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GIS-Based Earth Movement Prediction in a Tremor-Prone Region in Northcentral Nigeria Using an Integrated Approach

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This study develops a Geographic Information System (GIS)-based integrated model (RQ-PABLES method) to predict areas prone to earth movement within a tremor-prone region of north-central Nigeria. The RQ-PABLES approach combines geological, geophysical, hydrogeological, nuclear, and GIS datasets to assess the causes and predict potential future tremors. Eight weighted parameters, radon in groundwater, radon in subsoil, quarry proximity, slope/basement relief, percolation, elevation, and lineament density, were integrated to produce an earth-movement prediction map. Field validation confirmed that quarry activities are the dominant cause of tremors in the study area. The results indicate high radon concentrations exceeding EPA and NIS limits, confirming radiological implications associated with subsurface movement. The integrated model successfully delineated zones as 'highly likely', 'likely', and 'not likely' to experience movement in the event of future tremors. The RQ-PABLES workflow provides a reproducible framework for assessing geodynamic risks in intraplate settings, informing urban planning and quarry regulation policies.

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INTRODUCTION

Although Nigeria is not situated along a recognized active seismic belt, the occurrence of earthquakes since 1933 indicates that the country may not be entirely aseismic. Recent tremor events in northcentral Nigeria, notably in the Federal Capital Territory (FCT), have renewed concern over the potential for localized seismic activity. The debate on the origin of these tremors, whether tectonic, anthropogenic, or hydrological, remains unresolved. Previous studies (Adepelumi et al., 2008; Goki et al., 2020) have attributed these events to either the reactivation of ancient fault systems or intense quarrying activities. However, limited quantitative approaches exist for predicting earth movement in such intraplate environments.

This study addresses that gap by developing a hybrid GIS-based prediction method that integrates geological, hydrogeological, geophysical, and nuclear data. The unique feature of this study is the inclusion of radon gas as a predictive variable. Variations in radon concentration in groundwater and subsoil have been identified as precursors to seismic events in several regions globally. This work aims to establish a replicable, data-driven method (RQ-PABLES) capable of identifying areas with varying likelihoods of earth movement in northcentral Nigeria.

The study area

The area covered by this work is located within latitude 9° 03’ 28.26” N and longitude 7° 29’ 42.29” E. It covers the entire Federal Capital Territory (FCT) (Figure 1). The widespread rock units of this area consist of “Older granites” of the Pan- African granitoid and migmatite-gneiss complex. This comprises an inhomogeneous cluster of gneisses (ortho and para-), migmatites, and successions of basic and ultrabasic rocks. Petrographically, the Pan-African Orogeny caused the recrystallization (via partial melting) of the migmatite and gneissic rocks.

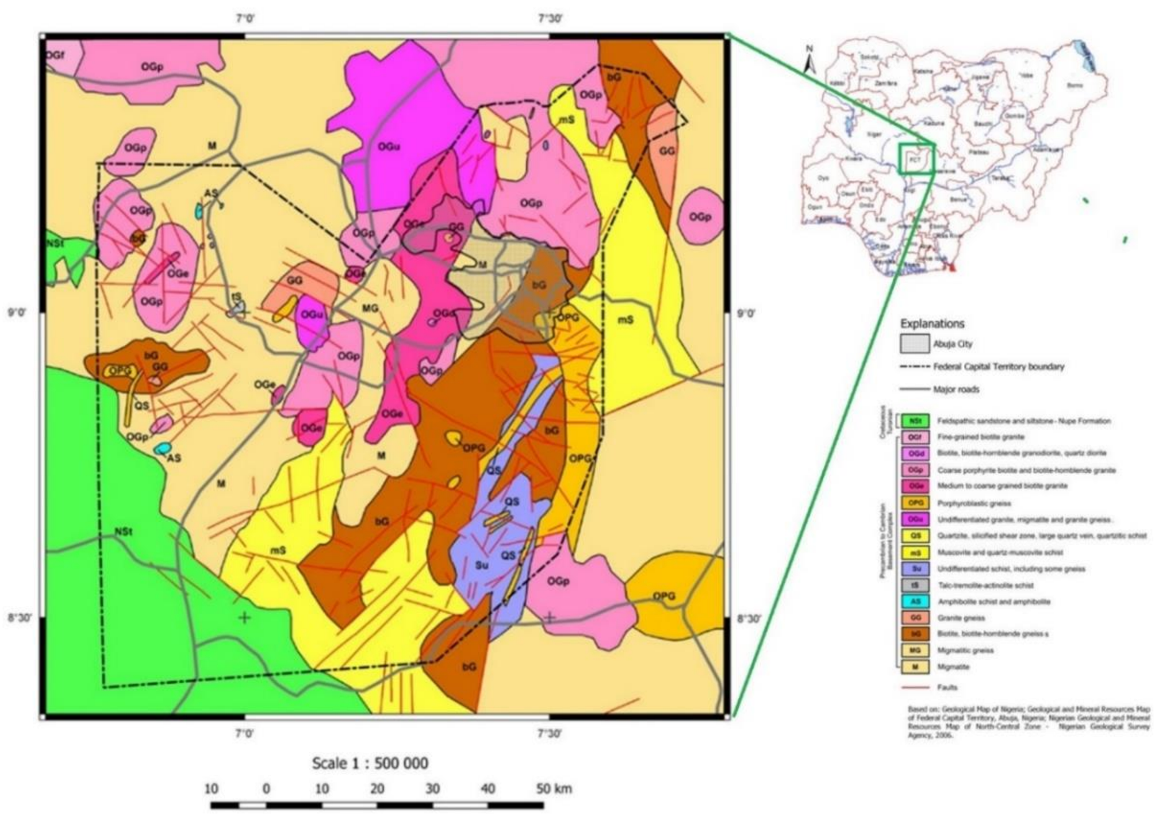


Figure 1: Updated geologic map of the FCT based on field investigation and complemented by GSNA, 2006 (geologic and mineral resources map of the FCT) (inset: map of Nigeria depicting the location of the study area)

The migmatite-gneiss complex comprises rocks that range in age from 600 million years to 3 billion years, i.e., from Pan-African to Eburnean, as reflected in the numerous chrono-successions of the migmatite-gneiss complex, the majority of which originated during the orogenic cycle. The rocks of the migmatite-gneiss complex are characterized by varying mineralogy, chemical composition, texture, and structure. These variations are attributable to the progressive/gradual regional metamorphism of meta-sedimentary rocks (Arabi *et al.,* 2021).

MATERIALS AND METHODS

The study employed an integrated approach combining five main techniques: geological, geophysical, hydrogeological, nuclear, and GIS-based analyses. The workflow (Figure 2) illustrates the sequence of data acquisition, processing, and integration for the RQ-PABLES method. The study area, located within latitude 9°03′28.26″ N and longitude 7°29′42.29″ E, covers the Federal Capital Territory (FCT) and its environs.

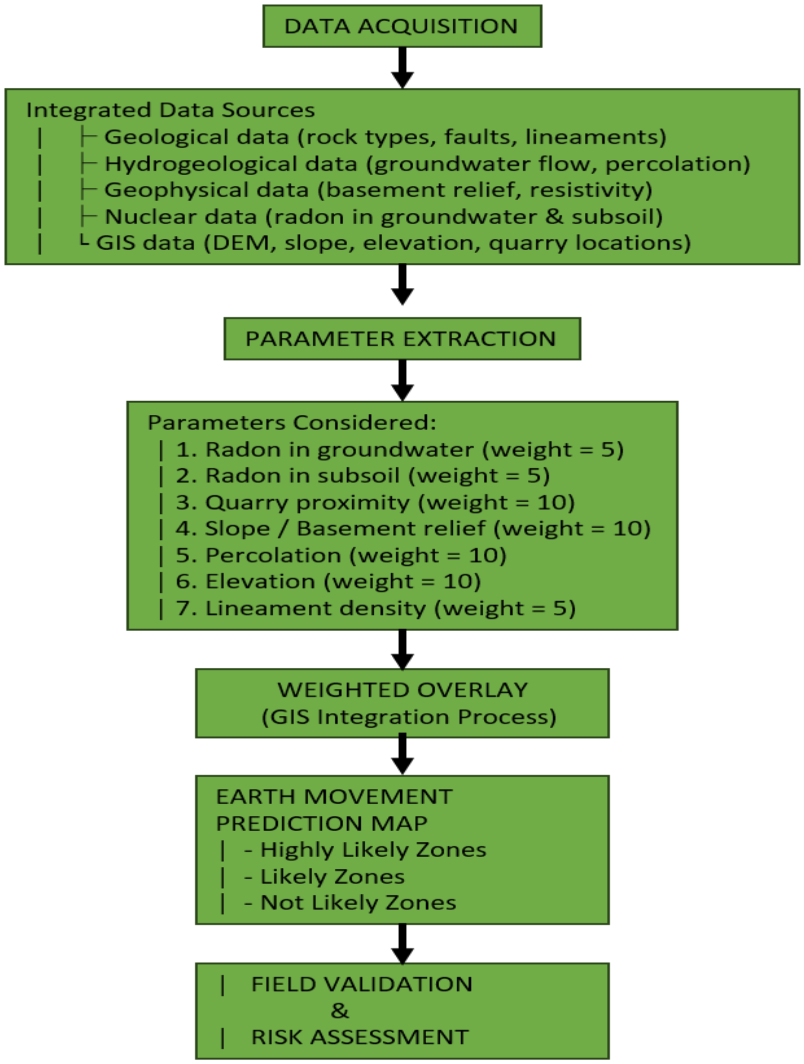
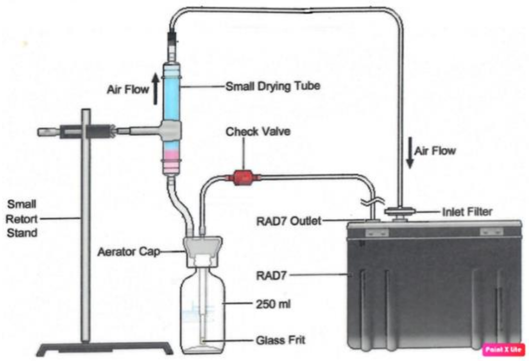


Figure 2. Workflow of the RQ-PABLES method (conceptual schematic to be inserted).

Eight major parameters were considered in the model: (1) radon in groundwater (Fig. 3a), (2) radon in subsoil (Fig. 3b), quarry proximity, (4) slope/basement relief, (5) percolation, (6) elevation, (7) lineament density, and (8) basement configuration. A detailed field exercise was conducted (Fig. 4a- d) to obtain geological, hydrogeological, geophysical, and radon data to feed into the model (RQ-PABLES) requirement. Each parameter was weighted between 1 and 10 based on its influence on earth movement. The cumulative weighted overlay was performed in a GIS environment to generate the earth-movement prediction map, classifying areas as ‘highly likely’, ‘likely’, or ‘not likely’ to experience movement.



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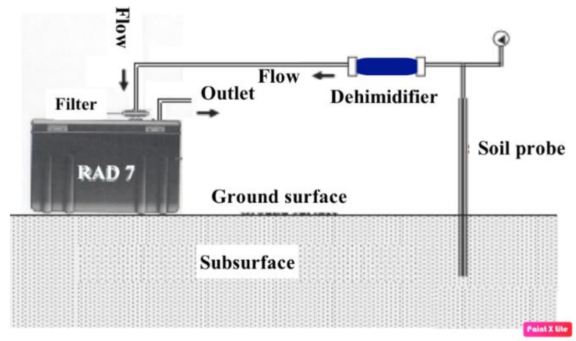

3b

Figure 3 (a): Setup adopted during in-situ measurement of radon concentration in groundwater (after RAD 7 manual 2009 edition), Figure 3 (b): Setup for soil radon depth profiling

Fig. 4 (a) Fig. 4 (b)

Fig. 4 (c)

Fig. (d)

Figure 4: Photograph of the (a) geology team depicting some activities, (b) hydrogeology team measuring water quality parameters, (c) geophysical team conducting vertical probing of subsurface geo-electric layers, (d) nuclear team conducting radon measurement in groundwater sample and depth profiling.

RESULTS AND DISCUSSION

Results show that radon concentration in groundwater ranges from 609 to 92,500 Bq m^{-3} (0.6 to 92.5BqL^{-1}) (Fig. 5), exceeding both EPA and NIS permissible limits. Subsoil radon concentration increases with depth, indicating potential pathways for gas migration through fractures caused by seismic or quarry-induced stress. Quarry proximity exhibited the highest weight (10), confirming its major role in triggering earth movement in the study area. Areas of high lineament density and slope corresponded spatially with zones of elevated radon activity and known surface manifestations of movement.

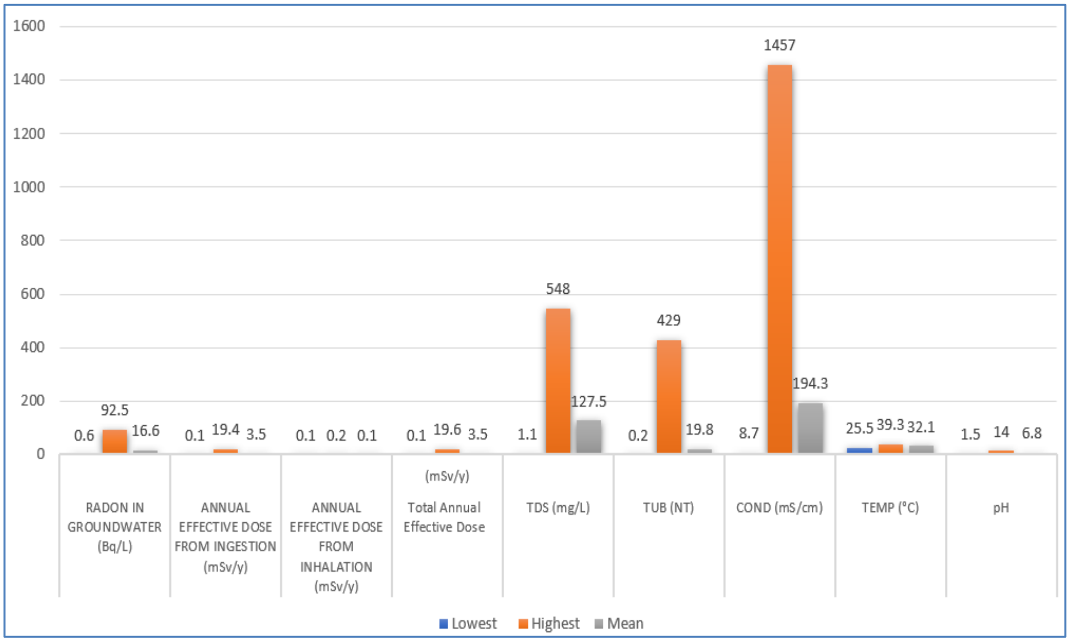

Figure 5: Mean values recorded for radon in groundwater, calculated annual effective dose due to ingestion, inhalation, total annual effective dose, and some physicochemical parameters. TUB = turbidity, COND = conductivity, TEMP = temperature

The integrated RQ-PABLES model identified three susceptibility zones (Fig. 6 a and b). Highly likely zones correspond to regions around Mpape, Saupe, and Dushepe; likely zones include Dakwa, Gwi, and Yebu; and not-likely zones occupy the northwestern portion of the study area. Field validation confirmed a strong correlation between model predictions and observed tremor manifestations. The results refute earlier assumptions that groundwater over-abstraction causes the tremors, instead implicating quarry detonation and slope instability as dominant drivers.

CONCLUSION

This study presents a novel integrated approach (RQ-PABLES method) for predicting earth movement in tremor-prone areas of north-central Nigeria. The combination of geological, hydrogeological, nuclear, and GIS datasets provides a robust framework for identifying zones of varying seismic susceptibility. The study confirms that quarry activities, rather than groundwater abstraction, are the main cause of tremors in the area. High radon levels indicate radiological risks linked to subsurface movement. The predictive framework developed here can serve as a valuable tool for seismic risk management and environmental planning.

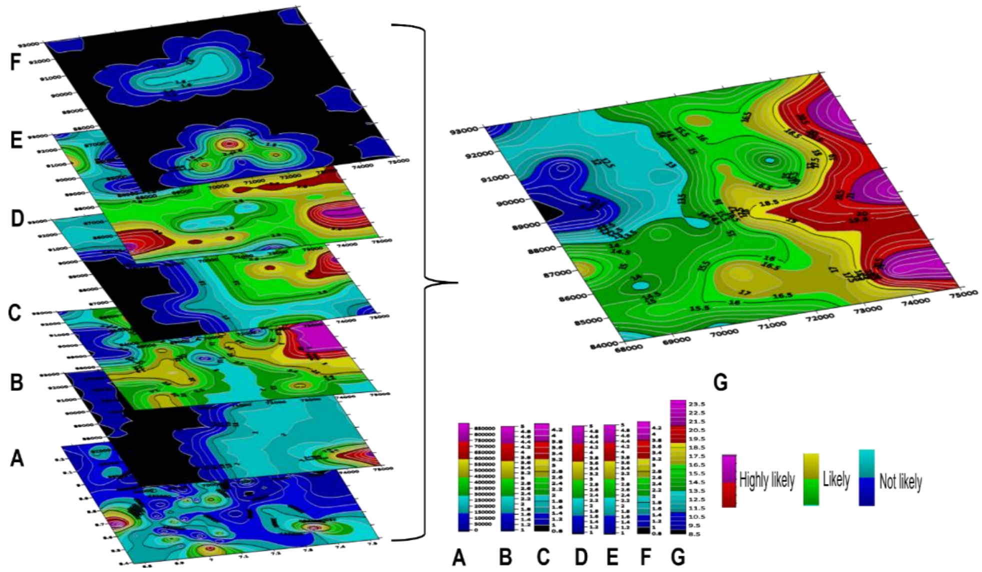

Figure 6 (a)

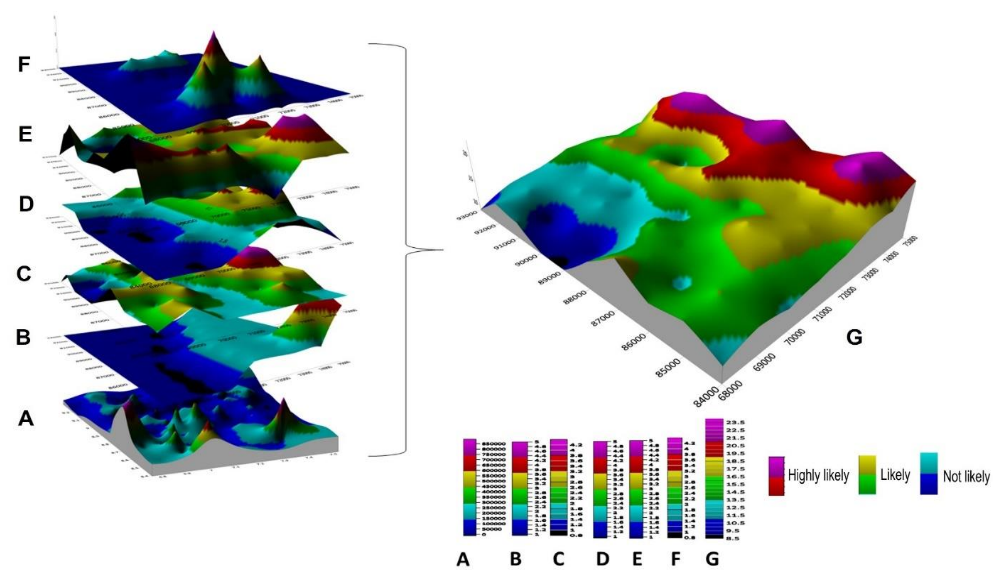

Figure 6 (b)

Figure 3.9: (a) Superimposed 3D contour (b) surface maps of radon, quarry proximity, slope, elevation, lineament, and corresponding earth movement predictive map (A = Radon in groundwater and subsoil, B = Quarry proximity, C Slope. D = Elevation. E = Lineament, F = Percolation, G = Predictive model

***Recommendations*:**

a) Mandate inclusion of land-movement prediction studies in Environmental Impact Assessments (EIA).

b) Establish continuous radon monitoring networks in groundwater and subsoil.

c) Enforce standard quarry–residential distance regulations.

d) Conduct periodic geotechnical assessments of slopes and quarry environments.
e) Review and relocate quarries situated within identified high-risk zones.

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