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Full Length Research Paper

Towards an integrated seismic hazard monitoring in Nigeria using geophysical and geodetic techniques

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Nigeria is not situated where major seismic activities are observed in the world; but the country has experienced pockets of tremors comprising of magnitudes ranging from 4.3 to 4.5. The vibrations of the September 11, 2009 event with magnitude 4.4 and epicenter at Allada, Benin Republic, 128 km west of Lagos, Nigeria, was felt in parts of Ibadan and Ogun State, South-western Nigeria. In the same vein, an earthquake with body wave magnitude of 4.4 had occurred in Nigeria in 2000 and was recorded by some agencies like the International Seismological Centre (ISC). Most of the previous events occurred in South-western Nigeria where a major fault (the Ifewara-Zungeru fault), is believed to exist. Despite these events, effective monitoring for early warning is non-existent in Nigeria. With the obvious knowledge of earth's dynamism, the need to adopt proactive measures on seismic hazard monitoring is being seriously pursued with the help of seismological and geodetic equipment. This paper examines prospects of integrated seismic hazards monitoring in Nigeria.

Key words: Earthquakes, Ifewara-Zungeru fault, geophysical and space-based equipment, Nigerian National Network of Seismological Stations, integrated monitoring scheme.

INTRODUCTION

A hazard is a phenomenon or process, either natural or man-made that can endanger a group of people, their belongings and environment (Wikipedia, The Free encyclopedia, en.wikipedia.org/wiki/Hazard). Natural disasters, whether of meteorological origin such as cyclones, floods, tornadoes and droughts or of geological nature such as earthquakes, volcanoes, landslides and subsidence, are well known for their devastating impact on human life, economy and environment. With tropical climate and unstable land forms, coupled with high population density, poverty, illiteracy and lack of well-developed infrastructure, developing countries are more vulnerable to suffer from the damaging potential of such disasters. Though, it is almost impossible to completely neutralize the damage due to these disasters, it is possible to minimize the potential risks by developing disaster early warning strategies and prepare developmental plans to provide resilience to such disasters. Most hazards are dormant or potential with only a theoretical risk or harm. Seismic hazard which is the focus of this paper is a natural hazard. Earthquakes, for instance, are a phenomenon that defies human understanding. However, with advanced technologies today, it is almost possible to predict earthquake ground motion with proper understanding of seismic sources and properties of seismic waves. Although it is impossible to curb sub-surface tectonic activities, people in places prone to such disasters are now better prepared for any possible occurrences. Historical records indicate that some communities in Nigeria have experienced earthquakes in the past (Onuoha K. M. University of Nigeria, Nsukka, personal communications; Akpan and Yakubu, 2010; Figure 1 and Table 3), despite the fact that Nigeria lies far

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Abbreviations: ISC, International seismological centre; **GPS,** global positioning system; **NNNSS,** Nigerian national network of seismological stations; **NASENI,** national agency for science and engineering infrastructure; **OSGOF,** office of the surveyor general of the federation; **CORS,** continuously operating reference stations; **ITRF,** international terrestrial reference frame; **CGG,** centre for geodesy and geodynamics; **NARSDA,** national space research and development agency.

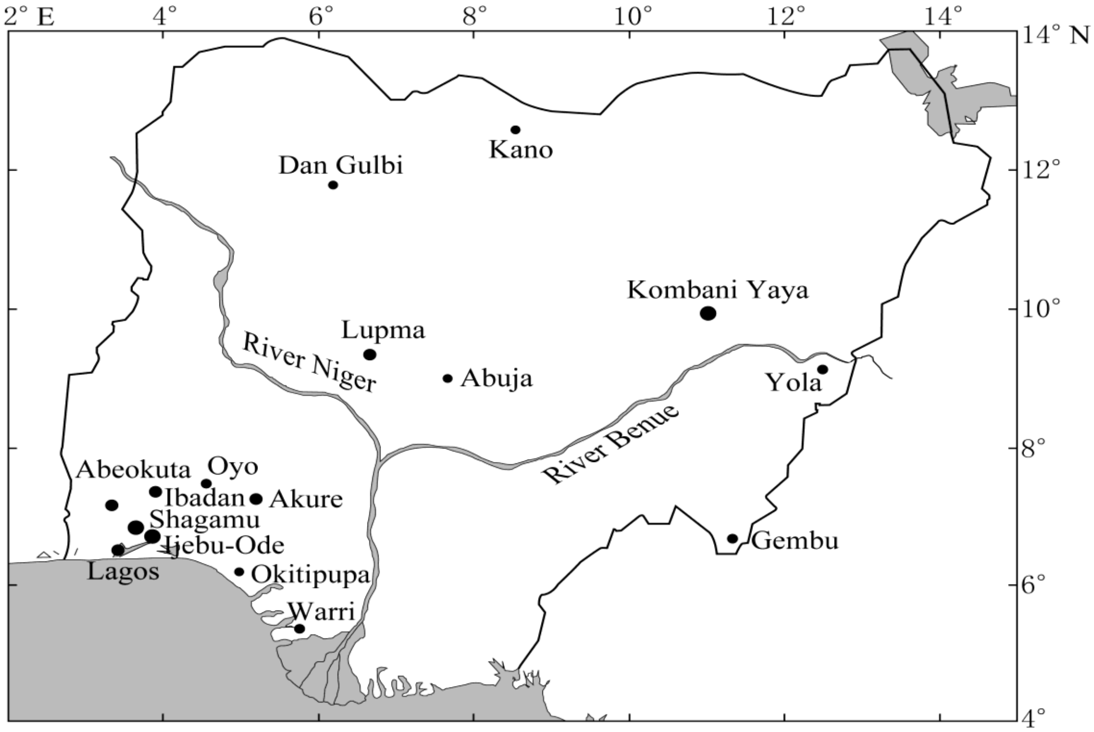

Figure 1. Map of Nigeria showing the areas where some earth tremors were felt (diameter of the solid dot denotes intensity of the events, after Akpan and Yakubu, 2010), not drawn to scale.

from the world's active plate boundaries. Most of the events that occurred in Nigeria were not instrumentally recorded because there was no such equipment in the country at that time.

Unlike the East African region, West African was not known to be seismogenic in the past and because of this, most people tend to believe that seismic activities are confined to North Africa and the surrounding areas of the rift valley system in East Africa (Onuoha, 1988). But recent findings have shown that Nigeria may not be completely free from earthquakes (Adepelumi, 2009; Akpan and Yakubu, 2010). Since tremors were recorded in Nigeria in the past, any future occurrences of Earth tremors in the country are likely going to occur along these fault zones (Figure 2). Possible mechanisms for these intra-plate tremors have been examined to include regional stresses created by Nigeria's position between two cratons and zone of weakness resulting from magmatic intrusions and other tectonic activities in the sediments (Eze et al., 2011). Historical and recent seismicity data do indicate that disastrous earthquakes have occurred in other parts of Africa far away from the Atlas Mountain region and also in the areas far from the rift valley system (Onuoha, 1988). This development indicates that Nigeria and indeed some West African countries are likely to witness devastating earthquakes in future. This is in line with recent review of earthquake occurrences and observations in Nigeria which shows several minor tremors had been experienced in some parts of the country in 1933, 1939, 1964, 1984, 1990, 1994, 1997, 2000 and 2006 (Akpan and Yakubu, 2010) (Table 3). The intensities of these events ranged from III to VI based on the modified Mercalli Intensity Scale. Of these events, only the 1984, 1990, 1994 and 2000 events were instrumentally recorded. They had magnitudes ranging from 4.3 to 4.5 (Akpan and Yakubu, 2010). Just recently at 03:10 GMT on September 11, 2009, an earth tremor occurred in Allada, Benin Republic. This earthquake was felt in some parts of South-western Nigeria (Akpan and Yakubu, 2010).

This event further re-awakened the imperative of seismic hazard monitoring for early warning should there be an impending major earthquake in the future as predicted by (Adepelumi, 2009), who employed the Empirical Earthquake Recurrence Model (a time-dependent model) to predict the probabilistic occurrences of earthquakes in the south-western town of Ijebu-Ode and environs between the year 2008 and 2028. The time interval for the occurrence of the next large earthquake in Ijebu-Ode area using the maximum of the conditional probability of earthquake occurrence was determined using the Weibull probability density model. The results obtained by (Adepelumi, 2009) provide useful information regarding earthquake potential and seismicity of the study area, to the effect that most possibly, a large earthquake of magnitude $M \geq 5$ may occur in the next 30 years in Nigeria counting from 2008 or before 2038. The event occurrence tends to be very high in the next 15 to 20

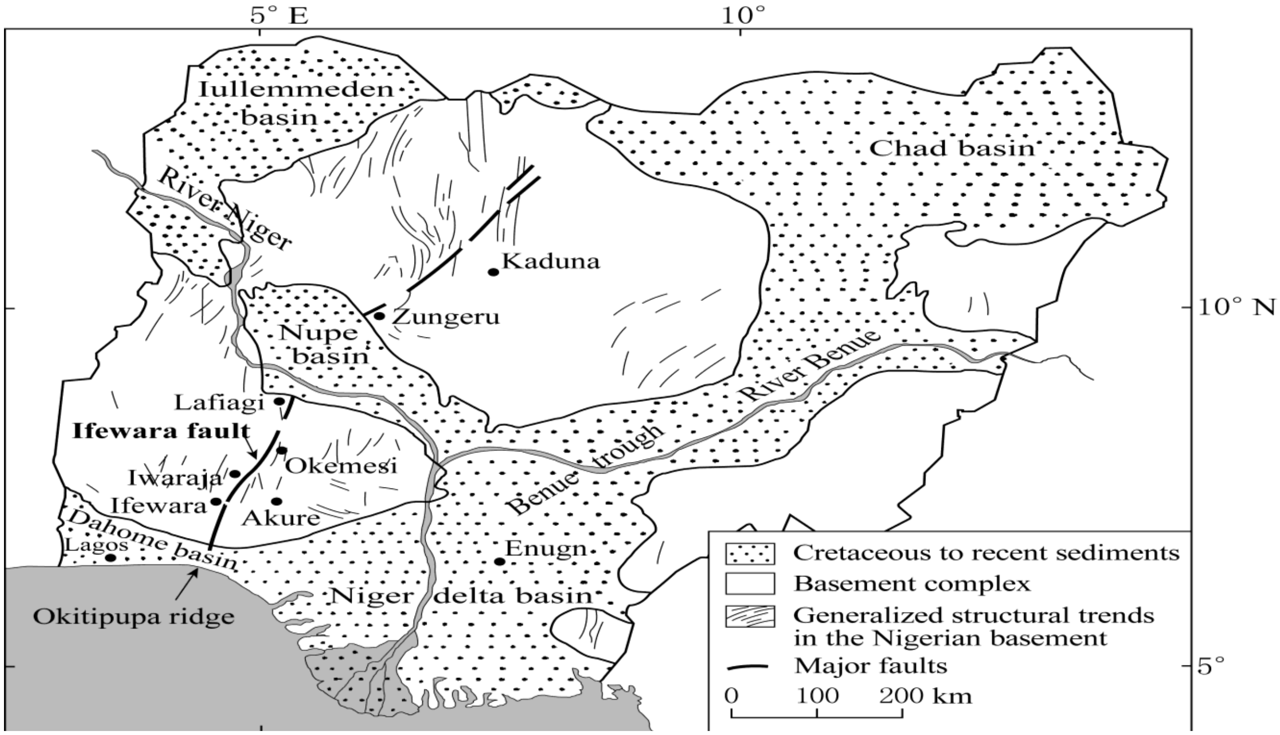

Figure 2. Map of Nigeria showing the Zungeru-Ifewara fault (Odeyemi, 2006; Akpan and Yakubu, 2010).

years in this Ijebu-Ode seismic region (Adepelumi, 2009). Aside the statistical prediction for earthquake occurrence in Ijebu-Ode in future, remote sensing, geological and geophysical studies had earlier revealed the presence of a NNE-SSW trending Ifewara-Zungeru fault zone (Figure 2) which has been shown to be linked with the Atlantic fracture system (Anifowose et al., 2010; Adepelumi et al., 2008; Olujide and Udoh, 1989; Olurufemi et al., 1986). The Ifewara area of southwestern Nigeria constitutes part of the schist belts in the Nigerian Basement Complex, a part of the African crystalline shield.

Generally, the geology of the area carries the imprint of the end-Proterozoic Pan-African orogeny (Adepelumi et al., 2008). Some of the other important fault systems in Nigeria are the Anka and Kalangai fault systems. Anka and Kalangai fault systems are not discussed here elaborately. But sufficed it to say that these fault systems are interpreted to have resulted from transcurrent movements and particularly, the 250 km long, NE-SW trending Ifewara fault zone has been shown to be linked with the Atlantic fracture system (Adepelumi et al., 2008). The dynamics of the Atlantic fracture zones have been suggested to be responsible for the seismic activities experienced in the areas (Akpan and Yakubu, 2010). Despite the results from various studies (Adepelumi, 2009; Adepelumi, 2008; Onuoha, 1988) that indicate that Nigeria could witness major earthquakes in the future, attention has not been given to seismic hazard monitoring to evolve early warning scheme for the country. In fact, there is no record of a comprehensive seismic hazard studies in Nigeria to help in the sitting of critical facilities like nuclear power plants for electricity generation, dams, rail lines, high rise buildings, roads, etc. This could be realized feasibly at the moment using geodetic and seismological techniques which is the subject of this paper other techniques for seismic hazard monitoring and evaluation could also be considered in future. Earth-quakes are caused by movement of the earth's crust and researchers are finding ways to measure such movement with extreme precision using Global positioning system (GPS) technology. The idea of collocating seismographic stations with GPS motoring system is to achieve this aim. With GPS such measurements, matched with historical data plus growing experience with earth movement and precursors of an earthquake are holding out the promise of accurate prediction of earthquakes in the future.

GPS can play a very important role in monitoring of the post-earthquake crustal deformation pattern for understanding the complex earthquake mechanism. GPS can measure movement of tectonic plates to within a centimeter anywhere. These measurements have provided a much better understanding of tectonic setting (Personal communication, Dr. Dodo J. D., Centre for Geodesy and Geodynamics, Toro). These planned GPS control points can be used for continuous monitoring of existing faults in Nigeria, especially the Ifewara-zungeru fault.

Table 1. Location of current and proposed seismic stations in Nigeria.

No.	Station code	Name	Geological foundation	Instrument installed
1	Oyo	Oyo	Granite	SP-400 seismometer, DR4000 recorder
2	IBN	Ibadan	Gneiss	No instrument installed
3	IFE	Ile-Ife	Gneiss	EP-105 broadband seismometer, DR4000 recorder
4	AWK	Awka	Shale and siltstone	EP-105, Broadband seismometers, DR4000 recorder
5	NSU	Nsukka	Sandstone	EP-105 broadband seismometer, DR4000 recorder
6	ABK	Abakiliki	Sandstone	No instrument installed
7	ABJ	Abuja	Granite	No instrument installed
8	TOR	Toro (Central)	Gneiss	EP-105 broadband seismometers, DR4000 recorder
9	KAD	Kaduna	Granite	EP-105 broadband seismometer, DR4000 recorder
10	MNA	Minna	Granite	No instrument installed

MONITORING EARTHQUAKES USING SEISMIC EQUIPMENT

Since 2006, the centre for geodesy and geodynamics, Toro has been managing the Nigerian National Network of Seismological Stations (NNNSS) established by the National Agency for Science and Engineering Infrastructure (NASENI), Abuja. The NNNSS presently has six operational stations (Table 1 and Figure 3) equipped with 24-bit 4-channel data acquisition system and broadband seismometers. Efforts are being made to network all the stations for real-time data collection. The networking of these stations will open a window of opportunity for data sharing with neighbouring countries and some agencies abroad. Seismic signals are usually measured in three orthogonal directions: Vertical (Z), North-South (N) and East-West (E). The seismic sensor measures the ground motion and translates it into a voltage and recorded by the recorder (Havskov and Ottemoller, 2010). A new tsunami detector which comprise of seismometers and other monitoring equipment like pressure sensor, has been successfully used in the Gulf of Cadiz for tsunami monitoring (Francesco et al., 2008). The tsunami detection procedure is based on triggered pressure and seismic events. The seismometer triggers on local strong earthquakes which could also be considered to monitor coastal areas of Nigeria for early warning in future. Velocities from 20 GPS sites on the island of Jamaica and seismic data from the Jamaican Seismic Network had also been used to quantify motion of the proposed Gonˆave microplate and study deformation and earthquake hazard in Jamaica (DeMets and Wiggins-Grandison, 2007). An important objective of GPS and seismic measurements in the northern Caribbean region is to better understand how motion across the Caribbean–North America Plate boundary is partitioned by the plate boundary structures and what this implies for local and regional tectonics and seismic hazard. With the realization of the integrated monitoring scheme (Figure 5), this approach can also be applied to study deformations and earthquake hazard in Nigeria.

USE OF GLOBAL POSITIONING SYSTEM IN MONITORING SEISMIC HAZARD

The use of GPS to monitor crustal deformations, with the ultimate aim of predicting natural disaster like earthquakes, volcanic eruptions and other seismic hazards, is one of the greatest challenges faced by scientists in this century. But research has shown that earthquakes could be predicted from the analysis of pre-signals in terms of changes in triangular network of GPS stations (Murai, 2010). Beyond the existing continuous GPS stations in Nigeria (Table 2 and Figure 4), Nigeria is also planning to collocate Continuously Operating Reference Stations (CORS) GPS in all the existing and planned seismographic stations in Nigeria, in triangles (Figure 5) for comprehensive monitoring of crustal deformation. Triangles are formed basically with all possible combinations of selected GPS stations regardless of distance and many large earthquakes in Japan and in other Asian regions were predicted using this method, from daily area changes within the triangles (Murai, 2010). In Nigeria, there are no dense GPS stations except GPS stations provided by Office of the Surveyor General of the Federation (OSGOF) (Figure 4). But it is possible to show pre-signals of even past big earthquakes from a very coarse GPS network (Murai, 2010). Since the earth is so complicated in the crustal movement, it would be possible in the future to predict big earthquakes in Nigeria to some degrees using pre-signals to make early warning of such big earthquakes. In the case of the Haitian quake, the GPS monitoring system helped document rising stresses along the fault which crosses southern Haiti, suggesting a large amount of force that could be released in a severe quake (Manaker et al., 2008). The effectiveness of GPS technology was dramatically used to predict the Haitian quake by a team of Purdue University researchers led by Geophysics Professor, Eric Calais (Manaker et al., 2008). They accurately predicted that an earthquake would take place in Haiti and that the quake would be greater than 7.0 magnitudes.

The Purdue team has been studying the Enriquillo and

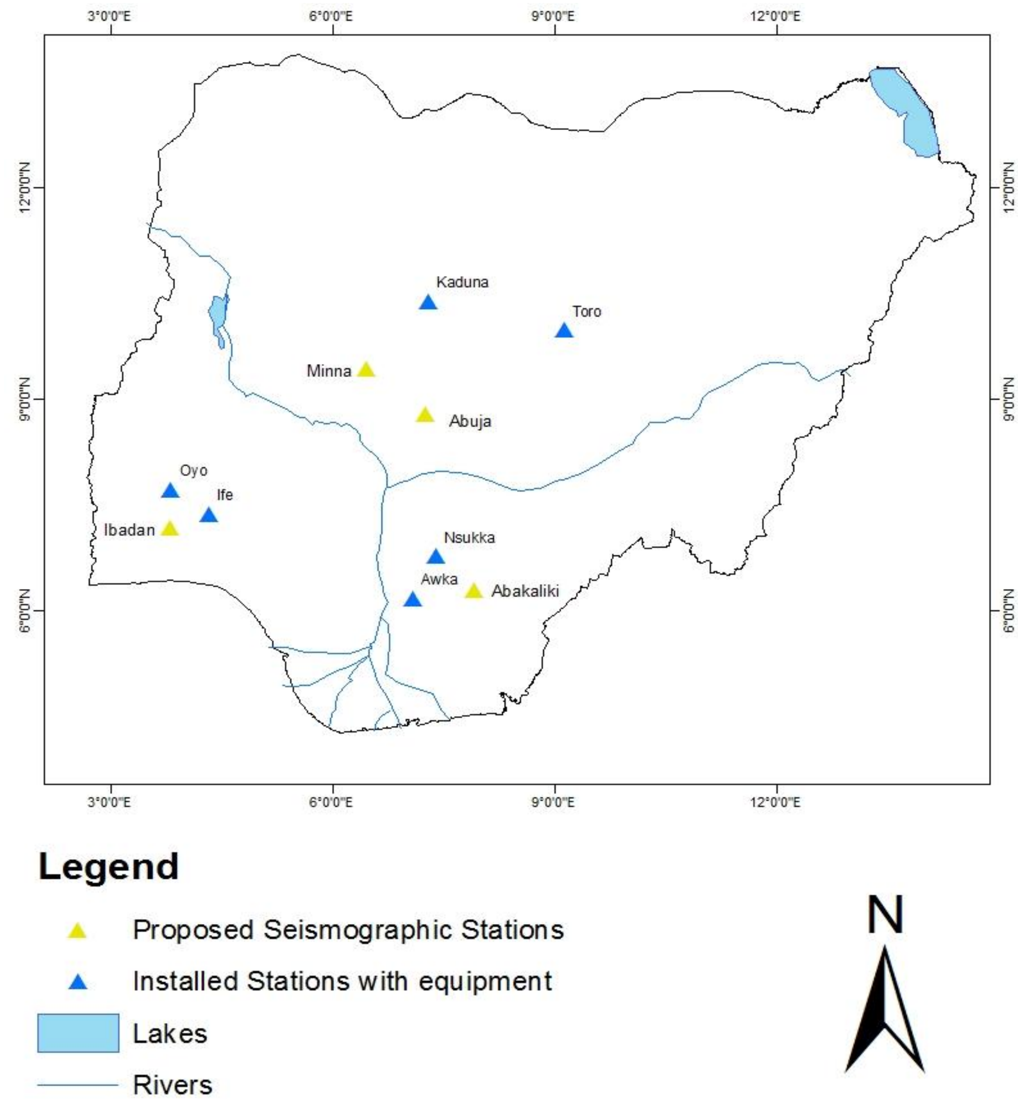

Figure 3. Distribution of seismic stations (station names and codes are given in Table 1) in Nigeria. Blue triangles are those stations that are operational, whilst the yellow triangles show proposed stations.

Table 2. The coordinates and the ellipsoidal height of the 9 CORS stations (Courtesy: Space-Based Geodetic System Department, Centre for Geodesy and Geodynamics, Toro).

Station ID	Station Location	Approx. latitude (N)	Approx. longitude (E)	Ellipsoidal height (M)
OSGF	Office of the Surveyor General of the Federation, FCT, Abuja	090 01' 39.597''	070 29' 10.830''	532.6447
ULAG	University of Lagos, Lagos	060 31' 2.375''	030 23' 51.444''	44.5752
RUST	River State University of Science and Technology, Port Harcourt	040 48' 6.609''	060 58' 42.677''	45.5892
UNEC	University of Nigeria Enugu Campus	060 25' 29.301''	070 30' 17.968''	254.4055
BKFP	Birnin Kebbi Federal Polytechnic	120 28' 6.876''	040 13' 45.271''	250.0118
ABUZ	Ahmadu Bello University Zaria	110 09' 6.263''	070 38' 55.274''	705.0666
GEMB	Gembu, Taraba	060 55' 1.917''	110 11' 2.185	1795.6424
CGGT	Centre for Geodesy & Geodynamics, Toro	100 07' 23.141''	090 07' 5.922''	916.4462
FUTY	Federal University of Technology, Yola	090 20' 59.073''	120 29' 52.072''	247.4062

Table 3. A list of historical earthquakes that occurred and tremors that were felt in Nigeria.

Year-month-day	Origin time	Felt areas	Intensity	Magnitude	Probable epicenter
1933	-	Warri	-	-	-
1939-06-22	19:19:26	Lagos, Ibadan and Ile-Ife	-	6.5 (Mr), .3(Ms)	Akwapin fault in Ghana
1963-12-21	18:30	Ijebu-Ode	V	-	Close to Ijebu-Ode
1982-10-16	-	Jalingo and Gembu	III		Close to Cameroun Volcanic line
1984-07-28	12:10	Ijebu-Ode, Ibadan, Shagamu and Abeokuta	VI	-	Close to Ijebu-Ode
1984-08-02	10:20	Ijebu-Ode, Ibadan, Shagamu and Abeokuta	V	-	Close to Ijebu-Ode
1984-12-08	-	Yola	-	-	Close to Cameroun volcanic line
1985-06-18	21:00	Kombani Yaya	IV	-	Kombani Yaya
1990-06-27	-	Ibadan	-	3.7(ML)	Close to Ijebu-Ode
1994-11-07	05:07:51	-	-	4.2(ML)	Dan Gulbi
1997	-	Okitipupa	IV	-	Close to Okitipupa
2000-03-07	15:53:54	Ibadan, Akure, Abeokuta, Ijebu-Ode and Oyo	-	4.5(mb), .9(MS)	Close to Okitipupa
2000-05-07	11:00	Akure	IV	-	Close to Okitipupa
2005-03	-	Yola	III	-	-
2006-03-25	11:20	Lupma	III	-	Close to Cameroun volcanic line

Figure 4. Geodetic and geophysical control network in Nigeria (Courtesy: Space-Based Geodetic System Department, Centre for Geodesy and Geodynamics, Toro).

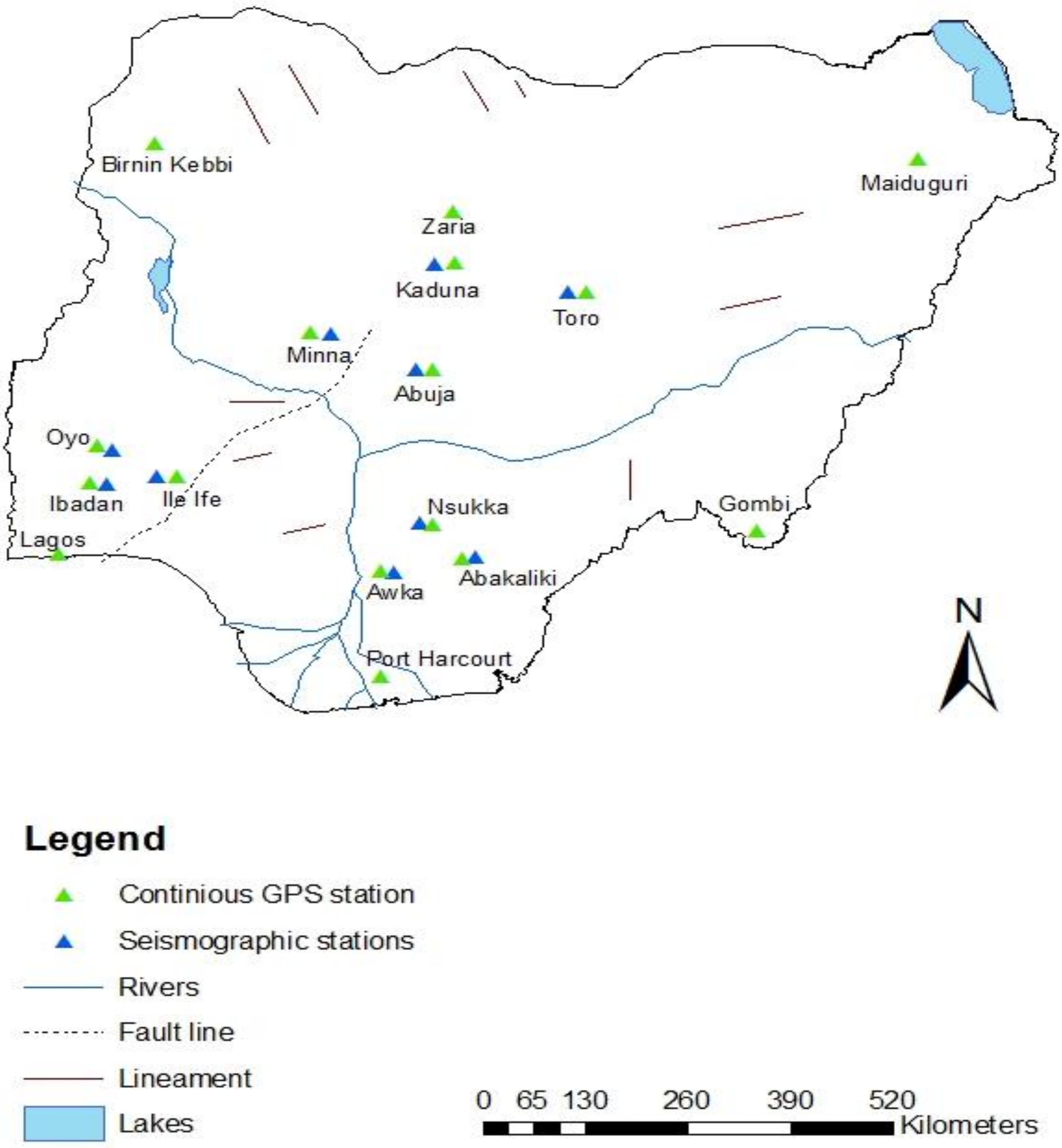

Figure 5. Map of Nigeria showing the proposed locations for the instrumentation making up an Integrated Geo-hazard monitoring scheme.

Septentrional faults in Haiti and the Dominican Republic that caused the Haitian quake since the late 1990s. Haiti was of course tragically racked by an earthquake on January 12, 2010. In Nigeria, an extensive high precision Geodetic and geophysical control network has been established in some parts of the country by OSGOF (Figure 4). These controls are located in Toro, Abuja, Yola, Port Harcourt, Gembu, Lagos, Nsukka, Birnin Kebbi and Zaria for primary purpose of national mapping. But, the Centre for Geodesy and Geodynamics, Toro whose mandate is to monitor crustal deformations among others, is to use geodetic, geophysical and geological surveys for variety of applications. The extensive horizontal and vertical geodetic and geophysical control network that will be established through these collaborative efforts with other related agencies, like OSGOF, RECTAS and the huge amount of valuable data that will be generated will contribute significantly towards monitoring the crustal dynamics of Nigeria sub-continent and will be augmented through the launch of an extensive National Programme on GPS and Geodetic Studies for earthquake hazard estimation. To achieve this, accurate measurements have to be carried out in nearby stable network. However, inter-seismic strain which often occurs over broad area can really only be effectively monitored from a geophysically stable network such as the International Terrestrial Reference Frame (ITRF) (Personal Communications and Presentations by Dr. Dodo. J. D). The aim of this GPS campaign is to obtain the first geodetic measurement (unified geocentric datum) in the country. This is presently being undertaking by the Space Based Geodetic Department, Centre for Geodesy and Geodynamics. Using GPS campaign, 1 to 5 days of continuous GPS dual-frequency carrier-phase observations will be collected at a widespread network of monitoring marks (usually permanent stations or pillars) spanning known seismic prone zones. A one-day observation typically archived an accuracy of 10 mm while five days observations improve the accuracy to 5 mm. The same site will be observed over several epoch and time-series will be plotted to see if there is any station movement between the epochs (and therefore site velocities) within ITRF.

DISCUSSION

It has been shown from the preceding sections that there is need for effective and efficient seismic hazard monitoring in Nigeria even though the country is not located in regions usually associated with high seismicity. The use of seismological and geodetic equipment for the monitoring is seen as a viable tool for the continuous monitoring of seismic activities and analysis for better understanding of geodynamic nature of Nigeria’s crust. Nigeria is presently seriously considering the option of generating electricity from nuclear power plants, hence holistic monitoring of seismic activities and hazard is very paramount in order to achieve this goal. Disaster preparedness measures are now been considered through retrofitting and earthquake resistant designs for new buildings, lifeline and other critical structures (for example, bridges, hospitals, nuclear and conventional power plants, airports, chemical factories, oil refineries, military installations, explosives and mining areas). These projects, no doubt, require holistic planning to include best practices on disaster prediction, management and early warning to mitigate effects arising from possible earthquake related disasters. Due to the fact that earthquakes are not common in Nigeria, millions of Nigerians do not have basic knowledge of how and why earthquakes occur or what to do when there is early warning prior to an earthquake or/and emergency measures to take in an earthquake situation. However, establishment of institutional collaborations that will see Federal and State governments working together to publish natural hazards preparedness booklets will help in enlighten people about earthquakes.

The manifestation of these plans is seen in the recent establishment of a network of seismic stations in Nigeria. Establishment of ten of these stations is ongoing with six located in Ile-Ife and Oyo (south west), Nsukka and awka (south east), Kaduna (north central) and Toro (North East) already functional (Table 1 and Figure 3). These will provide useful information regarding seismicity in Nigeria as well as for continuous monitoring of seismic activity in the vicinity of sensitive structures, such as nuclear power plant sites. Efforts are being made to collocate GPS stations with the seismic stations. The Centre for Geodesy and Geodynamics (CGG), which is one of the six activity centers under National Space Research and Development Agency (NARSDA), is presently developing capabilities to join the rest of the world on plate-tectonic, crustal deformation monitoring as well as landslides and subsidence, monitoring of coastal deformation and sea level-rise from expected climate change in the coastal areas, etc from its Main Observatory located in Toro, Bauchi State, Nigeria.

Beyond hazards monitoring using space-based techniques in the country, densification of monitoring equipments along identified faults within Nigeria is a viable option for comprehensive disasters monitoring (Figure 5). The densification project would equally take into account, installation of more seismographic stations across Nigeria in future and collocation of GPS with the seismographic stations. Nigeria and Cameroon are close to cementing collaborative arrangement on a joint hazard monitoring scheme for data and knowledge sharing as well as research/monitoring along Cameroon volcanic line. Therefore, the equipment planned along the North-East region will help to realize the lofty objective of the collaboration. Another region of interest is the border line along the South-West of Nigeria, bordering Benin Republic. This region has experienced series of vibrations arising from earthquakes with epicenters located in neighbouring West African countries, for example, the recent Benin event. The three Seismo-graphic stations in triangulation are already constructed in this region but will be collocated with GPS equipment soon which is also part of effort to monitor Ifewara-Zungeru fault (Figure 2).

CONCLUSION

Although, no active faults have been identified in Nigeria, a careful review of seismicity in the country by Osagie

(2008), Akpan and Yakubu (2010) showed that Nigeria may not be as aseismic as has hitherto been believed. Historical evidence indicates that earth tremors have been felt in some parts of country. While a few of the felt earthquakes actually had their epicentres in Nigeria (Figure 1), some of the more widely felt ones actually originated outside Nigeria. There is also the Zungeru-Ifewera fault (Adepelumi et al., 2008; Anifowose et al., 2010); running from the Mid-Atlantic ridge across to North-Western Nigeria, But there is no confirmation that this fault is active at the moment.

Since past geology provides a clue to the future, we expect minor earthquakes to keep occurring in Nigeria in the future (Onuoha, 2010; Adepelumi, 2009). Therefore, there is need to carefully monitor those activities that have the potential to trigger earthquakes in Nigeria through the densification of seismic stations and integrated with spaced-based techniques for example, GPS.

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