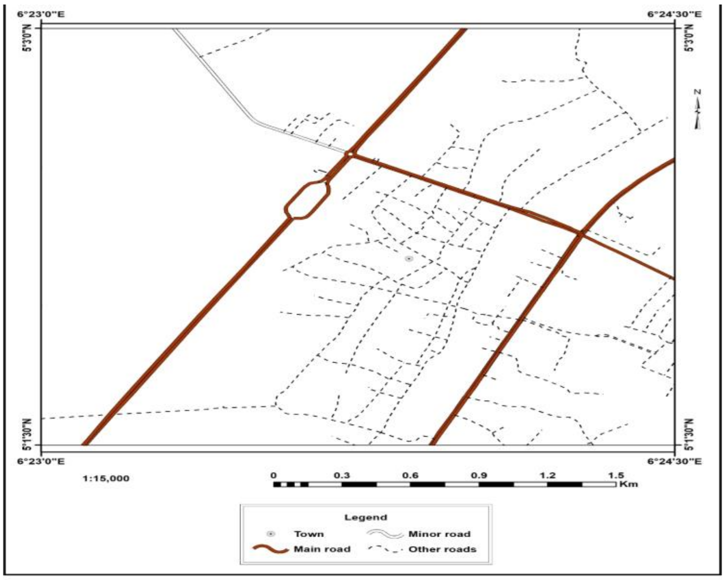


Fig. 1.14: Image Showing the Accessibility Map of Igbogene

Data and Materials

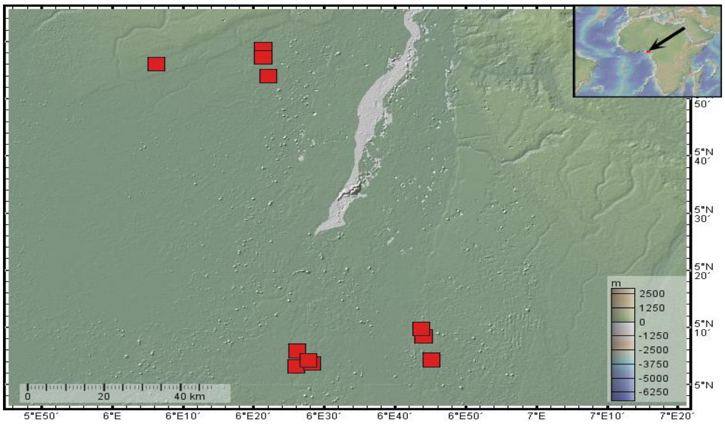
Two methods were employed to collect data: fieldwork and structured questionnaires. We created the questionnaires with structured questions, which were then distributed to a diverse group of residents in the communities, including civil servants, military personnel, laborers, market vendors, schoolchildren, farmers, professionals in the building and construction industry (such as bankers and lawyers), artisans, and elderly men and women. The design of the questionnaires enabled us to verify, validate, and assess earlier press releases and findings about the earth tremor.

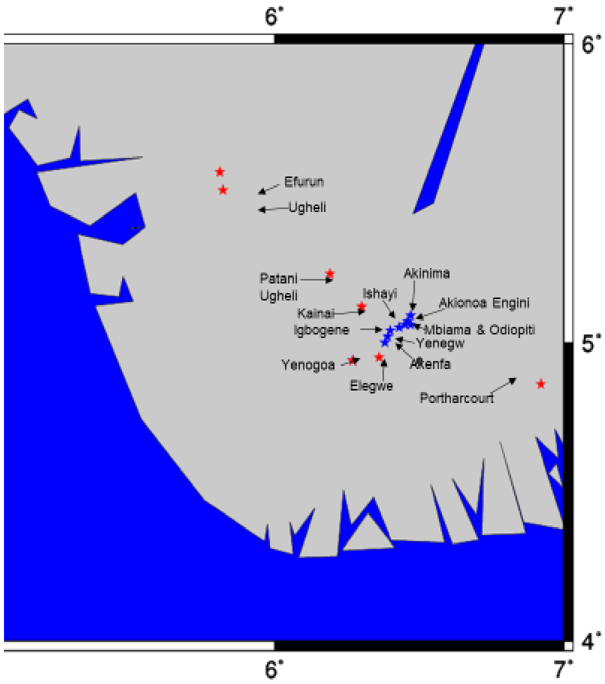
The structured questionnaires included questions about several aspects related to the vibrations or sounds experienced. These questions covered the following:

- How long ago did the vibration or sound occur?
- How intense was the event?
- How did people and buildings respond to it?
- Were there any reports of fatalities resulting from the tremor?
- How frequently do similar vibrations occur in the area?
- When was the last recorded incident of this type?
- Are there any mining or exploration companies nearby that use explosives for oil and gas prospecting?
- Was there a possibility of sabotage at nearby oil and gas facilities at the time the vibrations were felt?
- Was there any physical damage to buildings, roads, bridges, etc.?
- Additionally, there were other relevant inquiries.

The second stage of the methodology entailed physically visiting every community impacted by the earthquake, accompanied by a few locals in the communities affected by the tremors, in order to obtain firsthand information, compile data and supporting documentation, and evaluate the extent of damage to roads, buildings, and other vital infrastructure (Fig. 1.15). Photographs were taken during this phase; some of these can be found for reference in the report's Appendix section.

A





B

Figs. 1.15 (A & B): Maps showing areas investigated (Red Squares) in line with table 1.

Results and Discussion

The feedbacks from the structured questionnaires administered to different residents of the communities where the tremors were felt are summarized as thus:

1. A loud sound was heard before the shaking in a few communities covered
2. The severe vibrations were felt twice, at a few-second interval
3. Heavy ground vibrations were felt in most of the communities covered
4. People were visibly frightened and experienced palpable fear
5. Vibrations were felt by both people indoors and those outside their houses
6. Serious cracks on the walls of buildings, even newly constructed ones
7. Objects were moved, some rotated around 360 degrees
8. People ran out of their houses
9. Windows and louvers were rattled in a few cases,
10. The vibrations were felt in the entire community

The Modified Mercalli Scale was utilized to determine the macroseismic intensity of the tremor based on the feedback obtained from the questionnaires. On the Richter scale, the corresponding local magnitude for the intensity was calculated to be between 3.0 and 3.6. Table 1 showed the locations of the sound, the vibrations experienced, and the building damage. Table 1 also indicated that the Igbogene community in Bayelsa suffered the greatest damages (>50) to structures as a result of the earthquake. In Bayelsa State, Yenegwe (>30) is the second area most severely affected. Building damage in Rivers State was highest in Ishaiyi (>20) and lowest in Odiopiti (5).

Table 1: Community covered during the field investigations

S/N	Place	LGA, State		Latitude and Longitude		Impact of vibration	No. of buildings affected	No. of deaths
		State	LGA	Lat (°N)	Long. (°E)			
1	Igbogene	Bayelsa	Yenagoa	5 02.377	6 24. 049	Strongly felt, loud sound	> 63	No
2	Yenegwe	Bayelsa	Yenagoa	5 08.99	6 23.655	Strongly felt	>35	No
3	Akenfa (I-III)	Bayelsa	Yenagoa	4 53. 962	6 22.059	Less felt; loud sound	25	0
4	Agudama	Bayelsa	Yenagoa	4 58.788	3 22.203	Not felt	No damage	0
5	Etegwe	Bayelsa	Yenagoa	4 57.233	6 21.333	Not felt	No damage	0
6	Opolo	Bayelsa	Yenagoa	4 57.129	6 20.537	Not felt	No damage	0
7	Biobolo	Bayelsa	Yenagoa	4 56.923	6 19.717	Not felt	No damage	0
8	Amarata	Bayelsa	Yenagoa	4 56.058	6 17.135	Not felt	No damage	0
9	Yenagoa	Bayelsa	Yenagoa	4 56.123	6 06.320	Not felt	No damage	0
10	Ishiayi	Rivers	Ahoada West	5 3.236	6 26.024	Strongly felt, loud sound	>20	0
11	Mbiama	Rivers	Ahoada West	5 05.851	6 26.234	Strongly felt	>10	0
12	Odiopiti	Rivers	Ahoada West	5 3.703	6 28.229	Strongly felt	>17	0
13	One man Country	Rivers	Ahoada West	5 4.224	6 27.736	Felt, no sound	No damage	0
14	Akinima	Rivers	Ahoada West	5 5.210	6 25.080	Strongly and Widely felt, sound	5	0

Summary of Major Findings

The estimation of local earthquake magnitude from macroseismic intensity data in Igbogene, Bayelsa State, Nigeria, involves several key findings:

1. Macroseismic intensity data collected in Igbogene were used to estimate the magnitude of earth tremors with minimal error.
2. It was not clear whether the earth tremor at Igbogene was caused by a natural source or as a result of anthropogenic (human activities).
3. Although the magnitude of the Earth tremor was small, the damage to structures as shown in the appendix was as a result of soil amplification since Igbogene is located on a sedimentary basin.
4. Some buildings affected by the earth tremor were constructed with substandard building materials.
5. The intensity, which is a measurement of the visible damage, was easily estimated using microseismic data collected in the field.
6. The fact that Nigerian seismic stations were unable to record the event indicated that the local magnitude of the earth tremor was not as big as anticipated, going by the observed damage to structures in the affected communities along the borders between

Rivers and Bayelsa States, with the highest damage concentration established at Igbogene.

Conclusion

There was significant media coverage of the earth tremor that occurred on June 10, 2016, which had its epicenter located near the border between Bayelsa and Rivers States. The effects of this earth tremor were widely felt in the affected communities within both Bayelsa and Rivers States.

Since no operational seismic stations in Nigeria recorded the earth tremor due to the distances from the stations' locations to the suspected epicenter of the event, the macroseismic intensity survey was adopted to estimate the earth tremor's location. The results of the investigation indicated an intensity of V on the Modified Mercalli scale and a magnitude of 3.0 to 3.6 on the Richter scale for the earth tremor. Based on the verified data regarding the earth tremor that affected the communities (see Table 1), it is crucial to implement workable solutions immediately. These solutions should include seismotectonic studies of the Niger Delta region and its surrounding areas, as well as microzonation and vulnerability assessments. Additionally, the effective densification of seismic stations with short-period sensors for robust microseismic monitoring is essential to achieve the desired outcomes. If these measures are carried out with caution and expertise, they will significantly contribute to disaster mitigation and future planning in the area.

The estimation of local earthquake magnitude from macroseismic intensity data represents a critical step in understanding seismic activity, especially in regions like Igbogene, Bayelsa State, where seismic events may not be well-documented. This research successfully leveraged macroseismic intensity data for estimating the location and magnitudes of a local earth tremor at Igbogene. By correlating macroseismic intensity reports with known seismic events, the study has demonstrated how qualitative observations can be quantitatively transformed into reliable estimates of magnitude, contributing to both scientific knowledge and community preparedness.

The findings indicate that local characteristics, such as geological features, soil composition, and building structures, etc., significantly influenced the vibrations experienced during the event. Consequently, the methodology developed in this study, which incorporates local data and context-specific adjustments, provides a more accurate tool for magnitude estimation than conventional models, which often rely solely on generalized intensity equations.
finally, the project not only contributes to academic knowledge but also serves as a vital resource for practical applications in disaster risk reduction in Igbogene, Bayelsa State. By implementing these recommendations, stakeholders can significantly enhance seismic resilience and contribute to community safety.

Challenges Encountered and Recommendations

Some of the challenges encountered during this study are:

1. **Data Availability**: Acquiring the macroseismic intensity data needed for the study was challenging due to the high costs and difficult terrain in the area.
2. **Distance:** The location was quite far from the researchers' base; therefore, it presented a significant challenge.
3. **Climate:** The few times it rained, it was difficult to assess the location because of the soil texture of the environment.

The following short and medium-term recommendations are advanced for implementation:

1. Comprehensive seismotectonic research is essential throughout the Niger Delta region.
2. Site effect study is crucial in the impacted areas to determine the degree of soil amplification and the susceptibility of structures.
3. It is crucial to create a centralized database for collecting and managing macroseismic intensity reports. This repository should facilitate easy access for researchers and professionals conducting further studies on seismic activities in Igbogene and Bayelsa State in general.
4. Local communities should be educated about the significance of observing and reporting seismic events. Workshops could be organized to train residents on how to assess and document earthquake effects, ensuring that future data collection will be thorough and inclusive.
5. The installation of seismic sensors and monitoring equipment would enhance the capacity for real-time earthquake detection. Collaborations with national geological institutes or universities could help establish such monitoring networks, thereby providing live data that complements intensity observations.
6. The study suggests ongoing research to refine intensity-magnitude relationships, particularly by integrating real-time data collection from local communities. This approach would enhance the robustness of future magnitude estimations. Subsequent studies should focus on refining the estimation models through advanced statistical and machine-learning methods. This will allow for the incorporation of larger datasets, ultimately improving precision and reliability.
7. The outcomes of this study should be integrated into regional disaster preparedness programs. Local government and disaster management agencies can use the findings to essentially inform and develop public education campaigns, early warning systems, and effective emergency response protocols tailored to the specifics of Igbogene.
8. Collaboration between local researchers, governmental bodies, and international seismological institutions can enhance Igbogene's capacity to understand and respond to earthquakes in the future. Sharing insights and resources can aid in devising more holistic approaches to seismic risk management.

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Appendix

Figure A1. Buiding showing cracked wall at Igbogene, Bayelsa State

Figure A2. Building showing caved-in ceiling in one of the communities

Figure A3. Building showing a cracked wall at Ishiayi, Rivers State

Figure A4. Building showing a cracked wall at Yenegwe, Bayelsa State

Figure A5. Building almost collapsing at Ishiayi, Rivers State