Seismic Activities in Ghana: A Systematic Review

Baah. Asare-Bediako[a], *Cyril D. Boateng*[a,b*], *Nicholas Opoku*[c], *Sylvester K. Danuor*[a], *Lawrence N.B. Arthur*[a], Yvonne M. Anokwa[d]

[a]*Department of Physics, College of Science, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana*

[b]*Caburu Company Ltd, P. O. Box MD 2046, Madina, Accra, Ghana.*

[c]*Geological Survey Department (Seismology and Earthquake Engineering Division), Box M80, 6 Mayor Rd, Accra, Ghana*

[d]*Ministry of Lands and Natural Resources – GLRSSMP, P. O. Box M 212 Ministries-Accra, Ghana*

**To whom correspondence should be addressed: E-mail: cyrilboat@knust.edu.gh*

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Abstract

Seismic activities pose significant challenges to societies globally. Therefore, it is crucial to understand their occurrence, patterns, and impacts. By studying seismic activities, including earthquakes, researchers can investigate their occurrence, distribution, and characteristics which can provide effective management and risk reduction strategies. The southern part of Ghana is prone to earthquakes and this study aims to shed more light into the nature of seismic events in the area and country at large. A systematic review was conducted using the PRISMA technique across three electronic databases (SCOPUS, Dimensions and Google Scholar) to identify relevant studies published between 2000 and 2023. Extraction of data and quality assessment were performed in order to ensure reliability and validity of included studies. Results identified only 17 papers from published records to meet the inclusion criteria. Despite the grave threat earthquakes pose to vital infrastructure and human life in Ghana, research in this area remains remarkably deficient. Our findings underscore the urgent need for further study given the catastrophic potential of seismic disasters in the region. Moreover, upon scrutinizing the methodologies deployed in extant literature concerning seismic activity in Ghana, a recurring constraint that emerged was the scarce availability of data. In essence, this study offers an indispensable panorama of earthquake research in Ghana, bridging the existing knowledge chasm on seismic phenomena in the region. The insights gleaned from this review promise to fortify our comprehension of Ghana's seismic activities, thereby bolstering the country's capabilities for more effective preparedness and response strategies.

Keywords: Seismic activities, Systematic Review, Risk Reduction, Ghana

1. Introduction

Beyond Ghana's thriving marketplaces and busy streets is a potential geological time-bomb that quietly lies beneath the surface. Positioned on the west coast of Africa, Ghana shares its external borders with Cote d’Ivoire to the west, Burkina Faso to the north, and Togo to the east. (Figure 1). The West African Craton, where Ghana is located is a region with little to no seismic activity [1]. Despite this, the country has recorded destructive earthquakes near its southern regions [2].

Study shows that these seismic events may be attributed to an already existing zone of weakness in the Earth's crust and this zone enables the concentration and accumulation of tectonic stresses, even if they originate from a distant source [3]. The seismic events in Ghana are characterized by local fault systems and intraplate seismic activities, which differ from the conventional plate tectonic theory [4].

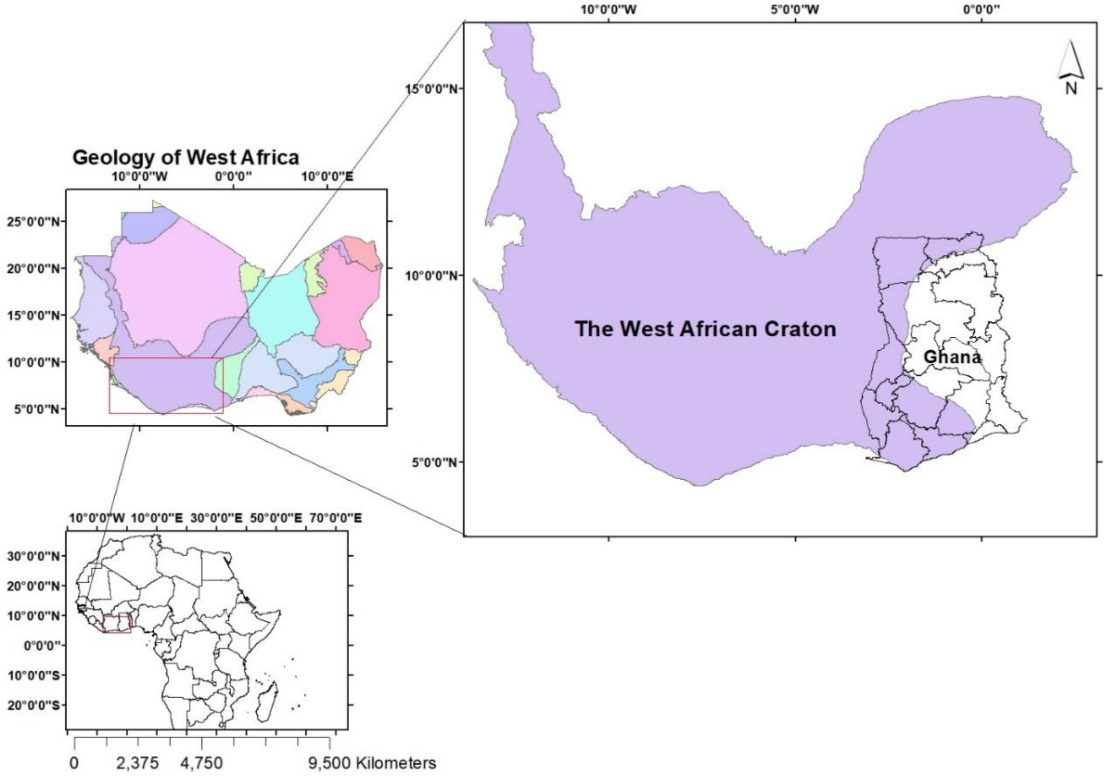

Figure 1. A map highlighting the position of Ghana on the West African Craton

The United States Geological Survey (USGS) estimates that approximately 10,000 individuals ~~per~~ die as a result of earthquakes every year. 80% of these are recorded in developing countries like Ghana. Major earthquakes Ghana has experienced occurred in the years 1636, 1862, and 1939 [5]. Increased awareness and understanding of Ghana's seismic activity have brought attention to the potential negative impacts on property, human life, and economic development. However, lingering questions remain about Ghana’s preparedness for a major earthquake and its attendant consequence. To better comprehend the seismicity of the area and develop practical strategies to lessen the effects of seismic events on the populace and the economy, a comprehensive study of seismic activities in Ghana is therefore required [6].

In this paper, we present a systematic review of seismic activity in Ghana. This review will take into account past trends, present trends, and potential risks in the future. We intend to contribute to the ongoing efforts to better understand the nature of seismic activities in Ghana by reviewing the frequency of published papers on the research area, examining the published records, and also delineate the possible danger zones in the country by evaluating seismic data and published records. By examining the seismological observatory's capacity to identify seismic events and react to them, we also aim to evaluate the efficacy of Ghana's current seismic monitoring and response systems.

Finally, this paper aims to raise awareness of seismic activity among Ghanaian policymakers, the general public, and other stakeholders. By making information about earthquakes and related phenomena easily accessible, we aim to encourage a culture of preparedness and resilience which will lessen the impact of future seismic disasters.

2. Geological Setting

Ghana falls within the West African Shield (as shown in Figure 1) which has remained stable for over 1700 million years [7]. Five major rock units underly the country. They are the Birimian, the Tarkwaian, the Dahomeyan, the Togo Series, and the Buem Formation [1]. The Birimian Supergroup constitutes a substantial component of the West African Shield and is considered to have been deposited during the Paleoproterozoic age. The Tarkwaian rock units on the other hand, consist of clastic sedimentary rocks which are products of the erosion and transportation of materials derived from the Birimian provenance [8]. The Dahomeyan, Togo Series and the Buem Formation are predominant rock units that underlie the eastern parts of the country [1]. A geological map of the various geological units of Ghana is shown in Figure 2. The southern region of Ghana where most of these seismic events seem to occur is dominated by rocks of the Birimian Supergroup which are composed of volcanic and sedimentary rocks. These rocks have been subjected to several phases of deformation and metamorphism, resulting in the development of several structural features such as folds, faults, and shear zones [9]. The country is also home to major fault systems, including the Akwapim-Togo Ranges fault system, the Coastal Boundary Fault, and the Romanche Fracture. The Romanche Fracture is an offshore fault system related to the opening of the Atlantic Ocean [2]. Figure 2 shows the northeastern direction of the Akwapim Fault Zone. It extends through Kpong, Ho, and the Republics of Benin and Togo. Seismic studies have established that Coastal Boundary Fault is the most active fault system across the country [10]. At a distance 3 to 5 kilometers from the coast, the Coastal Boundary Fault strikes at a north-northeasterly angle of 60-70 degrees, down throwing the block south of it over a distance of several kilometers [2]. The two faults intersect at Nyanyano; a vicinity around Accra which had its fair share of earthquakes in the past. A review by Amponsah [1] shows that at the junction of the Coastal Boundary Fault and the Akwapim Fault Zone, earthquakes have occurred in the past and continue to be a potential occurrence in the future.

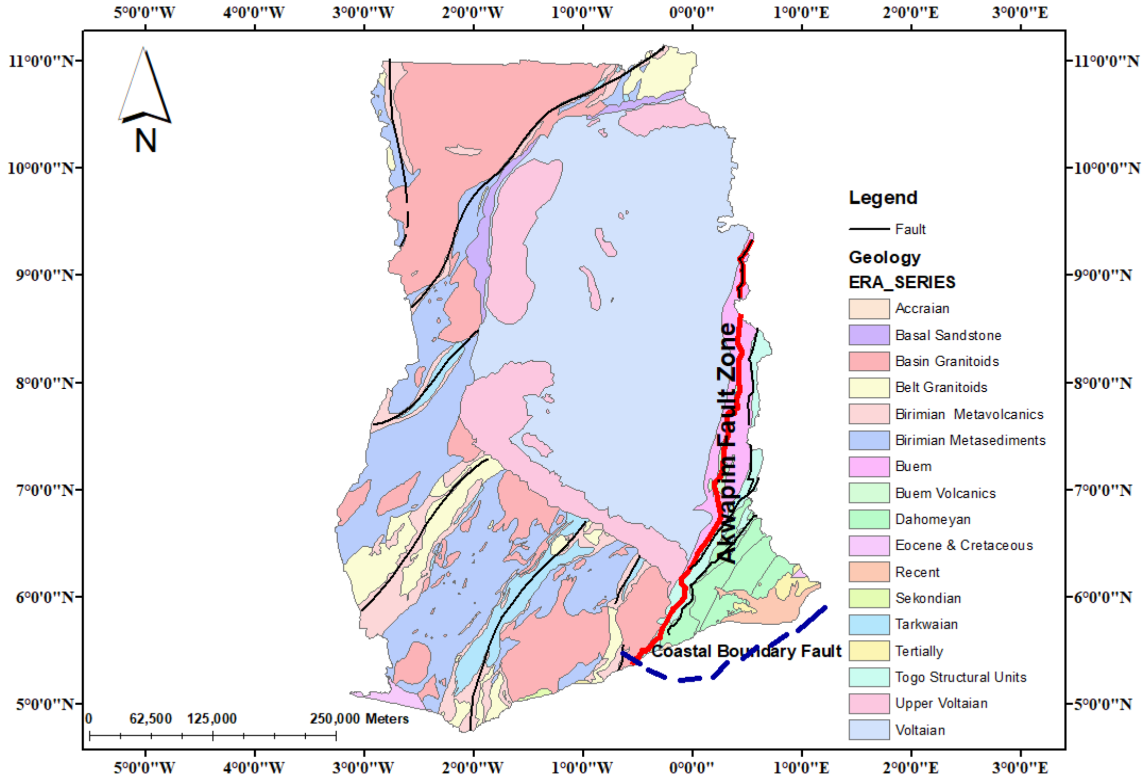

Figure. 2. A geological map of the various geological units of Ghana showing major fault zones

3. Systematic Review Methodology

This study was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [11]. In our study, we employed a combination of keywords to categorize scientific papers that were relating to seismic activities in Ghana. We searched for papers written in English ranging from the year 2000 to date using three electronic bibliographic databases; SCOPUS, Google Scholar, and Dimensions. Specific keywords used in our search were ("earthquake" OR "geohazard" OR "seismic") AND "Ghana". After the search 154 papers were identified from the three databases; 30 from Google Scholar, 95 from Dimensions, and 28 papers from Scopus. Table 1 shows a breakdown of the identified papers from the databases.

Table 1: Various databases and the number of papers identified

Database	Number of papers
SCOPUS	29
Dimension	95
Google Scholar	30
	154

After exporting all the papers from the three databases, 113 duplicate papers were identified and removed using a Python algorithm. There were no restrictions on the source title; however, our search was limited to the following areas: Earth and Planetary Science, Environmental Science, Engineering, Physics and Astronomy, Energy, and Multidisciplinary areas. Figure 3 shows a schematic workflow for the data screening process.

After including relevant areas and removing duplicates, 41 papers were left. These 41 papers remaining were assessed for further analysis by three other reviewers independently by reading their abstract texts. Finally, after reviewing, 17 out of the 41 papers (42.5%) were identified by the reviewers as meeting the eligibility criteria for our research.

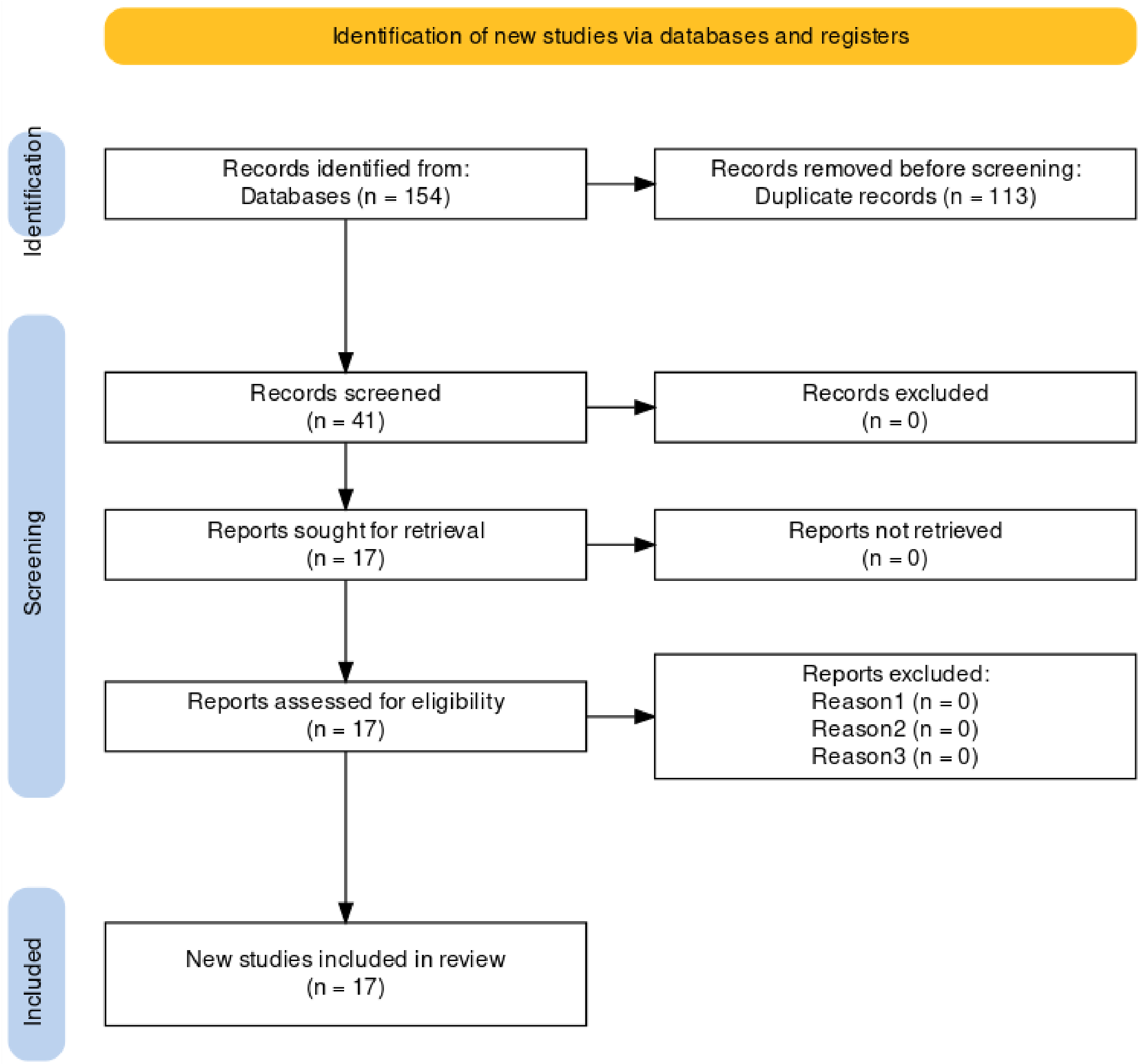

Figure 3: Schematic workflow for the data screening process using the PRISMA technique

4.0 Results

4.1 History of Seismicity in Ghana

In general, the West African Craton is considered a stable one; however, Hartnady and Benouar [12] have observed the existence of relatively slow motions on the western part of the plate where Ghana can be situated. Southern Ghana is considered seismically active due to the existence of the Akwapim Fault, which runs through the southeastern parts of the country as well as the Coastal

Boundary Fault and the Romanche fracture which represent the offshore fault systems. The activity along these faults have led to Ghana experiencing several earthquakes ranging in magnitude from 2.0 to 6.5 on the Richter scale. Historical earthquakes in Ghana can be dated back as far as 1615. The country recorded its first earthquake in Elmina, a town located along the coast of the country [13]. In 1636, a very severe earthquake with a magnitude of 5.7 on the Richter scale struck the Western region of the country in a town named Axim. A goldmine collapsed and workers were buried and several other buildings destroyed. The country's capital, Accra was also severely affected by an earthquake in 1862. Cracks were left on important buildings and a majority of the buildings were damaged, including the Christiansborg Castle, rendering it uninhabitable. Benin and Togo, two of Ghana's neighbouring countries, were also affected by the earthquake along the coast. The largest recorded earthquake in the country was a magnitude 6.5 event in 1939 that wiped out a whole village, Nyanyano (in the vicinity of Accra), causing significant damage and loss of life.

Recent seismic activities in Ghana have been relatively low, with the largest reported earthquake measuring 4.3 on the Richter scale in 2013, the strongest since 1939. Table 2 outlines other noteworthy earthquakes across the country. In addition to these major earthquakes, smaller earthquakes with magnitudes between 2.0 and 4.0 have occurred, but these are typically not felt by the public and do not cause significant damage.

Table 2: Major Earthquakes with magnitude, M_L >= 4.0 in Ghana Occurring Between 1615 and 2000

Town/Region	Date	Magnitude (M_L)
Axim	18th Dec 1636	5.7
Accra	7th Oct 1862	6.5
Apam	23rd Nov 1870	4.5
Kade	27th Feb 1907	4.1
Coast of Accra	22nd June 1939	6.3
Koforidua	18th Aug 1939	5.3
Offshore, Kokrobite	27th Oct 1995	4.0

4.2 Yearly Distributions

Figure 4 shows the annual distribution of papers from all accessed databases from 2000 to 2023. The chart shows that there were not more than three (3) papers published in a particular year. The maximum number of articles (3) was published in the year 2023. This was followed by 2 papers each in 2013, 2014 and 2022. One paper each was published in the years 2002, 2004, 2009, 2012, 2015, 2018, 2020 and 2021. There were no papers published in the years 2001, 2003, 2005-2008, 2010, 2011, 2016, 2017, and 2019. The trend reveals fluctuations in research activity on the seismicity of Ghana, with some years experiencing higher publication rates and others showing lower or no publication activity. Generally, the low number of papers published shows that the area is still understudied, and additional studies are required to completely comprehend the seismicity of Ghana.

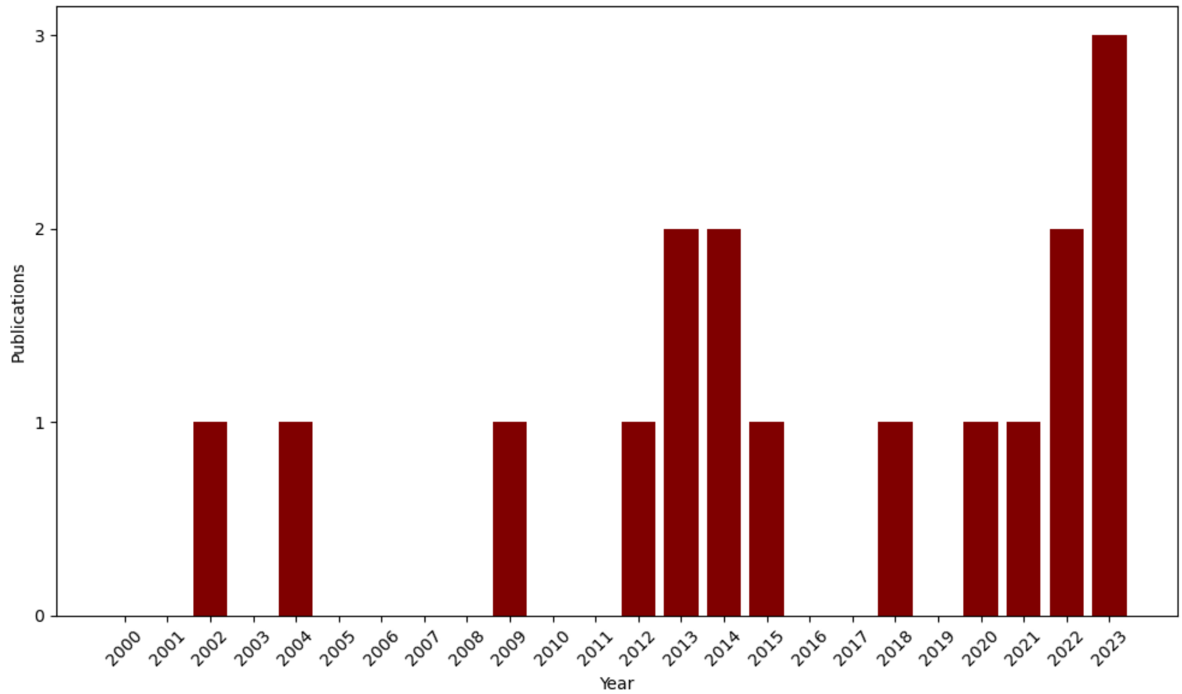

Figure 4. Total number of publications from 2000 to 2023 compiled from three databases using the PRISMA method

4.3 Methodologies Used in Assessing the Seismicity of Ghana

This section delves into the methodologies used in various research studies identified from the systematic review process. Recent developments in seismic hazard assessment have made it evident that both the probabilistic and deterministic approaches are of equal importance [14].

Amponsah (2002) [13], discussed the use of seismograph stations to record local earthquakes in southern Ghana from 1973 to 1997. The spatial relationship between the faults and the earthquakes was examined using the data collected from the seismograph stations. The epicenters were also located using the difference in arrival times. The majority of the earthquake epicenters that were found were scattered at the intersection of the Coastal Boundary fault and the

Akwapim fault zone, indicating that the faults remain active. This was shown on a microseismic map of southern Ghana.

Again, Amponsah (2004) [1], provided a comprehensive overview of Ghana's seismic activity, including historical, current, and potential tendancies, as well as efforts to mitigate the impact of earthquakes on the country. The duration method by Bacon and Banson (1980) [15] was utilized to calculate local magnitude in cases where the amplitudes were clipped together. Amponsah (2004) [1] presented several results related to seismic activity in Ghana. The majority of Ghana's earthquakes, according to the paper, occurred in the western region of Accra at the junction of the country's two main fault systems, the Coastal Boundary Fault and the Akwapim Fault Zone. Also, due to the presence of an old thrust zone that has been reactivated, the epicenters of the identified earthquakes were correlated with the degree of the activity of the faults. The paper provided important insights into the nature and causes of earthquakes in Ghana, which can help in mitigating the impact of earthquakes on the country.

Amponsah et al. (2009) [16], employed the deterministic approach. The deterministic approach used in this paper was a hybrid approach that relied on the modal summation and finite difference method. The parameters of the laterally heterogeneous local (2D) model, the earthquake source, and the average regional structural (1D) model (bedrock model) formed the input data for the ground motion simulation. The seismic ground motion along four profiles in the metropolis were computed using these techniques. Along the geological cross sections, synthetic seismic waveforms that generated peak ground acceleration, velocity, and spectral amplifications for engineering design were also produced. Peak ground acceleration and velocity calculated were between 0.14 and 0.57 g and 9.2 and 37.1 cm/s, respectively. These matched intensities between VII and IX on the Modified Mercalli Intensity scale. The greatest earthquakes were felt in areas underlain by unconsolidated sediments. The findings provided a practical manual for civil engineers to follow when designing urban structures for sustainability and safety.

Using a deterministic approach, Amponsah et al. (2012**)** [2]**,** used isoseismal maps from several earthquakes to quantify the seismic hazard in Ghana. The authors developed an earthquake catalogue that established the basis for a building code in Ghana. For the purpose of applying the building code, deterministic seismic hazard maps with distinctive hazard parameters including peak ground acceleration and macroseismic intensity, were developed for the application of the building code.

The study in Kutu (2013) [17] acquired and examined field data on tectonics and geology. The authors also reevaluated historical records of seismic activities in southern Ghana. Results of this study demonstrated that the tectonic activities of the Romanche Fracture and the St. Paul's transform-fracture systems are what cause the seismicity of southern Ghana. Reactivated faults in the Romanche Fracture Zone were the source of the onshore earthquakes recorded in Accra and the surrounding area. The reactivated faults that led to the earthquakes in the Axim region were a result of the St Paul's fracture zone, which extended through southern Cote d'Ivoire and into Ghana. Since 1879, seismic activity has decreased throughout the St. Paul's transform. However, there is ongoing seismic activity in southern Ghana as a result of motions recorded across the Romanche Transform and fracture zone. The study found that the Atlantic seafloor transform faults and fracture zones of West African extend to Ghana and have a substantial role in the earthquake activity in both Ghana and West Africa.

Kutu et al., 2013 [18], reinterpreted the 1939 Accra Earthquake using new field data after reevaluating historical earthquake data from southern Ghana. The authors compared historical earthquakes to determine any possible trends of seismic cyclicity in Accra and southern Ghana after reevaluating and reinterpreting the data. The findings indicated that the 1939 Accra Earthquake, which occurred 40 kilometers south of Accra, was a shallow-focus tectonic event brought on by high-angle underwater strike-slip faults.

Also, Amponsah (2014) [19], presented a research on the microseismic activity in southern Ghana. To comprehend the seismic activity in the area, geological and instrumental earthquake recordings from Ghana was examined. The paper also discussed the major faults in the region and their intersection, which are responsible for the seismic activity. The authors used the available data to identify the most seismically active areas in Ghana and suggested earthquake disaster mitigation measures to reduce the impact of any major event that may occur in the country.

Musson (2014) [20] compiled an earthquake catalogue for Ghana from secondary sources and interpreted the data to provide a new understanding of the seismicity in the region. He suggested that a significant portion of the recorded seismic activities around Accra are as a consequence of prolonged aftershock sequence of the 1862 earthquake. His research also highlighted the shortcomings of seismic monitoring in the country, which can guide future initiatives to enhance seismic monitoring and our comprehension of seismicity in the area.

Ahulu and Danuor (2015) [10] presented a comprehensive study of the establishing of a National Digital Seismic Network Observatory in Ghana. Per the authors, the approach involved a network system of six digital stations that transmitted data through a satellite to a central observatory. The observatory utilized a deterministic approach to monitor various seismic events. The data collected was analyzed by the Ghana Geological Survey's Seismic Network Observatory and made available to relevant institutions for the objective of reducing the effects of earthquake disaster.

On the other hand, Ahulu et al. (2018) [21], used a probabilistic approach to develop a seismic hazard map for the southern part of Ghana. Data from an earthquake catalogue that covered the years 1615 to 2009 was used to obtain the input parameters required for the hazard assessments. The findings from the study indicate that the seismic zones of Accra and Tema exhibit the most significant seismic hazard, characterized by an estimated peak ground acceleration of approximately 0.2 g.

Amponsah et al. (2020) [22], discussed the seismic risk in Ghana and the efforts and challenges in mitigating it. The method used in the paper included an observation survey that was carried out in March 2019 in the wake of three earthquakes that were registered in March 2018, December 2018, and March 2019 and had local magnitudes that varied from 3.0 to 4.8. The purpose of the survey was to evaluate how randomly selected locals perceived, dealt with, and responded to earthquake events. The study included distribution of questionnaires to the municipalities of Weija-Gbawe and Awutu Senya East.

Kadiri and Amponsah (2021) [6], employed a probabilistic approach, specifically probabilistic seismic hazard assessment (PSHA), to compute the area-characteristic seismic hazard parameters for Ghana, Togo, Benin, Cote D'Ivoire, Burkina Faso, and Nigeria. It involved the use of statistical models to estimate the probability of ground shaking of a certain intensity or higher occurring at a given location over a specified time period. The method took into account various factors such as the historical seismicity of the region, the tectonic setting, and the geological structure of the area. The maximum likelihood estimate was used to compute the parameters, and the ZMAP and Ha3 programs to calculate the parameters for the whole area and subcatalogues, respectively. The findings of their study can be used to assess the likelihood of future earthquakes in the region and to develop appropriate measures to mitigate the potential impact of earthquakes.

Custódio et al. (2022) [23] employed a deterministic approach to estimate an improved 1D crustal velocity model and the hypocentral parameters of 73 recently detected earthquakes in southern Ghana. The approach involved finding the best-fit solution by reducing the RMS error function of the observed and calculated arrival times.

Irinyemi et al. (2022) [24] employed a probabilistic approach for seismic hazard analysis relying on the probabilistic approach by Cornell (1968) [25] which was later modified by McGuire (1995) [26]. Depending on the regional characteristic maximum credible magnitude (Mmax), the authors calculated the maximum predicted peak ground acceleration (PGA) for dam locations throughout the West Coast Basin in southern Ghana. The probabilistic seismic hazard analysis (PSHA) was performed using the OpenQuake software; an open-source platform for seismic hazard and risk assessment. The PSHA model was based on a logic tree approach that considered different seismological models, ground motion prediction equations (GMPEs), and site conditions. Their research also estimated the PGA values for the dam sites for a 10,000-year return period, which is a common standard used in seismic hazard analysis. The findings of the study indicate that the PGA values for the dam sites were between 0.31 g and 0.52 g for a 10,000-year return period. These values indicated the high risk of damage to dam sites in southern Ghana due to seismic activity.

Mohammadigheymasi et al., 2023 [27], used an approach based on a Deep Learning (DL) model called EQTransformer tool, which used a convolutional neural network to estimate the probability of an event being an earthquake. The DL model was trained on a large dataset of earthquake waveforms to learn the features that are characteristic of earthquakes. Once trained, the model can be used to detect earthquakes in new seismic data by analyzing the waveform signals. The approach is probabilistic because it estimated the probability of an event being an earthquake rather than making a deterministic decision. The probabilistic approach allowed for a more nuanced analysis of seismic data and can help to reduce false positives and false negatives in earthquake detection.

Mohammadigheymasi et al., 2023 [3], conducted comprehensive research to characterize regional seismicity in Ghana. The authors employed deep learning (DL) to process the Ghana Digital Seismic Network (GHDSN) dataset collected between September 2012 and April 2014. EQTransformer is a DL model with a hierarchical attentive mechanism (HAM) for P- and S-phase picking as well as simultaneously identifying earthquakes. 559 arrival times (292 P and 267 S phases) were identified in a joint inversion using grid search in 1D velocity model space and a simultaneous inversion for the hypocentral parameters. The outcomes of the deep learning-based seismicity analysis support the intraplate character of the tectonic activity in the area. By combining all identified catalogues and newly detected events, the updated seismic catalogue for Ghana up to April 2022 was presented. The authors suggests that the results of this study can be utilized to increase the understanding of the seismogenic sources and processes in the region, which can be valuable for seismic hazard assessment and risk mitigation.

Mohammadigheymasi et al., 2023 [28] applied deep learning techniques to an 18-month dataset of the Ghana Digital Seismic Network (GHSDN) recorded from 2012 to 2014, using the IPIML workflow. The IPIML workflow is a six-step automated event detection, phase association, and earthquake location workflow that integrates the pair-input deep learning (PIDL) model and waveform migration location (MIL) methods. The author starts with data formatting and applies MIL (Migration Location) techniques, which are less sensitive to spurious signals on individual stations, making them more efficient for locating events with large picking uncertainties or false picks. Also, the author incorporates machine learning-aided earthquake MIL (MALMI) method, which applies back-projection and stacking to the estimated continuous phase probabilities of selected portions of continuous seismic waveforms detected by the deep learning algorithm. The workflow produced a catalog with 461 events, which is 6.3 times larger than the catalog obtained from his previous article by applying EQT with default settings. The IPIML workflow identified a previously unknown seismogenic fault with a clear spatial trend, providing more insights into fault activities and seismic hazards in the region.

Table 3 shows a breakdown of the different methodologies employed in the various papers we identified from our systematic review.

4.4 Location of Earthquakes and Danger Zones

Earthquakes can strike at any moment, with little to no warning. Therefore, it is crucial to have accurate information about earthquake occurrences in different regions and their magnitude at any given time. One of the key methods to understand, monitor, and assess earthquake activity is through the use of earthquake mapping [29]. Figure 5 is a seismicity map of Ghana showing the various seismic events from 1615 to 2021 with larger circles representing larger magnitudes and ranging from 0 to 6.5 on the Richter scale.

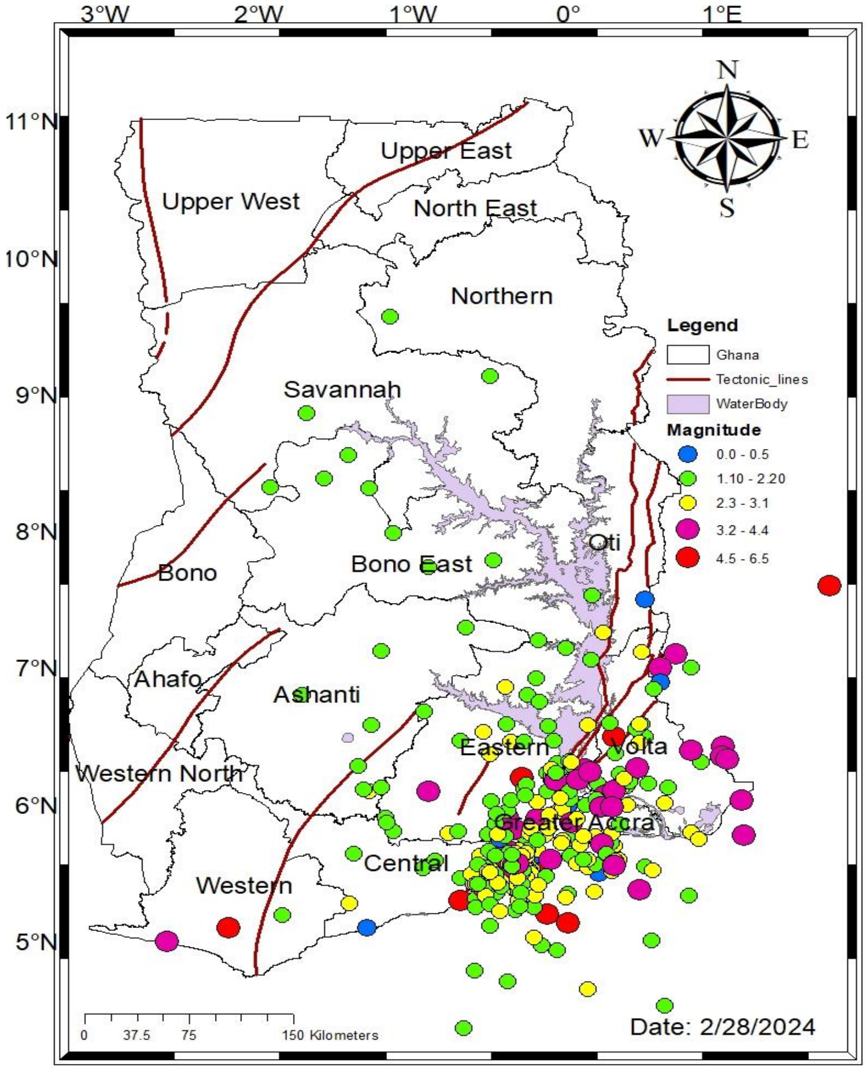

Figure 5. A seismicity map of Ghana highlighting the distribution of earthquake events from 1615 to 2021; larger dots represent higher magnitudes and smaller dots represent lower magnitudes.

Based on the seismicity map (Figure 5), it is evident that the southeastern part of the country is more prone to earthquakes compared to other regions. This closely aligns with the research findings presented in the publication by Ahulu (2018) [21]. Despite this fact, other regions within the country that have also experienced tremors in the past (as shown in Figure 5). The Ghana Seismological Observatory has installed various seismic stations around the southern regions (as shown in Figure 6) to detect seismic activities, however, the system is not dense enough and some of these tremors which occur outside the southern region are unregistered by the seismometers.

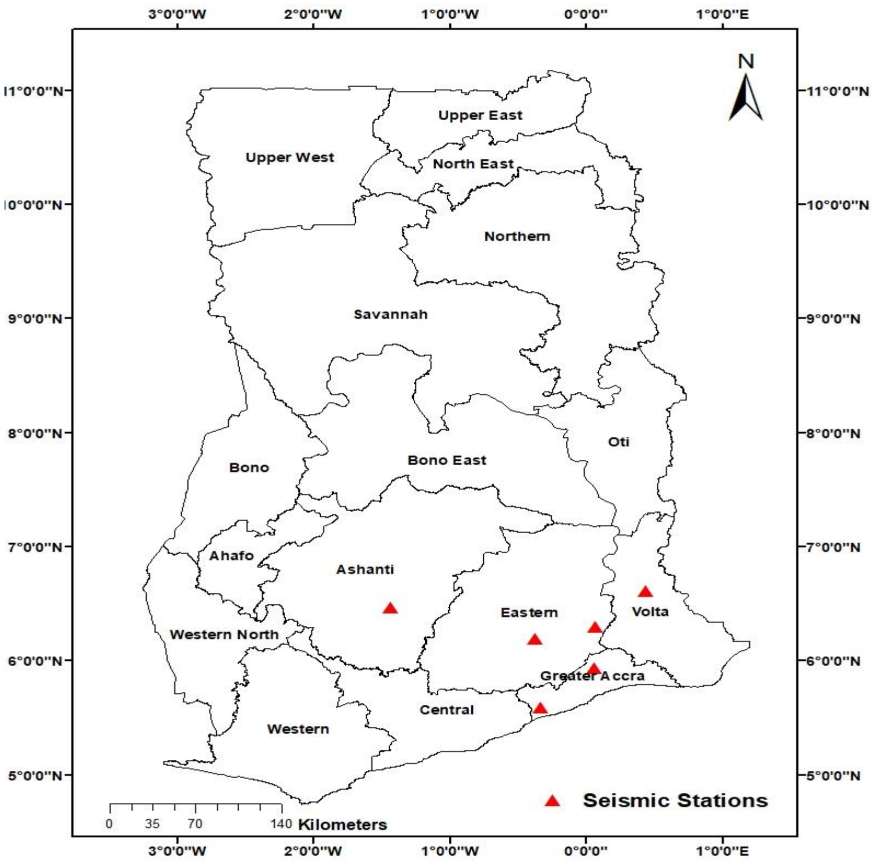

Figure 6. A map showing the distribution of the various seismic stations in Ghana

Although, seismicity maps are based on historical data and are not always indicative of upcoming earthquakes it is still crucial to be conscious of the possibility of earthquakes in any area (not only the southern parts) and take the appropriate precautions.

5.0 Discussion

The purpose of this study was to assess the general seismicity of Ghana over the past 20 years. To obtain more in-depth knowledge on the research area, we analysed related papers from three electronic databases; SCOPUS, Dimensions and Google Scholar. Detailed information about the methodologies of existing studies on the seismic activity of Ghana was explored using a systematic review process.

Our results clearly indicate a paucity of published papers on the general seismic activity in Ghana over the last two decades. This can be attributed to the low awareness and priority given to this field by key stakeholders including government institutions, academic institutions and funding agencies. African countries like Ghana suffer most of the toughest challenges worldwide, however only 1% of global research output is produced by African countries [30]. This limited research effort in the research area is alarming given the likelihood of a devastating earthquake in the southern parts of Ghana [1].

Another significant aspect is the seismicity map generated in our review. The map shows Ghana's seismic hazard areas, with some areas having a greater earthquake risk than others. Accra, the capital of the country is the most active and hazardous earthquake area in Ghana. The area holds most of the resources and important infrastructure in the country including the Golden Jubilee House which is the Seat of Government, Parliament House of Ghana, Ghana Ports and Habours Authority, Council for Scientific and Industrial Research (CSIR), the University of Ghana, etc. As a result, it is anticipated that many buildings will potentially be damaged and collapse during an earthquake, resulting in extensive damage and fatalities. This can also disrupt transportation and access to essential services such as electricity, water supply and communication services.

The review exposes the unpreparedness of the country should an earthquake occur. The seismic stations of the country although modern, are only limited to the southern sector and not dense. This could be problematic since the stations would not be able to provide detailed information for underlying fault systems for comprehensive disaster preparedness. The monitoring system also faces several challenges, including limited funding, a lack of advanced technology, and a shortage of trained personnel. Ahulu and Danuor (2015) [10] studied the nature of Ghana's digital seismic stations and were of the view that it was very expensive to pay for both local internet access and the satellite communication services needed for real-time transmission, which are rented from a US corporation. The authors also reiterated the lack of trained professionals to oversee and manage the network system's mechanical and technological aspects.

In addition to our findings, we analysed the various methodologies employed by other researchers in the field. The methodologies used in the various studies have shed more light into seismic activity and hazard assessment in Ghana. However, it is important to acknowledge and address the common limitations observed across these methodologies. One recurring limitation we observed was the limited availability of data. Studies that relied on historical earthquake records or datasets from particular time periods may have had coverage, quality, or duration restrictions. The reliance on secondary sources makes data susceptible to errors and inconsistencies and more difficult to validate its accuracy. As a result, efforts should be undertaken to enhance data collection and set up dependable, long-term monitoring mechanisms to guarantee comprehensive and reliable datasets for future studies.

Table 3. Methodological Frameworks in Previous Studies

Author	Year	Methodology Used
Paulina Amponsah	2002	-Used seismograph stations to study earthquakes in Ghana
Paulina Amponsah	2004	-Used the duration method for magnitude calculation focusing on the Western Region of Ghana
Paulina Amponsah	2009	-Employed hybrid (modal summation and finite difference) approach for ground simulation in Accra
Paulina Amponsah	2012	-Used isoseismal maps to assess seismic hazards, creating a catalog for a building code
Jacob Kutu	2013	-Field data analysis on tectonics and geology coupled with reassessment historical seismic records in southern Ghana
Jacob Kutu	2013	-Reinterpreted the 1939 Accra Earthquake with new field data, reevaluating historical earthquake records
Paulina Amponsah	2014	-Analysing geological and instrumental earthquake Recordings to investigate microseismicity activity
Roger M.W Musson	2014	-Compiled an earthquake catalog from secondary sources. The study emphasized deficiencies in the seismic monitoring system providing insights for future initiatives.

Sylvanus Ahulu	2015	-Conducted a comprehensive study on establishing a National Digital Seismic Network Observatory
Sylvanus Ahulu	2018	-Employed a probabilistic approach to create a seismic Hazard for Ghana utilizing earthquake data from 1615-2009
Paulina Amponsah	2020	-Addressed seismic risk in Ghana but conducting an observation survey in randomly selected locals
Kadiri Umar Afegbua	2021	-Applied a probabilistic seismic hazard assessment to compute seismic parameters for Ghana, Benin, Togo, Burkina Faso and Côte d'Ivoire using statistical models
Custódio Susana	2022	-Utilized a deterministic approach to determine a 1D velocity crustal model that determined hypocentral parameters for recently detected earthquakes in Ghana
Stephen Irinyemi	2022	-Calculated Peak Ground Acceleration (PGA) at dam sites in the western coast of Ghana and employed logic tree analysis to generate seismological models
M. Hamzeh	2023	-Employed a Deep Learning model, specifically the EQTransformer tool, which utilizes a convolutional neural network to probabilistically estimate the likelihood of an event being an earthquake

M. Hamzeh	2023	-Conducted a comprehensive study characterizing regional seismicity in Ghana using deep learning (EQTransformer model)
M. Hamzeh	2023	-Utilized deep learning on an 18-month dataset from Ghana Digital Seismic Network to automate event detection and earthquake location

6.0 Conclusion

Earthquake occurrences in Ghana serve as a stark reminder of the importance of disaster preparedness and response measures, particularly since the country is located in an area that is prone to seismic activities. Our systematic review, using the PRISMA technique, carefully examined the available literature. We found 17 relevant papers that formed the basis of our analysis.

The results of this systematic review highlighted the need for more studies on Ghana's seismic activity as well as increased efforts to plan for and respond to earthquakes. Efforts should be focused on expanding data collection efforts, improving seismic monitoring infrastructure, refining modeling techniques, and conducting further research to enhance our understanding of the region's seismogenic sources and processes. By addressing these limitations, future studies can provide more robust and accurate assessments of seismic hazard in Ghana, facilitating effective disaster preparedness and mitigation strategies. The National Disaster Management Organization (NADMO) can utilize the seismicity map developed in this assessment to plan for any disaster, such as where to site the country’s assets or convey people to safeguards. To better prepare for and lessen the effects of earthquakes, it is crucial that the government and local communities collaborate. This may entail making investments in earthquake-monitoring stations, setting up resistant building codes and infrastructure, raising public knowledge of readiness for and responses to earthquakes, and funding studies into earthquake prediction and early warning. It is important for Ghana to conduct risk assessments, prepare emergency plans, strengthen infrastructure, and improve public education on earthquake safety.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

All participants provided informed consent to participate in the study.

Registration Information

This systematic review was not registered in a review registry.

Review Protocol Information and Access

A review protocol was prepared for this systematic review, but it has not been hosted online. For access to the protocol or further details, please contact Cyril Boateng at cyrilboat@knust.edu.gh.

Amendments to Review Protocol

We want to note that no amendments were made to the original review protocol in the course of this systematic review. The methods and criteria outlined in the initial protocol as described in the protocol, were followed without modification.

Data Availability

The data used in this study is not publicly available in any online repository. However, the data can be made available upon request. Interested researchers can contact Cyril Boateng at cyrilboat@knust.edu.gh for further information.

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