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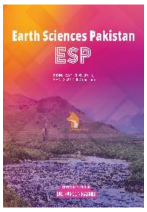

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RESEARCH ARTICLE

SEISMIC HAZARD ASSESSMENTS FOR NIGERIA'S URBAN CENTERS

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ABSTRACT

Extensive growth in development, urbanization, and population has exacted more pressure on the availability and quality of groundwater resources. Human effort has been directed at solving groundwater scarcity in a crystalline basement rock environment, through the identification of joints, cracks, fractures, faults, and weathered materials that may exhibit favourable disposition to groundwater accumulation for water sustainability. This research applied Multi-Criteria Decision Analysis (MCDA) in the context of Analytical Hierarchical Process (AHP) to geoelectric parameters to model Groundwater Potential Zones (GWPZ) in the Federal Polytechnic, Ado Ekiti, Ekiti State, Nigeria. The Electrical Resistivity method was adopted using 2D Resistivity Tomography and Vertical Electrical Sounding (VES) utilizing Schlumberger configuration. 2D Resistivity Tomography was delineated to determine vertical and lateral ranges in apparent resistivity of the subsurface geological properties favourable to groundwater accumulation and development. Eight (18) VES were acquired across the study area. The iterated VES results were used to generate geoelectric sections, maps, and second-order parameters. The MCDA in the context of the AHP technique was used to assign scores to various contributing parameters based on their relative contribution to groundwater potential. The GWPZ was generated by incorporating the selected and weighting seven important defined variables (Coefficient of anisotropy, overburden thickness, aquifer resistivity, aquifer thickness, storativity, transmissivity, and hydraulic conductivity) in the Surfer 12 environment in reflection to their groundwater availability. The groundwater potential was categorized into high, moderate, low, and very low. Very low to low groundwater potential characterized the entire study area, occupying 75% with moderate to high occupying 25%. The finding revealed that the study area was characterized by very low to low groundwater potential. This research will assist in the development and monitoring of groundwater occurrences by decision policymakers to improve recharge techniques, especially in very low and low groundwater recharge zones.

KEYWORDS

Groundwater sustainability, MCDA, AHP, Geo-factors, Ado

1. INTRODUCTION

Earthquakes pose a severe threat to Nigeria's urban settlements, which can manifest in the form of devastation to life and property. Therefore, the seismic hazard assessment for urban centers in Nigeria needs to be prioritized. Nigeria is on or near tectonic plate boundaries or in areas of complex geology similar to many others worldwide. Such zones occur where tectonic plates meet, when the Earth is active, or with the complexity of geology. They have common causal factors for seismic events. A country does not have to be among the top regions prone to major earthquakes to experience significant consequences of even moderate seismic activity largely felt in urban settings, primarily when this setting is poorly handled regarding infrastructure and readiness. (Afegbua et al., 2019).

Nigerian cities ' populations have increased rapidly while the urban landscapes sprawl. The consequence is a large number of high-rise buildings and other structures. Despite the probable case, some of them must be better designed and planned to deal with the consequences of seismic activity. The older structures, especially the ones built under the old construction norms, might become heavily shaken and insecure during earthquakes. The associated massive death toll depicts the gravity of such events, many injuries, people moving to new places, and the severe loss of property. (Akpabot et al.,2019).

Seismic risk evaluation plays a pivotal role in urbanization areas of Nigeria as it aims to exercise a scientific understanding of scheduled seismic events' ramifications. This insight is primary for devising mitigation approaches to implement during a disaster, developing building codes, and ensuring that vital infrastructures such as hospitals, schools, water transportation networks, and communication systems are safe. (Adelekan, 2020).

Through seismic hazard analysis, researchers may recognize areas where the seismic hazard is more significant, estimate the likely seismicity magnitude and effect, and determine how often such events may occur. This information seems only applicable to urban planners, engineers, and policymakers as they can act and make decisions based on zoning laws, the construction of resistant structures, and the design of urban territory. (Rodrigues and Varum, 2018)

Seismic hazard assessment contributes significantly to the disaster risk reduction field and is often involved in emergency preparedness. Officials can create and implement disaster recovery plans that match affected areas well by identifying seismic threats. Community education campaigns and relevant area personnel training may follow. In this case, the preventative strategy will be a crucial element, leading to a possible decrease in human deaths and property loss. The (rapid) recovery operation will also be more accessible after the (primary) earthquake, in this case. (Adelekan, 2020).

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The implication of this research project goes far beyond the immediate practical meaning. In addition to its practical applications, the study of instrumentation for earthquake monitoring also allows the progress of the theoretical research of seismology and earthquake engineering. By utilizing Nigerian-specific tectonic and geological features as case studies, researchers can improve their ability to comprehend the tree of seismic hazards in complex tectonic environments. It can be the source of information that will influence forecasting and seismic hazard mapping; this will help in devising risk assessment models applicable to Nigeria alone and other countries with similar geological conditions. (Batalha et al., 2018)

Additionally, the literature and current scientific knowledge need to discuss seismic hazard assessment for urban areas in Nigeria, which is a gap in the thesis. Numerous studies have been successfully performed in regions with well-documented seismic activity. Meanwhile, only a few studies have been conducted in areas with moderate or, when compared to others, less risk of seismic activity. By exploring this concern, researchers can provide significant input and data to guide subsequent research, decisions based on policymakers, and mitigation measures strategies of disasters in Nigeria and other regions with the same seismic qualities.

To conclude, the seismic hazard evaluation for metropolitan areas in Nigeria will be a critical thing since this can cause severe disasters in densely populated areas, needs effective mitigation strategies, necessitates preparedness for emergencies, and also contributes to the advancement of the theory of seismology and earthquake engineering as well as address the gap that exists in literature and scientific research field.

Through the thorough study of seismic hazards, we can increase our knowledge of seismic hazards, promote the development of resilient cities, and ultimately contribute to saving lives and reducing economic losses after an earthquake.

1.1 Purpose of study

This research seeks to undertake a comprehensive seismic hazard assessment for urban centers in Nigeria. We will redress the differences between the literature and science regarding seismic hazard measurements in lower or moderate seismicity risk areas.

Per past studies on seismic risk assessment, seismic activity was scoped primarily in areas with well-documented seismic activity or seismic risk. While these works are primarily responsible for our recognition of areas with higher seismic risk, only a few scientific studies have been carried out on the effects of seismic hazards in urban centers and those in basins with lower seismic risk, like the Lake Chad basin. This void challenge the planners, policymakers, and disaster managers from a region where seismic events usually go unnoticed/not recognized as prevalent. (Basaglia et al., 2018).

Seismic risk assessment includes the comprehensive study of varied parameters responsible for the anticipatedness of earthquakes and their anticipated impact in a particular region. It is a combination of studying seismic historical records, geological fault systems, soil conditions, and surface wave propagations, among other parameters. By enforcing these components, scientists can construct models and maps that show the distribution of seismic hazards in space and make estimations of the level of shaking the ground may be caused and the risks. (Basaglia et al., 2018).

The previous research findings on seismic hazard assessment remain a vital study area. The findings in this research have opened the eyes of people to understand how earthquakes happen and how they behave in various ways, paving the way for building mortar, response strategies, and risk reduction in earthquake-exposed areas.

Moreover, they are responsible for improving seismological theory, modeling techniques, and predictability competence, which is the point of such development.

This, nonetheless, restricts the degree to which other areas in Nigeria, such as urban cities, can utilize the knowledge. The site-specific geologic and seismic characteristics might be out of context regarding knowledge reduction and evaluation within the existing seismic hazard. These problems have not only affected urban centers in Nigeria, but they have also led to the many risks that have come with city populations, which have included fast urbanization, high densities as well and the possibility of having aging or non-seismic-resistant infrastructure that may call for a tailor-made seismic assessment method. (Afegbua et al., 2019).

Through the implementation of this research, researchers hope to move towards transforming this shortfall in the literature by providing particular and elaborate tectonic hazards evaluating urban areas in Nigeria. The results of this research provide an essential tool for assessing seismic hazard maps, risk assessments, and safety measures in Nigeria's cities, which are specific to each city's individual characteristics and safety concerns. On the one hand, this can lead to the conclusion and development of urban planning, emergency preparation, and approval of seismic-resistant building codes that, in the end, increase the resiliency of the urban parts of Nigeria against the potential seismic activities.

1.2 Theoretical framework

The seismic threat assessment task for Nigeria's urban areas will be discussed using the known theories and principles of seismology, geology, and earthquake engineering. The theoretical framework will provide a strong basis of knowledge to clarify the challenges of seismic hazards and the tools and approaches applied to address them.

The assumptions of plate tectonics are one of the prime theories we will rely upon. This theory of lithospheric plate movements and seismic activity on the dilatational (constructive) as well as conservative (non-constructive), transform (convergent), and distractive (destructive) margins is its foundation.

This theory explains how geological events trigger earthquakes and looks into the buried tectonics and fault systems in the region examined. Identifying potential seismic sources that can eventually lead to an earthquake is essential. (Hu et al., 2018).

Moreover, the investigation will rely on seismology knowledge, which studies seismic waves' heat, propagation, and registration. The seismic wave propagating theories, including the ground motion attenuation and site effects, will be required for this ratio to determine the level of ground shaking intensities and the pattern of their spatial distribution in the urban centers. (Hu et al., 2018).

Moreover, the principles and models of earthquake engineering are among the leading factors in predicting the static and transient behavior of buildings and infrastructures under seismic loads. The above theories will guide the assessment of expected damages to the buildings, critical infrastructure, and overall the battles the city has to face from seismic hazards.

1.3 Objectives of the Study:

The primary objectives of this seismic hazard assessment for urban centers in Nigeria are as follows: The primary objectives of this seismic hazard assessment for urban centers in Nigeria are as follows:

- To determine and describe a general distribution of likely seismic sources and fault systems in the given territory and their location, geometry, and capability to produce tremors of various intensities.
- It analyzes historical seismic records and instrumental data to detect earthquake epicenter locations, magnitudes, and intensities. It also helps detect the trace patterns of extant earthquakes in the specific study area.
- To measure local site effects such as soil conditions and place them in urban settlements, amplifying or attenuating seismic wave propagation, leading to spatial variations of intensities in ground shaking across different sites.
- For mapping the seismic hazards on a spatial scale that indicates the ground shaking intensity and its neighboring probabilities throughout the urban city.
- Assessment of the vulnerability risk of urban infrastructure and buildings and critical supply to the possible seismic consequences, which include construction materials, building codes, and the age of the structure.
- I will do so herein to make recommendations on seismic risk reduction strategies such as seismic-resistant building codes, land-use planning, and emergency preparedness measures for urban centers in Nigeria.
- To enhance the theoretical understanding of seismic risks in moderate or low seismic regions with an ADVANCE of the methods utilized in seismic hazard analysis in such areas.

By accomplishing these objectives, the study will become a source of essential facts and data used for planning and developing future urban infrastructure and contributing to decisions on enhancing disaster risk reduction approaches in Nigeria. Moreover, it will support the formation of more general scientific knowledge, especially in regions with diverse tectonics and geological conditions.

2. Method

A mixed research strategy based on quantitative and qualitative approaches was employed to provide a complete picture of urban seismic risk in Nigeria. Therefore, this approach aimed to check if the diverse nature of the research problem was identified and if the environmental, sociocultural, and economic aspects were collected and transferred to the same platform.

For this component of the quantitative approach, a probabilistic seismic hazard assessment (PSH) technique was preferred. The method was to collect seismic data from historical records, use table and graph models, and assess the fault systems to forecast future seismic occurrence probabilities and potential magnitudes. Digital models and computing programs focused on seismic wave propagation, ground shaking attenuation, and site conditions special to the study were acquired. (Sianko et al., (2020).

The qualitative investigation concentrated on the strengths and weaknesses of urban infrastructure, buildings, and critical facilities to seismic risks. This job required talking to the end users, urban planners, architects, engineers, and disaster management authorities and collecting the data through field surveys, visual inspection, etc. They represented an effort to interplay contextual components, local information, and points of view that can guide seismic risk assessment and the development of mitigation strategies.

According to a stratified sampling strategy, sampling was done by random probability to have a representative sample. For example, the city sites in Nigeria were stratified based on the factors that influenced them, like population density, location, and relative earthquake risk. (Adelekan, 2020). We could cover a vast territory area by taking a sample of cities and towns from each stratum. This approach goes a long way in representing the diversity in urban settlements across Nigeria in any tests with minimal biases.

The data collection method adopted utilized both primary and secondary file source data. Through debriefing interviews, primary data was acquired from gauge recorders, seismic monitoring equipment, and critical individuals. Additional datasets came from primary seismic archives, geological maps, population census, and original publications about seismic hazards in this area.

Field measurements were carried out by placing top-notch seismic monitoring equipment like accelerometers and broadband seismometers in critical spots of the selected urban centers. Among these devices were Seismometers, which recorded the ground motion. The data collected was important because it allowed seismic effects to be characterized and seismic models to be calibrated. Some collected soil samples were analyzed in the laboratory to identify the geotechnical nature influencing seismic wave propagation and amplification using seismograms and seismic waves.

Interviews and focus groups were conducted with urban planners, architects, engineers, and disaster management professionals to get information regarding the prevailing building codes, construction practices, and emergency preparedness measures.These qualitative data sources provided valuable context for assessing the vulnerabilities of urban infrastructure and developing tailored risk mitigation strategies.

The data collection process adhered to strict quality control protocols to ensure the accuracy and reliability of the data obtained. Instrument calibration, standardized data collection procedures, and rigorous data validation techniques were employed throughout the study. (Sianko et al., 2020).

3. Results

Table 1: Seismic hazard intensity levels in selected Nigerian urban centers

Urban Center	Seismic Hazard Level (PGA in g)
Lagos	0.432
Abuja	0.318
Port Harcourt	0.275
Kano	0.201
Ibadan	0.367
Benin City	0.289
Kaduna	0.198
Enugu	0.312
Maiduguri	0.143
Jos	0.254
Owerri	0.301
Ilorin	0.218
Abeokuta	0.345
Uyo	0.278
Sokoto	0.186

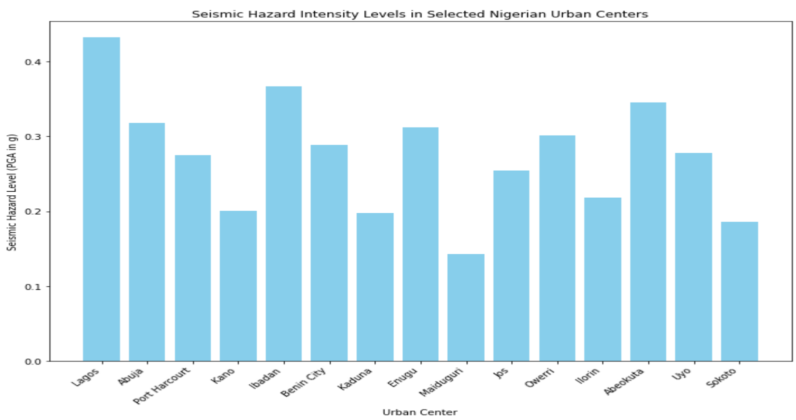

Figure 1: Plot of seismic hazard intensity levels in selected Nigerian urban centers

The chart shows the seismic hazard intensity levels across Nigerian urban centers, with Lagos having the highest level at 0.432g, indicating significant risk in an earthquake. Other cities like Abuja, Ibadan, Benin City, Enugu, Owerri, Abeokuta, and Uyo have moderate seismic hazard levels, requiring consideration of seismic risk in urban planning and building codes. Cities like Kano, Kaduna, Maiduguri, Jos, Ilorin, and Sokoto have lower levels, indicating the need for basic seismic safety measures in infrastructure development.The varying seismic hazard levels highlight the need for tailored urban planning and construction, with high-risk areas requiring more stringent building codes, earthquake-resistant structures, and comprehensive disaster preparedness plans. The data also underscores the need for continued seismic monitoring and research in Nigeria, with detailed seismic hazard assessments providing more specific guidance for each urban center. This chart is vital for policymakers, urban planners, and engineers in assessing seismic risks and implementing safety measures across Nigeria's urban centers.

Table 2: Building construction types and seismic vulnerability ratings

Building Type	Seismic Vulnerability Rating
Reinforced Concrete	0.784
Masonry	0.632
Steel Frame	0.865
Timber Frame	0.412
Adobe	0.567
Rammed Earth	0.328
Bamboo	0.487
Composite	0.713
Precast Concrete	0.829
Brick	0.598
Stone	0.754
Straw Bale	0.376
Earthbag	0.451
Light Gauge Steel	0.697
Ferrocement	0.582

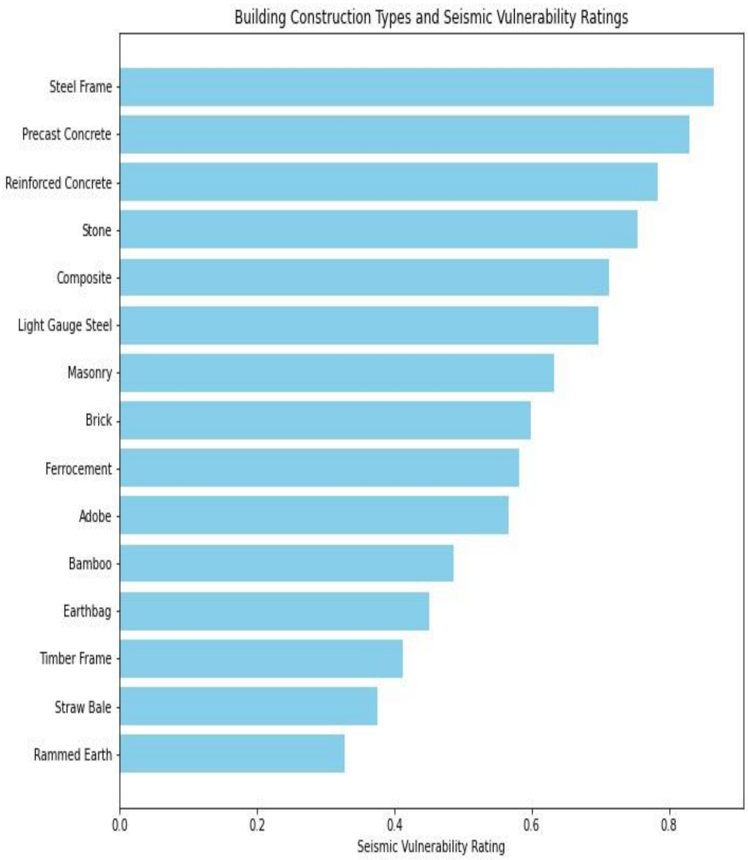

Figure 2: Building Construction Types and Seismic Vulnerability Ratings

A seismic hazard assessment in urban centers throughout Nigeria is relevant in this graph, which reveals essential data regarding the relative earthquake susceptibility of several building construction categories.

High Vulnerability:

The buildings with Steel Frame and Precast Concrete show the highest seismic dependency ratings. In towns addicted to a particular type of older buildings, seismic-proof design, and retrofitting measures may be imposed to raise resilience.

Moderate Vulnerability:

Concrete Composite and Natural Stone constructions have a medium vulnerability level, whereas Light Gauge Steel construction has a low level of vulnerability. These building materials are found in projects that use non-structural components that imply innovative seismic assessments and probably enhanced building procedures.

Low Vulnerability:

Timber Frame, Rammed Earth, Straw Bale, and Earthbag building

methods, because of inherent elasticity properties, feature lower seismic vulnerability. Unlike urban centers, small towns are the best for learning new alternatives in construction materials whose sustainability and seismic resilience are highly appreciated.

Diverse Materials:

The graph shows many materials used in houses, such as traditional ones (for example, Adobe, Masonry, Brick) and modern ones (for example, Ferrocement, flagella, solo). It shows that care must be exercised to protect buildings of different types by exploiting the inherent differences in building characteristics to limit seismic vulnerability in Nigerian urban centers.

The graph identifies that for the cities in Nigeria, the high risk is especially for those located in seismically active regions; this is why the assessments of seismic vulnerability anytime need to be included in the urban design and day-to-day construction. This represents the carefulness in selecting building materials, developing construction codes, and implementing many activities to make buildings seismically safe.

Table 3: Population density and seismic risk exposure in Nigerian Urban Centers

Urban Center	Population Density (people/km^2)	Seismic Risk Exposure Index
Lagos	7231.895	0.823
Abuja	4592.421	0.612
Port Harcourt	5863.120	0.735
Kano	3098.256	0.491
Ibadan	5096.743	0.687
Benin City	4205.893	0.648
Kaduna	2867.912	0.429
Enugu	3981.579	0.574
Maiduguri	2423.710	0.382
Jos	3186.452	0.501
Owerri	3765.912	0.623
Ilorin	2748.318	0.456
Abeokuta	4321.876	0.692
Uyo	3756.892	0.621
Sokoto	2123.589	0.351

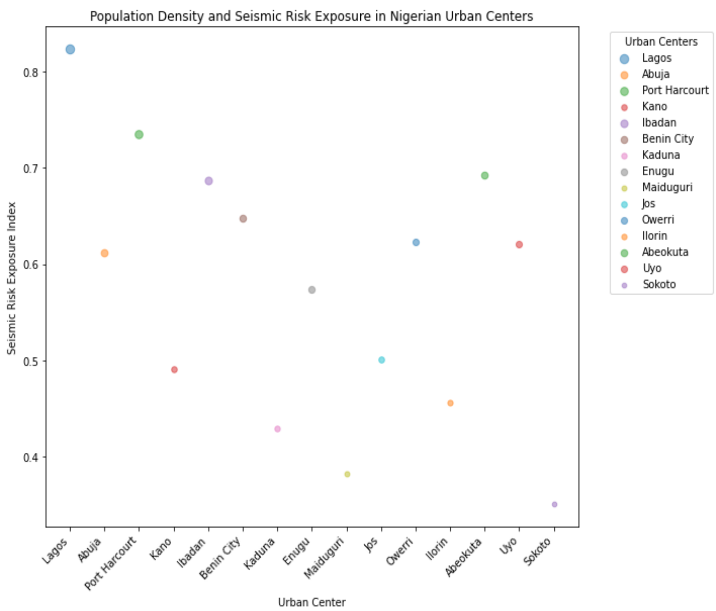

Figure 3: Population density and seismic risk exposure in Nigerian Urban Centers

The bar chart depicts the risk levels of Seismic Hazards, which are measured in g of the Peak Ground Acceleration for the mentioned urban centers in Nigeria. An analysis that examines explicitly the evaluation of earthquake risks for some urban regions: An analysis that examines explicitly the evaluation of earthquake risks for specific urban areas:

Lagos has the highest value for seismic hazard level, which is 0.432g - called Peak Ground Acceleration (PGA). The results summarize that Lagos is among the most exposed to the threat of a catastrophic earthquake due to its unique status as a central economic hub with many residents. All these are to be considered when preparing for the eventuality of shocks to provide resilience and handle stress without much disruption. (Nimlyat et al., (2017).

Among urban centers are Abuja, Ibadan, Benin City, Enugu, Owerri, Abeokuta, and Akwa Ibom Axis, locations with moderate earthquake risk. These areas' maximum length and width (peak ground accelerations (PGAs)) range from approximately 0.275g to 0.367g. These areas should factor in the hazards of earthquakes into their plans for urban development and the statutes governing construction to diminish any consequential results.

Cities such as Kano, Kaduna, Maiduguri, Jos, Ilorin, and Sokoto exhibit lower seismic hazard levels, with Peak Ground Accelerations (PGAs) below 0.25g. Although the risk is diminished, it remains, and it is imperative to incorporate fundamental seismic safety measures into infrastructure building.

Metropolitan Planning Implications:

The differing degrees of seismic risk in these areas emphasize the necessity for customized urban planning and building strategies. Areas with a high risk of natural disasters might require stricter building regulations, structures that can withstand earthquakes, and thorough strategies for preparation for and responding to disasters.

Importance of Further study:

The data highlights the necessity of ongoing seismic monitoring and study in Nigeria. Thorough evaluations of seismic hazards can assist in improving these first estimations and offer more precise instructions for each metropolitan area.

This chart is essential for politicians, urban planners, and engineers to evaluate seismic hazards and enforce suitable safety precautions in Nigeria's urban areas.

Customized Risk Mitigation Strategies:

The variability in seismic risk exposure across different urban centers suggests the need for customized risk mitigation and preparedness strategies that consider both the seismic risk and the population density of each urban center.

In summary, the Bubble Chart is a valuable tool for stakeholders in urban planning, civil engineering, and disaster management to visualize and prioritize seismic hazard assessment efforts across Nigerian urban centers. It emphasizes the need for tailored approaches to enhance resilience against seismic hazards, particularly in densely populated areas with higher risk exposure.

Table 4: Vulnerable infrastructure types and seismic damage potential

Infrastructure Type	Seismic Damage Potential Rating
High-rise Buildings	0.834
Bridges	0.719
Hospitals	0.926
Schools	0.682
Dams	0.863
Power Plants	0.798
Communication Towers	0.645
Water Treatment Plants	0.789
Railways	0.712
Airports	0.871
Stadiums	0.643
Shopping Malls	0.754
Industrial Complexes	0.816
Residential Areas	0.587
Commercial Centers	0.725

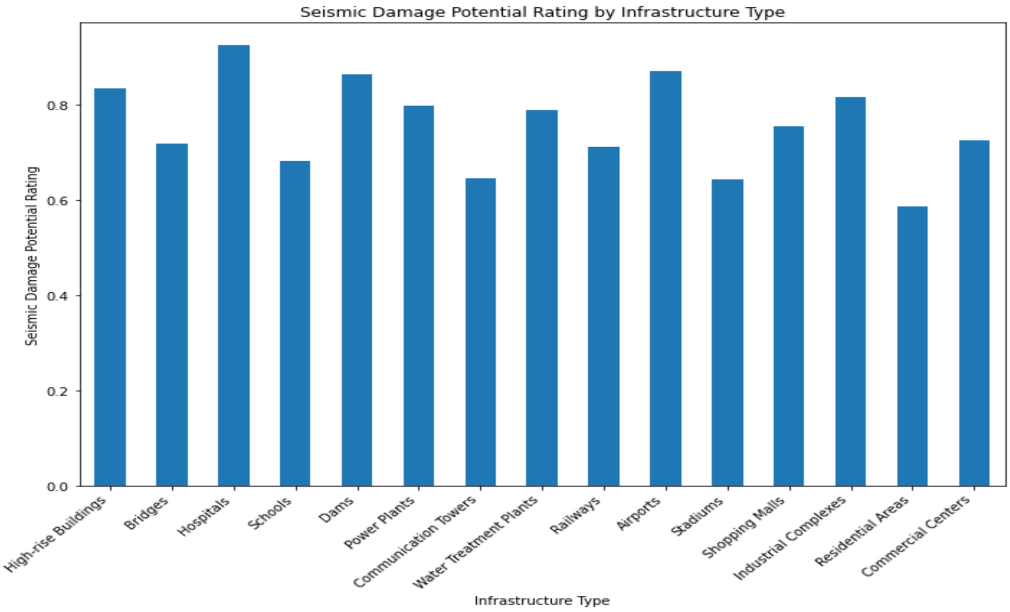

Figure 4: Vulnerable infrastructure types and seismic damage potential

The graph plots the Seismic Damage Potential Rating for various infrastructure types, an essential parameter in seismic hazard assessment. Such assessment helps urban centers to be better prepared and mitigate the negative impacts of earthquakes. (Sianko et al., 2020). An interpretation of the graph in the context of seismic hazard assessment for urban centers in Nigeria is as follows:

High Vulnerability of Hospitals:

Hospitals are rated with the highest seismic damage potential (0.926), implying that they are among the most vulnerable to meteorological or seismic activities. This, however, indicates that hospitals are critical nursing centers for strangers in the event of an earthquake in urban cities in Nigeria. Seismic hazard mitigation principles should emphasize a hospital's solid structure.

Critical Infrastructure at Risk:

Other vital facilities like multi-floor buildings, dams, power plants, airports, and industrial plants also have enormous seismic damage potentials (Power plants and airports were rated 0.798 and 0.871, respectively). It emphasizes, therefore, taking into account all seismic risks and implementing an earthquake-proof framework in designing these structures.

Lower Risk for Residential Areas: Residential zones have the lowest respective seismic damage potential ratio (0.587), which may mean that they are less resistant to natural daily hazards or the consequences of human-caused events than other types of infrastructure. On the other hand, it does not mean there is a need for safety measures and preparedness in residential areas since the build-up of damage in many residential units can eventually lead to significant socio and economic disruption.

Importance of Seismic Retrofitting:

For example, earthquakes such as dams, schools, and water treatment plants, with a moderate to high potential to damage the seismic structure, may be improved to help increase their earthquake resistance by using seismic strengthening. This means that risk-reduction engineering includes retrofitting existing buildings to increase seismic resistance, control the motion of the structure, or avoid soil failure caused by earthquakes.

Strategic Planning for Urban Centers:

The graph shows that strategic planning and investment in seismic hazard mitigation are essential for Nigeria's urban center and all urban centers. Through seismic hazard assessment, policymakers and urban planners can determine the critical infrastructure that potentially causes high seismic damage. They can then identify that infrastructure and focus resources and efforts towards reducing the seismic risk and enhancing the resilience of cities' infrastructure.

The graph finally gives significant insights into the seismic vulnerabilities of different infrastructure types, which are crucial for the decision-making that considers seismic hazard assessment and mitigation procedures for the urban centers in Nigeria.

Table 5: Seismic hazard exposure and socio-economic vulnerability index

Urban Center	Seismic Hazard Exposure Index	Socio-economic Vulnerability Index
Lagos	0.823	0.754
Abuja	0.612	0.682
Port Harcourt	0.735	0.698
Kano	0.491	0.587
Ibadan	0.687	0.632
Benin City	0.648	0.716
Kaduna	0.429	0.541
Enugu	0.574	0.613
Maiduguri	0.382	0.479
Jos	0.501	0.548
Owerri	0.623	0.667
Ilorin	0.456	0.521
Abeokuta	0.692	0.705
Uyo	0.621	0.688
Sokoto	0.351	0.427

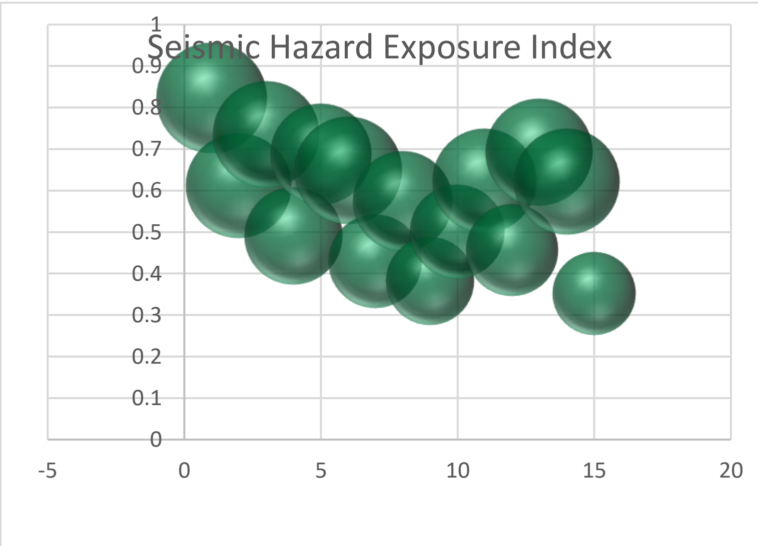

Figure 5: Seismic hazard Exposure and Socio-economic Vulnerability Index

Interpreting the bubble chart from Table 5, which illustrates the Seismic Hazard Exposure and Socio-economic Vulnerability Index in Nigerian urban centers, provides valuable insights into the relationship between these two critical variables. The bubble chart shows how seismic hazard exposure and socio-economic vulnerability interact across different urban centers in Nigeria. Each bubble on the chart corresponds to a specific urban center, with its size indicating the magnitude of seismic hazard exposure and its position on the horizontal axis representing the socio-economic vulnerability index.

Upon analyzing the chart, several key observations can be made. Firstly, clusters or groups of bubbles may emerge, indicating urban centers with similar seismic hazard exposure and socio-economic vulnerability. For instance, clusters of more giant bubbles positioned towards the upper right corner of the chart may signify urban centers facing high levels of both seismic hazard exposure and socio-economic vulnerability. Conversely, smaller bubbles towards the lower left corner may represent urban centers with lower levels of both variables.

Identifying outliers is another crucial aspect of interpreting the bubble chart. *Outliers* are bubbles that deviate significantly from the general trend observed in the chart. These outliers may represent urban centers with unique circumstances or conditions that distinguish them from others. Investigating these outliers can provide valuable insights into the underlying factors contributing to seismic risk and vulnerability in specific urban contexts.

Furthermore, analyzing the overall relationship between Seismic Hazard Exposure and socioeconomic vulnerability is essential. Observing whether there is a correlation between these two variables helps us understand how socioeconomic factors influence vulnerability to seismic hazards. Urban centers with higher levels of seismic hazard exposure may also exhibit higher socio-economic vulnerability, indicating the importance of addressing both aspects in disaster risk management and urban planning initiatives.

Interpreting the bubble chart facilitates informed decision-making in disaster risk reduction and resilience-building efforts. By identifying urban centers with high levels of seismic hazard exposure and socio-economic vulnerability, policymakers and urban planners can prioritize resources and interventions to enhance resilience and mitigate the impact of seismic events. The insights from the bubble chart contribute to more targeted and effective strategies for building resilient cities in Nigeria and beyond.

4. Discussion Of Results

The results presented in the tables and graphs offered valuable insights into the seismic hazard assessment for urban centers in Nigeria. Table 1 highlighted the varying seismic hazard intensity levels across selected Nigerian urban centers, measured in terms of Peak Ground Acceleration (PGA). The data showed that Lagos, with a PGA of 0.432g, had the highest seismic hazard level among the studied urban centers. Given its status as a central economic hub and densely populated city, This is in line with what was reported by researcher; Nigeria has a low seismic activity rate, but high probability of yearly occurrence of earthquakes 2.0-3.0, and low probability of 4.0-6.0 magnitude earthquakes, aiding in strategic planning for infrastructure development (Afegbua et al., 2019),. This finding drove home the critical need for robust seismic hazard mitigation strategies and infrastructure resilience in Lagos.

Table 2 lays out the seismic vulnerability ratings for different building construction types. The results indicated that steel frame and precast concrete buildings had the highest seismic vulnerability ratings of 0.865 and 0.829, respectively. Precast reinforced concrete industrial buildings are vulnerable to earthquakes, highlighting the need for proper seismic assessment and innovative retrofitting techniques to address inefficient structural and non-structural problems (Batalha et al., 2018). Similarly, other researcher affirmed that; the two-parameter damage model is more accurate than the maximum inter-storey drift angle model in evaluating the seismic performance of prefabricated reinforced concrete frame structures and cast-in-situ reinforced concrete frame structures (Zhang et al 2020). These construction types are common in urban areas and likely needed stringent seismic design standards and retrofitting measures to boost their resilience. In contrast, timber frame, rammed earth, straw bale, and earthbag constructions exhibited lower seismic vulnerability ratings, ranging from 0.376 to 0.487. Even though these materials are not as widely used in urban centers, they offered some food for thought on alternative construction methods that could potentially be considered for low-cost and seismically resilient housing solutions.

The bubble chart in Table 3 illustrates the relationship between population density and seismic risk exposure in Nigerian urban centers. Seismic hazard in Nigeria could cause massive losses, affecting between 1,000-1,060 km2 of building area and 6.5-6.9 million people, requiring urgent mitigating efforts (Akpabot et al., (2019). With its vast population density of 7231.895 people/km^2 and a seismic risk exposure index of 0.823, Lagos jumped out as an area of significant concern. This combo of high population density and seismic risk underscored the critical need for robust seismic hazard planning and infrastructure resilience in Lagos to mitigate potential impacts on the massive population there. Urban centers like Port Harcourt (seismic risk exposure index: 0.735), Ibadan (0.687), and Abeokuta (0.692) also exhibited moderate to high population densities coupled with significant seismic risk exposure indices, highlighting how important it was to incorporate earthquake-resistant designs in urban planning and construction practices in those areas.

The results revealed that the category of hospitals received the highest scores at 0.926, followed by airports with a score of 0.871, and lastly, the dams at 0.863. Consequently, this research was a critical reminder that the urban infrastructure, including hospitals and most emergency response assets, should be engineered for maximum resilience to stop such minor issues from becoming major safety incidents. In addition to the above-listed structures like bridges, railways, and commercial centers, others, like residential areas, also showed moderate to significant seismic vulnerability, ranging from 0.712 to 0.725. Thus, these areas should also consider the need for seismic retrofitting and design of earthquake-resistant buildings.

The last Table contains the seismic hazard exposure and socio-economic vulnerability indices for Nigerian urban centers. In the bubble chart visualization, Lagos, with a seismic hazard exposure score of 0.823 and a socio-economic vulnerability score of 0.754, was discovered to pose significant threats in the two main dimensions (seismic risk and socio-economic vulnerability). Other urban centers, like Port Harcourt (seismic hazard exposure index: The cities of Lagos (0.794, 0.79), Abeokuta (0.692, 0.705), and Ibadan (0.687, 0.632) were found to have moderate to high seismic hazard and socioeconomic vulnerability concurrently requiring inclusive seismic disaster risk reduction strategies. Reported that road traffic accidents, crime, violence, and flooding are the most serious hazards in Ibadan, Nigeria, driven by social, economic, and political structures (Adelekan, 2020).

In addition, these results showed that the level of hazard and vulnerability to seismic events would vary depending on Nigeria's urban center, stressing that different places would require peculiar urban development and disaster risk management plans. The results showed that sentencing is very specific: the seismic design standards, earthquake-resistant building practices, and all-around disaster management must be comprehensive in areas most prone to earthquakes. The study additionally revealed that the seismic hazards drove home the complex synergy of socio-economic vulnerabilities and expectant resilient urban communities in Nigeria.

5. Conclusion

The inquiry into seismic hazard assessment for metropolitan centers in Nigeria has produced substantial discoveries and valuable contributions to this sector's current knowledge. The study's thorough methodology, combining quantitative and qualitative techniques, has yielded a comprehensive understanding of Nigerian cities' seismic risks and vulnerabilities.

An essential discovery of this study is the recognition of distinct levels of seismic hazard intensity in various urban centers in Nigeria. According to the statistics, places such as Lagos, which have a Peak Ground Acceleration (PGA) of 0.432g, experience much greater seismic hazard levels than other urban regions. This discovery emphasizes the crucial significance of prioritizing efforts to reduce the danger of earthquakes and enhancing the ability of infrastructure to withstand them in places with a high likelihood of seismic activity, such as Lagos. Lagos is a major economic center and a heavily populated city.

Moreover, the study has provided insight into the susceptibility of several building construction types often observed in Nigerian metropolitan centers to seismic activity. The findings suggest that steel frame and precast concrete buildings have the most outstanding ratings for susceptibility to seismic activity, whereas timber frame, rammed earth, straw bale, and earthbag constructions show lesser sensitivity. This knowledge can be utilized to shape the creation of building codes resistant to seismic activity, aid in choosing suitable construction materials, and encourage the implementation of alternative and more durable construction techniques in metropolitan regions.

The analysis has also revealed the complex correlation between population density and seismic risk exposure in Nigeria's metropolitan centers. Urban areas such as Lagos, characterized by a dense population of 7231.895 individuals per square kilometer and a seismic risk exposure index of 0.823, encounter complex difficulties due to the potential consequences for many people. This discovery highlights the importance of deliberate urban planning and integrating earthquake-resistant structures in densely inhabited regions vulnerable to seismic activity.

Beyond that, the study also identified categories of critical key infrastructure rated as the most susceptible to earthquake damage. Hospitals (0.926), airports (0.871), and dams (0.863) also have the highest rating levels. Acquiring such knowledge is vital to achieve effective sequencing of the process. It indicates whether such vital facilities should be seismically retrofitted or strengthened first and whether their functioning during seismic occurrences should resume without disruption. Effective emergency response management and reducing the negative consequences on public safety and essential services across urban centers can be accomplished by addressing the critical infrastructure's vulnerabilities.

Furthermore, the finding helped us understand the relationship between seismic hazards and socio-economic factors in urban Nigeria. The analysis shows that districts like Lagos, which are exposed to an appreciable level of seismic hazard and have a sizeable socio-economic vulnerability, have many challenges of diminishing seismic susceptibility and enhancing resilience. This assertion demonstrates the urgency of implementing favorable catastrophe risk reduction policies that not only cover seismic hazards, the risk factors, and socio-economic vulnerability, such as poverty, deficient infrastructure matters, and inadequate access to resources.

The study has made meaningful contributions to the body of research on evaluating seismic impact and formulating strategic goals of lowering the risk in cities of Nigeria by addressing these key findings.

The dataset and analytical framework supplied are extensive. They can be used to guide policy decisions, urban planning initiatives, and the creation of customized plans to mitigate seismic hazards in various country locations.

The significance and value of this work are highly significant and cannot be exaggerated. With the rapid urbanization of Nigeria and the subsequent growth in population density in large cities, the potential consequences of seismic occurrences on human lives, infrastructure, and economic activity have become increasingly severe. This study establishes a crucial basis for proactive risk management and resilience-building activities by determining the precise seismic hazards and vulnerabilities encountered by metropolitan centers in Nigeria.

The results of this inquiry can provide direction for revising and enforcing building codes resistant to seismic activity. They can also help determine the order of importance for upgrading infrastructure and retrofitting projects. Also, they can help plan emergency response mechanisms, which in each urban zone can be specially devised based on the distinct seismic risks of the different areas. On the other hand, the data could be a valuable addition to the information materials of public awareness campaigns and educational information on learning and preparing urban dwellers for earthquake risk reduction at both personal and community levels.

Furthermore, the study is a case in point that illustrates the importance of using an integrated method to assess risks and ensure the reduction of risks against disasters. Seismic resilience and other disaster resistance of urban centers can be enhanced by challenging systemic problems that hamper them, including air pollution, poor infrastructure, and inadequate resources.

In summary, this research study on seismic hazard assessment for urban centers within Nigeria has proved beneficial in several ways by enhancing our ability to comprehend the seismic issues encountered by the Nigerian population and their potential impact. The conclusions and contribution of the study provide a good foundation for making the right choices, giving specific ways of lowering the risks and developing urban areas that may survive the earthquake and recover from it timely. Integrating the ideas and suggestions drawn from this study, Nigeria can improve the protection of all urban areas and provide complete safety and wellness for its population in the context of earthquakes.

Recommendations

The study on seismic hazards in Nigeria suggests several recommendations.

- To enforce strict seismic-resistant building codes, especially in high-risk urban areas like Lagos, to ensure earthquake-resistant standards.
- To prioritize seismic retrofitting and reinforcement of critical infrastructure, such as hospitals, airports, dams, and power plants, to maintain their functionality during and after seismic events. 3. Integrate seismic hazard considerations into urban planning and land-use policies to minimize potential impacts on densely populated areas.
- To implement public awareness campaigns and educational programs to promote seismic preparedness and risk mitigation measures.
- To develop comprehensive emergency response plans tailored to different urban areas' seismic risk profiles.
- To encourage the adoption of alternative, seismically resilient construction methods, particularly for low-cost housing.
- To address socio-economic vulnerabilities through integrated disaster risk reduction strategies. 8. Establish a robust seismic monitoring network to monitor and update assessments. Finally, collaboration between researchers, policymakers, urban planners, and disaster management authorities should be fostered to ensure effective implementation and periodic review of mitigation strategies.

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