

Assessing Earthquake Risk Exposure of Emergency Healthcare Facilities in Urban Ghana

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Abstract

Background

Seismic risk in Ghana, particularly within the Greater Accra Metropolitan Area (GAMA), is increasing and poses growing threats to critical infrastructure, including healthcare facilities. While existing studies focus largely on hazard assessment, limited attention has been given to the socio-spatial vulnerability of healthcare infrastructure and the institutional factors shaping this vulnerability. This study addresses this gap by examining both spatial exposure and governance dynamics.

Methods

A mixed-methods approach was employed, combining spatial analysis with qualitative institutional assessment. Primary data were collected through GPS mapping of healthcare facilities and semi-structured interviews with key stakeholders. Secondary data included historical earthquake records (1858–2024) from the Ghana Geological Survey Authority. Analytical techniques included Getis-Ord Gi* hotspot analysis, 5 km buffer analysis, and temporal trend analysis. Qualitative data were analysed thematically.

Results

Findings indicate a sustained increase in seismic activity, with events rising from 12 (1858–1969) to over 300 between 2011 and 2024. Seismic hotspots are concentrated in the southern and western areas of GAMA. Approximately 23.5% of healthcare facilities are located in high-risk zones, while about 67% lie within 5 km of active fault lines. Qualitative results show that vulnerability is driven by weak integration of seismic risk into planning, limited enforcement of building regulations, and fragmented institutional coordination.

Conclusions

Healthcare vulnerability in GAMA reflects the interaction of geophysical risk and governance challenges. Strengthening resilience requires integrating seismic risk into planning, improving regulatory enforcement, and enhancing institutional coordination.

1.0 Introduction

Disasters continue to pose significant challenges to global health and safety, with earthquakes among the most catastrophic natural hazards [1]. An earthquake can be defined as the sudden release of energy within the Earth's crust that generates seismic waves, often resulting in ground shaking, structural damage, and disruption of human activities. Globally, earthquakes accounted for approximately 8% of all

disaster events between 2000 and 2019, yet they were responsible for about 56% of disaster-related deaths, underscoring their disproportionate impact on human life [2]. Earthquakes have the potential to overwhelm healthcare systems, particularly in contexts characterised by weak infrastructure and limited emergency preparedness [3]. Consequently, there is growing emphasis on strengthening the resilience of healthcare systems through improved infrastructure, adequate medical resources, and enhanced emergency response capacity [1, 4].

Beyond their immediate impacts, earthquakes pose significant threats to the achievement of global health priorities, particularly Sustainable Development Goal 3 (SDG 3), which seeks to ensure healthy lives and promote well-being for all. Disruptions to healthcare infrastructure during seismic events can compromise access to essential services, increase mortality and morbidity, and undermine health system resilience [5]. Strengthening the capacity of healthcare facilities to withstand and respond to seismic hazards is therefore critical to advancing SDG 3 targets, particularly those related to universal health coverage, emergency preparedness, and health system strengthening.

While global statistics highlight the scale of the problem, the situation in sub-Saharan Africa presents a distinct but equally important concern. Although the region experiences fewer large-magnitude earthquakes compared to Asia and Latin America, its vulnerability is heightened by rapid urbanisation, weak enforcement of building regulations, and limited disaster preparedness systems. Recent studies [6, 7] indicate that seismic risk in Africa is increasingly intersecting with expanding urban populations and fragile infrastructure systems. Evidence across sub-Saharan Africa suggests that the impacts of seismic events are often amplified by underlying structural and institutional vulnerabilities rather than the magnitude of the hazard itself [8, 9, 10]. Weak enforcement of building regulations, rapid urbanisation, and limited disaster preparedness capacity contribute to heightened risks for critical infrastructure, including healthcare facilities, even under moderate seismic conditions [11, 12].

In Ghana, seismic risk is becoming an increasingly important concern, particularly in the Greater Accra Metropolitan Area (GAMA), which lies along active fault systems such as the Akwapim Fault Zone and the Coastal Boundary Fault. Historical events, including the 1939 Accra earthquake (M 6.5), as well as more recent tremors recorded between 2007 and 2024, demonstrate that seismic activity in the country is persistent rather than exceptional [7]. Emerging evidence suggests that the frequency of low- to moderate-magnitude earthquakes has increased in recent years, raising concerns about the preparedness of critical infrastructure, particularly healthcare facilities, in rapidly urbanising areas.

Despite these risks, many healthcare facilities in Ghana and across sub-Saharan Africa are not designed to withstand seismic forces, and disaster preparedness systems remain inconsistent. [13] highlights widespread structural vulnerabilities in healthcare infrastructure, compounded by limited emergency supplies, inadequate training, and constrained resources. According to [14], persistent challenges exist in the spatial distribution of healthcare infrastructure, which are further exacerbated by limited emergency resources, insufficient workforce capacity, and broader institutional constraints. In such contexts, earthquakes can lead to the collapse or dysfunction of health facilities, disrupt essential services, and

trigger cascading public health crises. Although existing studies in Ghana have contributed to understanding seismic hazards, including ground motion analysis, probabilistic risk assessment, and household preparedness [1, 6, 15, 16], there remains a critical gap in empirical, spatially explicit research on the vulnerability of healthcare facilities. This gap is significant because healthcare infrastructure plays a central role in emergency response, lifesaving interventions, and post-disaster recovery. Without resilient healthcare systems, the ability to respond effectively to seismic events and maintain continuity of care is severely compromised.

Addressing this gap is essential not only for reducing disaster risk but also for strengthening health system resilience and advancing global health goals. Accordingly, this study assesses the spatial vulnerability of healthcare facilities to earthquake hazards in the Greater Accra Metropolitan Area (GAMA), contributing to efforts to integrate disaster risk considerations into health infrastructure planning. The findings are expected to inform risk-sensitive urban planning, strengthen regulatory and institutional frameworks, and support policy interventions aimed at enhancing the resilience of healthcare systems in Ghana and other low- and middle-income countries.

1.1 Theoretical Underpinning

This study is grounded in disaster risk governance and resilience theory, which together conceptualise disaster risk as the outcome of interactions between physical hazards and socio-institutional processes. Moving beyond hazard-centric perspectives, these approaches emphasize that disasters are not solely natural events but are shaped by human decisions, planning systems, and institutional arrangements [17, 18]. In this context, vulnerability to earthquakes is understood as a socially produced condition, influenced by how infrastructure is designed, located, and regulated.

The disaster risk governance perspective highlights the role of institutions, policies, and decision-making processes in shaping exposure and vulnerability [12, 19]. It argues that risk is often embedded in governance failures such as weak enforcement of building regulations, fragmented institutional coordination, and limited integration of scientific risk assessments into spatial planning. In rapidly urbanising environments, particularly in low- and middle-income countries, these governance challenges frequently result in critical infrastructure being located in hazard-prone areas due to competing priorities such as accessibility, land availability, and cost considerations [20, 21]. From this perspective, the spatial distribution of healthcare facilities in seismic risk zones reflects underlying institutional and regulatory dynamics rather than purely geophysical factors.

Complementing this perspective, resilience theory emphasises the capacity of systems to absorb shocks, adapt to disturbances, and maintain functionality during and after hazard events [22, 23]. In the context of the health sector, resilience extends beyond the physical robustness of infrastructure to encompass a broader set of institutional and operational capacities. These include effective preparedness planning, availability of critical resources and medical supplies, coordination among key institutions, and the ability to anticipate, respond to, and recover from disruptions. A resilient healthcare

system is therefore not only one that can withstand structural damage but also one that can continue to deliver essential services under stress, minimise service interruptions, and adapt to changing conditions during emergencies [24]. This involves both pre-disaster measures, such as risk-informed planning and capacity building, and post-disaster recovery processes that enable systems to restore functionality and improve future preparedness.

Integrating disaster risk governance and resilience perspectives, this study adopts a socio-spatial lens to examine earthquake risk. It explores how institutional arrangements, planning practices, and regulatory systems interact with seismic hazards to shape the vulnerability of healthcare facilities in the Greater Accra Metropolitan Area (GAMA). This theoretical framing allows the study to move beyond purely technical assessments of seismic exposure and instead analyse how governance processes and socio-spatial inequalities contribute to patterns of vulnerability.

2. Materials and Methods

2.1 Study Area

The study was conducted GAMA; a metropolitan region centered in Ghana's capital Accra. It borders the Central Region to the West, the Eastern Region to the North, the Shai Osudoku District to the Northeast and the Ningo Prampram District to the East and has an absolute location of 5°58'93" N, 0°18'19"W. With an estimated population of 5,302,303 as of 2023 representing 17.7% of Ghana's total population GAMA is the most urbanized and economically significant region in the country [25]. The area covers 3,245 km², which is 1.4% of Ghana's total land area, and contributes over half of the nation's economic output, employing more than a quarter of the national workforce [25].

GAMA was selected due to its high population density, intensive urban development, and the concentration of critical infrastructure, particularly in the health sector. The metropolitan area is home to key health institutions such as Korle Bu Teaching Hospital, 37 Military Hospital, University of Ghana Medical Centre, and Greater Accra Regional Hospital (Ridge). In total, the region hosts a diverse network of 707 CHPS compounds, 299 clinics, 101 maternity homes, 32 health centers, 22 polyclinics, and 111 hospitals, including two psychiatric hospitals in Korley Klotey Municipal and La-Nkwantanang Madina [26]. These health facilities are operated by the government, Christian Health Association of Ghana (CHAG), private entities, and quasi-government organizations, and serve not only the resident population but also people from adjoining regions and neighboring countries.

2.2 Research Design

This study employed a mixed-methods research design [27], integrating quantitative spatial analysis with a qualitative institutional assessment to examine the vulnerability of emergency-responding healthcare facilities to earthquake hazards in the Greater Accra Metropolitan Area (GAMA). The mixed-methods approach facilitated methodological triangulation, enabling spatial patterns of seismic exposure to be interpreted alongside institutional, regulatory, and governance perspectives. While the quantitative

component focused on assessing the spatial and temporal exposure of healthcare facilities to seismic hazards, the qualitative component examined planning practices, regulatory enforcement mechanisms, and institutional decision-making processes that shape healthcare facility vulnerability. This integrated design ensured that vulnerability was conceptualized not only as a physical or locational condition but also as an outcome of governance and institutional processes.

2.3 Data Sources and Collection

2.3.1 Quantitative Data Collection

Quantitative data were obtained from both primary and secondary sources. Primary quantitative data consisted of the geospatial coordinates of healthcare facilities within GAMA, including hospitals, polyclinics, medical centres, hospitals, and other emergency-responding institutions. These data were collected through GPS-based field surveys, which enabled accurate spatial positioning and on-site verification of facility locations and classifications. Secondary quantitative data were sourced from the Ghana Geological Survey Authority (GGSA) and the Seismic and Earthquake Department. These datasets included historical earthquake records spanning 1858 to 2024, detailing earthquake and tremors magnitudes, epicenter locations, event dates, and fault line characteristics. Additional spatial datasets included seismic hazard classification maps and administrative boundary shapefiles required for spatial analysis and mapping.

2.3.2 Qualitative Data Collection

Target Population

The target population for the qualitative component comprised stakeholders directly involved in healthcare infrastructure development, disaster risk management, and seismic risk governance in GAMA. This included officials from the Health Facilities Regulatory Agency (HeFRA), District Health Directorates under the Ghana Health Service, healthcare facility managers or administrators, the National Disaster Management Organization (NADMO), the Ghana Geological Survey Authority, Planning Unit and relevant maintenance and emergency response personnel. These stakeholders were selected due to their central roles in planning, regulating, and managing healthcare facilities and disaster risk in the study area.

Sampling and Recruitment Procedures

A purposive sampling strategy was employed to select participants with relevant expertise and institutional responsibilities. A total of 36 participants were engaged in the study, comprising seven (7) healthcare facility administrators or managers, eight (8) Metropolitan and Municipal Health Directors, six (6) Metropolitan and Municipal Planners, four (4) emergency and paramedic personnel, four (4) officials from NADMO, two (2) officials from HeFRA, three (3) official from the Ghana Geological Survey Authority, and two (2) officials from maintenance departments. The number of participants engaged in the study was determined based on the principle of data saturation, where data collection continued until no new

themes or insights emerged. Inclusion criteria consisted of individuals directly involved in healthcare facility siting, regulation, disaster preparedness, or seismic risk assessment. Exclusion criteria included individuals without decision-making roles or those lacking sufficient experience in the relevant domains. Participants were recruited through formal institutional contacts and official requests to the respective organisations.

Data Collection Procedures

Data were collected using a semi-structured interview guide, which served as the primary qualitative research instrument. The guide ensured consistency across interviews while allowing flexibility to explore institution-specific experiences and emerging issues. Key themes included healthcare facility siting and permitting processes, enforcement of seismic building codes, inter-institutional coordination, and gaps in earthquake preparedness and risk integration. All interviews were conducted in person at the offices of the respective institutions within the Greater Accra Metropolitan Area (GAMA). Conducting interviews within participants' professional environments facilitated access, encouraged openness, and allowed for context-specific discussions. Each interview lasted approximately 45–60 minutes, providing sufficient time for participants to share detailed insights into institutional practices and challenges. The interviews were conducted by the lead researcher, who has formal training in qualitative research methods and prior experience in conducting key informant interviews within institutional and policy settings. This experience supported effective probing, clarification of responses, and the ethical management of the interview process.

To ensure the trustworthiness and rigour of the qualitative data, several strategies were employed. A pretest of the interview guide was conducted with a small number of participants to assess the clarity, relevance, and sequencing of questions, and to refine the instrument prior to the main data collection. Data triangulation was achieved by engaging participants from multiple institutions, including regulatory agencies, health directorates, and disaster management organisations, to capture diverse perspectives. A standardised interview guide was subsequently used to ensure consistency across interviews, enhancing dependability. Detailed field notes were taken during each interview, and responses were systematically documented to maintain accuracy and preserve contextual meaning. In addition, member clarification was undertaken during interviews to confirm the accuracy of participants' responses. The researchers also maintained a reflexive approach throughout the data collection process to minimise bias and strengthen the credibility of the findings.

2.4 Data Analysis

2.4.1 Quantitative Data Processing and Analysis

All spatial datasets were processed and analyzed using ArcGIS (ArcMap) version 10.8. Earthquake event records were converted into spatial point datasets by transforming geographic coordinates into X–Y formats and projecting all datasets into a consistent coordinate reference system to ensure spatial accuracy and compatibility. Healthcare facility GPS data were integrated with seismic hazard layers, fault

line networks, and administrative boundary datasets to generate thematic maps of GAMA. Seismic hazard zones were classified into low-, moderate-, and high-risk categories based on earthquake magnitude thresholds. These spatial layers formed the basis for subsequent exposure and clustering analyses. Spatial clustering of healthcare facilities relative to seismic hazards was assessed using the Getis-Ord Gi* hotspot analysis. This spatial autocorrelation technique identifies statistically significant clusters by comparing local concentrations of facilities within seismic risk zones to overall spatial patterns. Hotspots represented clusters of healthcare facilities in high-risk zones, while cold spots indicated areas of relatively lower exposure. Statistical significance was assessed at the 95% confidence level. A 5-kilometre buffer analysis was conducted around mapped fault lines and active seismic zones to assess proximity-based exposure of healthcare facilities. This buffer distance aligns with international recommendations for siting critical infrastructure away from active faults. Facilities located within the buffer were classified as highly exposed, while those outside were considered to have lower immediate seismic exposure. In addition, a temporal trend analysis was conducted using historical earthquake records obtained from GGSA to examine changes in seismic activity over time. Earthquake events were analysed using Microsoft Excel to generate time-series graphs illustrating variations in earthquake frequency and magnitude across defined temporal intervals. This analysis enabled the identification of long-term trends, recurrence patterns, and recent increases in seismic activity within GAMA.

2.4.2 Qualitative Data Analysis

Qualitative data were analysed using thematic analysis. Interview notes and documented responses were systematically reviewed, coded, and organized into recurring themes related to institutional practices and governance processes influencing healthcare facility vulnerability. Key themes included regulatory enforcement gaps, coordination challenges among institutions, planning and permitting practices, and preparedness limitations within the health sector. The qualitative findings were used to contextualize and interpret the quantitative spatial results, particularly in areas where healthcare facilities were concentrated within high-risk seismic zones. Integrating qualitative insights enabled a deeper understanding of how institutional and governance factors contribute to observed spatial vulnerability patterns. Qualitative data management and coding were supported using QDA Miner 6.0 to ensure systematic organization and transparency of the analytical process.

2.5 Ethics Approval and Consent to Participate

This study received ethical approval from the Ghana Health Service Ethics Review Committee (GHS-ERC 036/09/24), the Korle Bu Teaching Hospital Institutional Review Board (KBTH-STC/IRB/000215/2024), and the University of Education, Winneba Ethics Committee (UEWC/37). All procedures were conducted in accordance with the ethical standards and guidelines of these institutional review bodies, as well as relevant national and international research ethics regulations. Informed consent was obtained from all participants prior to data collection. Participants were fully informed about the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any stage without consequence. Confidentiality and anonymity were strictly maintained, and no personally identifiable information was

included in the analysis or reporting of findings. Institutional affiliations were anonymized where necessary to protect participant identity.

3. Results

3.1 Trend Analysis of Seismic Activities in the GAMA

This section examines long-term trends in seismic activity within the Greater Accra Metropolitan Area (GAMA) using historical earthquake records obtained from the Ghana Geological Survey Authority (GGSA). The analysis covers the period from 1858 to 2024 and focuses on identifying temporal patterns in earthquake occurrence and magnitude, with particular attention to the implications for critical infrastructure such as healthcare facilities. As presented in Table 1 and illustrated in Figure 1, seismic activity in GAMA has increased markedly over time. The period between 1858 and 1969 recorded relatively few seismic events (12 in total), indicating low documented seismic activity during the early historical period. This number increased modestly during 1970–1979 (19 events) and 1980–1989 (14 events), suggesting intermittent seismic occurrence. A more pronounced increase is observed from 1990 to 2000, during which 58 seismic events were recorded, signalling a shift toward more frequent seismic activity in the metropolitan area.

Table 1: Temporal Distribution of Recorded Earthquakes in the Greater Accra Metropolitan Area (1858–2024)

Seismic Activities Year Ranges	Number of Events
1858 – 1969	12
1970 – 1979	19
1980 – 1989	14
1990 – 2000	58
2001 – 2010	10
2011 – 2020	160
2021 – 2024	153

Source: GGSA, 2025

Although a temporary decline was observed between 2001 and 2010 (10 events), seismic activity escalated sharply in subsequent years. Between 2011 and 2020, a total of 160 seismic events were recorded, representing a substantial increase compared to previous decades. This upward trend persisted into the most recent period, with 153 events recorded between 2021 and 2024 alone, indicating sustained and heightened seismic activity over a relatively short timeframe. Table 1: Frequency of Recorded Earthquakes in Ghana by Year Range (1858–2024)

While most earthquakes in Greater Accra Metropolitan Area (GAMA) register low to moderate magnitudes, as shown in Figure 2, significant peaks reaching higher intensities occurred particularly during earlier decades (1858-1939: 3.0-6.5 magnitude, mean 4.5) and sporadically in recent years (1964-2024: 2.0-5.0 magnitude, mean 2.6). The rising frequency of moderate-magnitude events signals escalating seismic risk to urban infrastructure. This trend heightens concerns about healthcare facilities' vulnerability, which must maintain operational continuity during and post-earthquake, underscoring urgent seismic resilience priorities for GAMA's critical infrastructure. Institutional perspectives from key stakeholders corroborate the observed increase in seismic activity within the Greater Accra Metropolitan Area. Officials from the Ghana Geological Survey Authority noted a clear shift in seismic patterns over time:

"Over the past decade, we have observed a noticeable increase in the frequency of recorded tremors in the Accra area. Events that were previously occasional are now occurring more regularly, even if many remain within low to moderate magnitudes."(Seismologist, GGSA)

They further emphasised that this trend reflects both improved monitoring capacity and ongoing tectonic activity, with implications for urban risk:

"The rise in recorded seismic activity reflects both enhanced monitoring systems and continued tectonic movement along the coastal fault systems. This indicates that seismic risk is persistent and must be considered in urban planning processes."(Earthquake Monitoring Unit, GGSA)

Similarly, officials from the National Disaster Management Organization highlighted increasing operational concerns:

"From an operational perspective, reports of earth tremors in Accra have become more frequent in recent years. Even when impacts are not severe, the increasing occurrence raises concerns for preparedness and response planning."(Regional Officer, NADMO)"

"The issue is not only the magnitude of events but their frequency. Repeated tremors, even at lower magnitudes, can gradually weaken infrastructure over time."(Disaster Risk Officer, NADMO)

Within the health sector, facility managers expressed growing concern regarding system preparedness:

"Although most tremors are not destructive, their increasing frequency is concerning because healthcare facilities are expected to remain operational at all times."(Hospital Administrator)

"The current health system was not designed with this level of seismic risk in mind, and preparedness remains limited."(Health Director)

From a planning perspective, stakeholders acknowledged that seismic risk has historically been underprioritised:

“Seismic risk has not traditionally been a key consideration in planning decisions in Accra, partly because such events were considered rare. However, the increasing frequency now challenges this assumption.”(Planning Official)

3.2 Getis-Ord Gi* Hotspot Analysis of Seismic Activity

This section presents the empirical findings of the study, integrating quantitative spatial and temporal analyses to examine seismic activity patterns and the exposure of healthcare facilities within the Greater Accra Metropolitan Area (GAMA). The results are organized to first describe long-term trends in earthquake occurrence, followed by spatial clustering and hotspot patterns of seismic activity, and finally the differential exposure of healthcare facilities across seismic risk zones. Together, these analyses provide a comprehensive understanding of how seismic hazards are distributed across space and time and how these patterns intersect with critical health infrastructure vulnerability.

Figure 3 presents the results of the Getis-Ord Gi* hotspot analysis, which identifies statistically significant spatial clustering of seismic activity across the Greater Accra Metropolitan Area (GAMA). The analysis revealed 53 statistically significant hotspot zones, 18 cold spots, and 29 locations with no significant spatial clustering, indicating a heterogeneous spatial distribution of seismic activity within the metropolitan region. High-confidence seismic hotspots are predominantly concentrated in the southern and western sectors of GAMA, particularly within Weija-Gbawe, Ga South, Ablekuma South and West, and parts of Ga Central and Ga West. These hotspot clusters spatially align with known fault systems and areas experiencing rapid urban expansion, suggesting an interaction between underlying geological structures and intensified land-use pressure. The persistence of these clusters at high confidence levels (95–99%) underscores the heightened seismic exposure of these zones and reinforces their classification as priority risk for health facilities located within those zones.

In contrast, statistically significant cold spots—indicating areas of comparatively low seismic activity—were identified in Legon, Pokuase, and Achimota. These zones exhibit limited clustering of seismic events and may represent relatively safer areas from a seismic perspective. However, while cold spots suggest lower relative risk, they should not be interpreted as hazard-free zones, but rather as areas with reduced seismic intensity compared to identified hotspots.

This hotspot analysis highlights clear spatial inequalities in seismic risk across GAMA. The clustering of high-risk zones in the southern and western corridors has important implications for urban development and critical infrastructure planning, particularly for healthcare facilities that require high levels of operational continuity during seismic events. Integrating these spatial insights into land-use planning and infrastructure siting decisions is essential for reducing earthquake-related vulnerabilities in the metropolitan area.

Qualitative evidence from institutional stakeholders and facility-level actors reinforced the hotspot patterns identified through the Getis-Ord Gi* analysis and provided insight into the governance and planning dynamics underlying the observed spatial clustering of seismic risk. Officials from the Ghana

Geological Survey Authority confirmed that the southern and western parts of the Greater Accra Metropolitan Area correspond to known tectonic fault systems and have historically exhibited higher seismic activity. According to a GGSA official:

“...The western and coastal parts of Accra have long been identified as seismically active zones. Areas such as Weija, Gbawe, and parts of Ga South consistently fall within high-risk zones due to their proximity to fault lines ”(Seismologist, GGSA)

Stakeholders emphasised that while these geological risks are well established, rapid urban expansion has intensified exposure within these hotspot areas. Perspectives from planning and local government institutions highlighted that development in these zones is often driven by land availability and population pressure rather than hazard considerations:

“Urban expansion in Accra is moving toward the outskirts, especially in the western corridor. Unfortunately, these are the same areas where seismic risk is higher, but planning decisions are not always guided by that information” (Planning Official, 2025).

Insights from the Health Facilities Regulatory Agency and District Health Directorates further revealed that **healthcare facility siting processes are not systematically aligned with seismic risk data**. Officials noted that coordination between permitting authorities and geological institutions remains limited, resulting in facilities being located within identified hotspot zones:

“...There is limited integration of seismic risk into facility approval processes. In most cases, healthcare facilities are developed without prior geological assessment, especially in high-demand urban areas...” (HeFRA, 2025).

District health officials also acknowledged that healthcare access priorities often take precedence over hazard considerations, particularly in rapidly growing communities:

“Our focus is to ensure access to healthcare services for expanding populations. In many situations, facilities are located where land is available, even if those areas fall within zones of higher seismic risk” (District Health Directorate, 2025).

From a disaster management perspective, officials from the National Disaster Management Organization emphasised that the concentration of infrastructure within identified hotspot zones significantly heightens disaster risk:

“When critical infrastructure is concentrated in areas already prone to seismic activity, it increases the likelihood of widespread disruption during an event. Many of these hotspot areas are also densely populated, which compounds the risk” (NADMO, 2025).

At the facility level, healthcare managers confirmed that many facilities operating within hotspot zones face structural and operational constraints that limit their ability to respond to seismic risks:

“Some of the facilities in these areas were built without considering earthquake risks. Retrofitting is expensive, and there is limited funding to upgrade infrastructure to meet seismic standards” (Health Facility Manager, 2025).

Collectively, these qualitative insights reinforce the spatial clustering patterns identified in the hotspot analysis, indicating that the concentration of seismic risk in GAMA extends beyond underlying geological conditions. Instead, it emerges from the interaction between established fault systems, rapid urban expansion, and institutional constraints related to planning, regulation, and enforcement. These interrelated factors collectively drive the uneven spatial distribution of seismic risk across the metropolitan area.

3.3 Exposure of Healthcare Facilities to Seismic Hazards

Beyond the identification of seismic hotspots, an exposure analysis was conducted to evaluate the extent to which healthcare facilities in the Greater Accra Metropolitan Area (GAMA) are exposed to earthquake hazards. Using Inverse Distance Weighted (IDW) interpolation, seismic intensity surfaces were generated and classified into nine hazard zones, with magnitude values ranging from 1.2 to 4.9, allowing for a detailed assessment of spatial variation in seismic risk across the study area. Out of the 238 healthcare facilities assessed, 57 facilities (23.53%) comprising 33 hospitals, 14 medical centres, and 5 polyclinics were located within high-risk seismic zones characterized by magnitudes between 3.9 and 4.9. These facilities are predominantly concentrated in the southern and western corridors of GAMA, areas that spatially coincide with identified seismic hotspots and active fault structures. A further 179 facilities (74.7%) were situated within moderate-risk zones with magnitude values between 1.9 and 2.9, largely distributed across central and eastern parts of the metropolitan area. Only two facilities (0.84%) were found within low-risk zones (magnitudes between 1.2 and 1.9), located mainly along the northern fringe of the study area. These patterns indicate that the vast majority of healthcare facilities in GAMA are exposed to at least moderate seismic risk.

As illustrated in Figure 4, a 5-kilometre buffer analysis around mapped fault lines and zones of historical seismic activity revealed that 156 out of 238 healthcare facilities (67%) are located within or in close proximity to active fault zones. These exposed facilities are concentrated in Accra Metropolitan, Weija-Gbawe, Ablekuma North and South, Ga South, Ga Central, and Ga West, reinforcing the spatial overlap between healthcare infrastructure and areas of heightened seismic activity. The remaining 82 facilities (33%) were located beyond the 5 km threshold, indicating relatively lower immediate exposure to fault-related seismic hazards. Further statistical analysis demonstrated significant differences in seismic exposure based on facility ownership. Private healthcare facilities were more likely to be located within moderate- to high-risk seismic zones, particularly in peri-urban and densely populated areas where land-use regulation and enforcement are relatively weak. This finding highlights the influence of development patterns and regulatory gaps on healthcare facility exposure to earthquake hazards and underscores the need for risk-informed planning and stricter enforcement of seismic safety standards. Qualitative evidence from institutional stakeholders and facility-level actors reinforced these findings and provided

insight into the governance and planning dynamics underpinning observed spatial patterns. Officials from the **Health Facilities Regulatory Agency (HeFRA)** attributed the concentration of healthcare facilities in hazard-prone zones to weak coordination between infrastructure permitting authorities and geological risk assessment institutions. According to a HeFRA official:

“...Many facilities, especially in Accra, are within earthquake buffer zones because seismic risk is not assessed prior to construction. Permits are issued by district assemblies, and our evaluations are often conducted after buildings are completed, assuming compliance with required standards...” (HeFRA, 2025).

Perspectives from **District Health Directorates** further highlighted systemic gaps between health service delivery priorities and spatial planning processes. District health officials acknowledged that healthcare access pressures often override hazard considerations, particularly in rapidly urbanizing areas:

“Our mandate is to ensure service coverage for growing populations. In many cases, facilities are established where land is available or affordable, not necessarily where it is safest. Seismic risk is rarely a determining factor during siting decisions at the district level” (District Health Directorate, 2025).

Officials noted that district health authorities have limited influence over land-use approvals, which are managed by local government planning units, thereby constraining their ability to enforce risk-informed facility siting.

Insights from **Healthcare Facility Managers and Hospital Administrators** further underscored how operational pressures shape facility location and construction decisions. Several managers reported inheriting facilities already sited in hazard-prone zones, with limited capacity or resources to undertake structural retrofitting:

“Most of us manage facilities that were built years ago. We did not choose the location, and relocating is not an option. Retrofitting for earthquakes is costly, and there is no dedicated funding for that” (Health Facility Manager, 2025).

Others emphasized that private providers, in particular, face market-driven pressures that incentivize proximity to high-density communities despite underlying risk:

“Private facilities tend to locate close to where clients are. Unfortunately, those areas are often overcrowded and poorly planned. Seismic risk is not something investors usually consider unless it is enforced” (Hospital Manager, 2025).

The **Ghana Geological Survey Authority (GGSA)** confirmed that areas of high seismic vulnerability in Accra have been well documented and repeatedly communicated to relevant institutions, yet compliance remains weak:

“The threat of an earthquake in Accra is alarming, with potentially catastrophic consequences for healthcare facilities. The western part of Accra is particularly vulnerable, with a high risk of being

completely cut off from the rest of the city. Specific areas of concern include Kokrobite, Bortianor, Weija, Gbawe, Dansoman, parts of Korle Bu, and North Kaneshie, which would be disproportionately affected” (GGSA, 2025).

Similarly, officials from the **National Disaster Management Organization (NADMO)** emphasized that non-compliance with seismic construction standards significantly increases institutional vulnerability:

“Buildings in seismic zones must meet strict structural standards, including seismic force-resisting systems and robust load paths. However, in GAMA, most healthcare facilities within these zones do not meet these requirements, increasing the risk of structural failure during an earthquake” (NADMO, 2025).

The qualitative findings indicate that the spatial exposure of healthcare facilities in GAMA cannot be attributed solely to underlying geological conditions. Rather, it is shaped by a combination of institutional fragmentation, weak enforcement of regulatory frameworks, and competing development priorities. The lack of coordination among district health authorities, facility managers, and regulatory bodies results in fragmented planning processes, which in turn sustain the vulnerability of healthcare infrastructure to seismic hazards, despite the availability of long-standing scientific evidence on risk.

3.4 Differences in Seismic Magnitude across Healthcare Facilities

Beyond spatial exposure patterns, this subsection examines whether seismic magnitude exposure varies by healthcare facility ownership, given that institutional type may influence facility location, monitoring capacity, and reporting practices. An independent samples t-test was conducted to compare reported earthquake magnitudes between public and private healthcare facilities. As shown in Table 2, the analysis indicates a statistically significant difference in earthquake magnitude exposure between public and private facilities, $t(238) = 2.095$, $p = 0.037$, with a small-to-moderate effect size ($d = 0.307$). Public healthcare facilities recorded a higher mean earthquake magnitude ($M = 2.665$, $SD = 0.354$) than private facilities ($M = 2.556$, $SD = 0.358$). Although the mean difference is modest, the statistical significance suggests that facility ownership contributes meaningfully to observed differences in seismic magnitude exposure.

Table 2: Independent samples t-test comparing earthquake disaster magnitude across public and private health facilities

	Ownership	n	Mean	Std. D	Mean Diff.	t	p	Cohen’s D
Magnitude	Public	64	2.665	0.354	0.109	2.095	0.037	0.307
	Private	172	2.556	0.358				

To further illustrate these differences, Figure 5 presents the frequency distribution of public and private healthcare facilities across low- and high-magnitude seismic categories. Within the low-magnitude range (1.2-2.9), 45 private facilities and 15 public facilities were identified. In contrast, within the high-

magnitude range (2.9-4.9), 128 private facilities and 50 public facilities were recorded. While private facilities are numerically dominant due to their greater overall representation, the distribution shows that a substantial proportion of public facilities are concentrated in higher-magnitude zones, reinforcing their relatively elevated seismic exposure.

The combined statistical evidence from Table 2 and spatial patterns in Figure 4 confirm that facility ownership significantly influences seismic magnitude exposure disparities across GAMA healthcare facilities. These findings justify ownership-specific earthquake risk mitigation and preparedness strategies for urban settings.

4. Discussion

Despite increasing attention to seismic hazards in Ghana, the vulnerability of healthcare infrastructure remains insufficiently examined from a socio-spatial and governance perspective. As noted by [12] and [18], disaster risk is not simply a product of natural hazards but is socially constructed through the interaction of exposure, vulnerability, and institutional processes. In this regard, the findings of this study demonstrate that the exposure of healthcare facilities in the Greater Accra Metropolitan Area (GAMA) is shaped not only by seismic activity but also by planning decisions, spatial inequalities, and governance structures.

The results show a sustained increase in seismic activity within GAMA, particularly from 2011 onward, suggesting that seismic risk in the region is persistent rather than episodic. While [38] attribute rising earthquake detection partly to improvements in monitoring technologies, [28] emphasize that tectonic processes continue to drive seismic activity in urban fault zones. In the African context, [9] similarly highlight that seismic risks have historically been underestimated, even as evidence points to increasing activity across the region. These patterns are reflected in GAMA, where the frequency of recorded events indicates a changing hazard landscape with growing implications for urban infrastructure systems.

Spatial analysis further reveals that seismic risk in GAMA is unevenly distributed, with concentrations in the southern and western corridors. While this distribution aligns with known tectonic structures, it also overlaps with areas of rapid urban growth. As [11] argues in the context of Accra, urban expansion often occurs without adequate integration of hazard information into planning systems. This concern is echoed by [29], who show that in many rapidly urbanizing regions, development pressures tend to override risk considerations. The clustering of seismic hotspots in high-density urban zones therefore reflects not only geophysical realities but also planning failures and spatial development patterns that amplify exposure.

A key finding of this study is the significant exposure of healthcare facilities within high-risk zones and near active fault lines. This has critical implications for health system resilience, as healthcare facilities are expected to remain functional during disasters. According to [30], the ability of health systems to respond effectively during emergencies depends heavily on the structural and operational resilience of healthcare infrastructure. Similarly, [31] emphasize that poor siting decisions significantly increase

hospital vulnerability in seismic regions. In GAMA, the failure to maintain recommended buffer distances between critical infrastructure and fault lines highlights systemic gaps in risk-informed planning and regulatory enforcement, increasing the likelihood of service disruption during seismic events.

Beyond physical exposure, the findings underscore the role of institutional and governance factors in shaping vulnerability. Qualitative evidence from this study points to a disconnect between geological assessments and urban planning processes, with construction permits often issued without prior seismic evaluation. As [19] notes, disaster risk governance in many developing contexts is characterized by fragmented institutional arrangements and weak coordination mechanisms. [32] further argue that reliance on post-construction compliance, rather than proactive risk assessment, undermines resilience-building efforts. In GAMA, these governance challenges contribute to the continued development of healthcare facilities in hazard-prone areas, reinforcing patterns of systemic vulnerability.

The study also highlights the multi-hazard context within which healthcare facilities operate, particularly in coastal and peri-urban areas. In addition to seismic risks, these areas are exposed to flooding and soil instability, which can significantly amplify damage during earthquake events. [33] demonstrate that overlapping hazards often interact to produce compounded impacts, while [34] shows that such multi-risk environments require integrated planning approaches. In GAMA, facilities located on soft or reclaimed soils are particularly vulnerable, underscoring the need for multi-hazard risk assessments in infrastructure planning.

Differences between public and private healthcare facilities further illustrate how institutional characteristics influence exposure and reporting patterns. Public facilities were found to experience slightly higher seismic magnitude exposure, likely due to their concentration in older urban cores and stronger monitoring systems. In contrast, [35] suggests that private facilities may underreport hazard impacts due to weaker surveillance capacity or operational constraints. This distinction highlights the importance of considering institutional capacity and reporting practices when assessing vulnerability and designing interventions.

From a theoretical perspective, these findings reinforce the relevance of resilience theory, which emphasizes that system resilience depends not only on physical infrastructure but also on institutional capacity and governance effectiveness. [36] argues that resilience is shaped by the ability of systems to anticipate, absorb, and recover from shocks, while [37] highlights the importance of integrating sustainability and resilience in urban planning. In GAMA, the clustering of healthcare facilities in high-risk zones reflects a broader resilience deficit, driven by weak regulatory systems and limited integration of risk knowledge into planning processes.

While the study provides valuable insights, certain limitations should be acknowledged. The use of static spatial datasets may not fully capture the dynamic nature of urban growth, and the application of a uniform buffer distance simplifies the complexity of seismic risk. Nevertheless, as [29] note, such methodological constraints are common in data-limited contexts and do not undermine the broader validity of spatial risk assessments. Despite these limitations, the study makes significant contributions

by integrating spatial analysis with institutional perspectives to provide a comprehensive understanding of healthcare facility vulnerability. By linking empirical findings to disaster risk governance and resilience theory, the study offers both theoretical advancement and practical relevance, providing a strong basis for risk-informed planning and health system strengthening in Ghana and similar contexts.

5. Conclusion

This study examined the vulnerability of emergency-responding healthcare facilities in the Greater Accra Metropolitan Area (GAMA) to earthquake hazards. The findings show that a substantial proportion of facilities are located within moderate- to high-risk seismic zones, many in close proximity to active fault lines and identified seismic hotspots. Public healthcare facilities are particularly exposed, largely due to their concentration in older and densely developed urban areas with aging infrastructure and heightened geological susceptibility. The results further demonstrate that healthcare facility vulnerability in GAMA is not only driven by seismic processes but also shaped by fragmented spatial planning systems, weak enforcement of building standards, and limited integration of geological risk assessments into infrastructure development. From a resilience perspective, these patterns reflect systemic capacity gaps that undermine the ability of the health system to absorb seismic shocks and maintain essential services during disaster events.

6. Policy, Practice, and Future Research Implications

The findings of this study highlight the critical need to systematically integrate seismic risk considerations into health infrastructure planning and regulatory frameworks. Metropolitan, Municipal, and District Assemblies should incorporate seismic hazard data generated by the Ghana Geological Survey Authority into land-use planning processes and development approval systems to promote risk-informed siting of healthcare facilities. In addition, regulatory institutions such as the Ghana Standards Authority and the Health Facilities Regulatory Agency must enhance the enforcement of seismic design and construction standards. This necessitates a shift from predominantly reactive, post-construction compliance mechanisms toward proactive, pre-construction seismic risk assessment frameworks. Such an approach would reduce the likelihood of locating critical healthcare infrastructure within high-risk seismic zones. Strengthening inter-institutional coordination and clarifying regulatory mandates are equally important for improving compliance, accountability, and overall governance effectiveness.

At the operational level, healthcare institutions are required to prioritise earthquake preparedness and broader resilience-building strategies. This includes the systematic retrofitting of existing facilities located in high-risk areas, particularly aging public hospitals, as well as the development, regular review, and institutionalisation of facility-specific emergency preparedness and response plans. The implementation of continuous professional training programmes and simulation exercises is essential to enhance staff capacity to respond effectively to seismic events and to ensure the continuity of essential

health services. Furthermore, strengthened collaboration among key stakeholders, including the Ministry of Health (Ghana), the National Disaster Management Organization, and urban planning authorities, is necessary to align healthcare service delivery with risk-informed spatial planning and disaster risk management objectives.

Future research should build on the limitations of this study by incorporating detailed facility-level structural vulnerability assessments to better evaluate the performance of healthcare infrastructure under seismic stress. There is also a need to employ more advanced and dynamic spatial modelling techniques capable of capturing the evolving nature of urban expansion and shifting exposure patterns in rapidly growing metropolitan contexts such as GAMA. In addition, adopting a multi-hazard analytical framework that examines the interaction between earthquakes, flooding, and soil instability would provide a more comprehensive understanding of infrastructure vulnerability. Expanding the geographical scope of analysis to include other regions within Ghana, as well as conducting comparative studies across sub-Saharan African cities, would further enhance the generalisability and policy relevance of the findings.

Declarations

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Author Contributions: G.P.N. and O.A. contributed to the conceptualization and design of the study. G.P.N. led the data collection, analysis, and original draft preparation. J.A.-N., R.A.A., and W.A.D. contributed to data interpretation, critical review, and editing of the manuscript. All authors read and approved the final version of the manuscript.

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Data Availability: The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate: Ethical considerations were fully integrated into the qualitative research process. Prior to data collection, ethical approval and institutional permissions were obtained from relevant authorities with ethical approval reference numbers as Ghana Health Service (GHS-ER 036/09/24), Korle Bu Teaching Hospital (KBTH-STC/IRB/000215/2024), and the University of

Education, Winneba (UEWC/37). All participants were informed of the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any stage without consequence. Informed consent was obtained from all interviewees before interviews commenced. Participants were assured of confidentiality and anonymity, and no personally identifiable information was included in the analysis or reporting of results. Institutional affiliations were referenced only in general terms to protect participant identity.

Consent for Publication: Not applicable.

Clinical trial: Not applicable.

Competing Interests: The authors declare that they have no competing interests.

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Figures

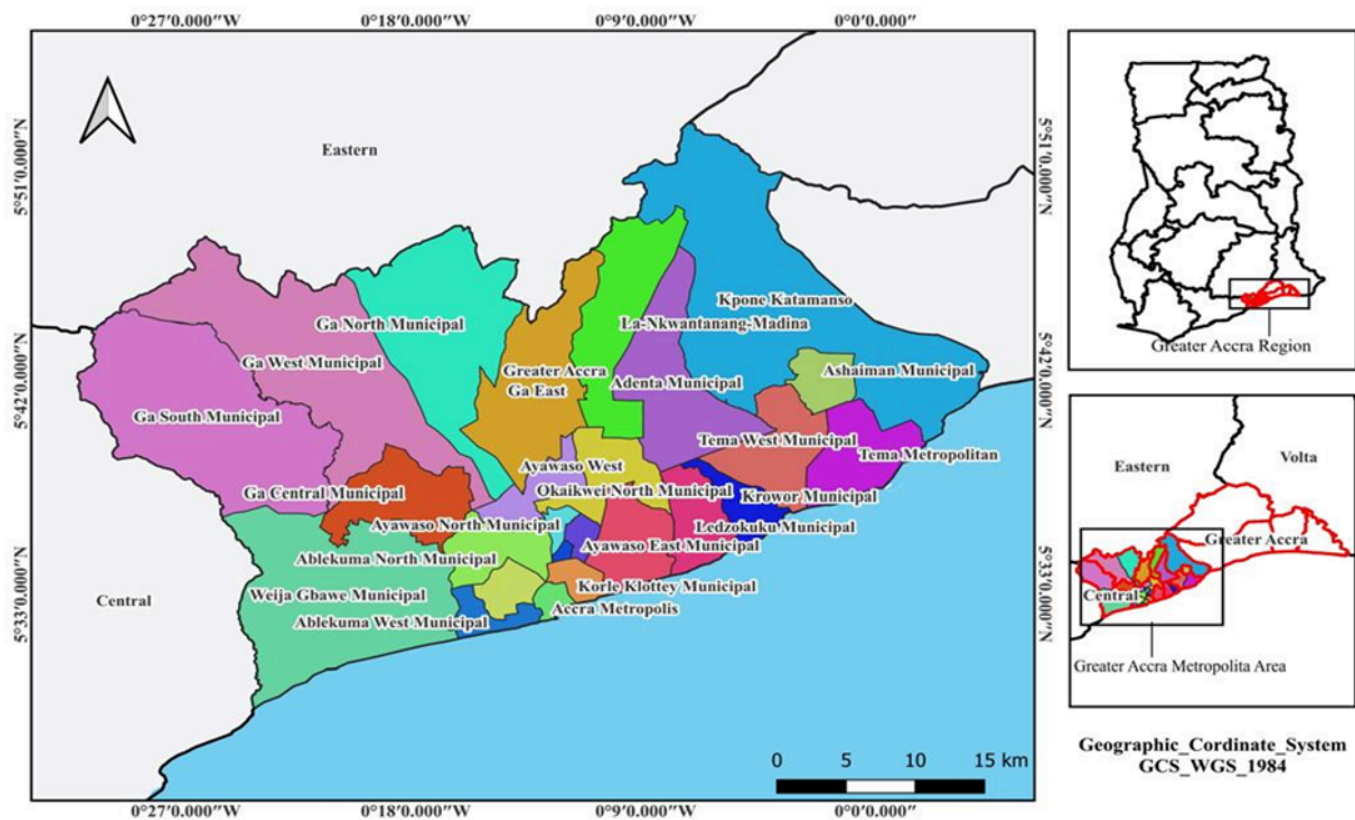


Figure 1

Map of Greater Accra Metropolitan Area (GAMA)

Source: Authors construct, 2025

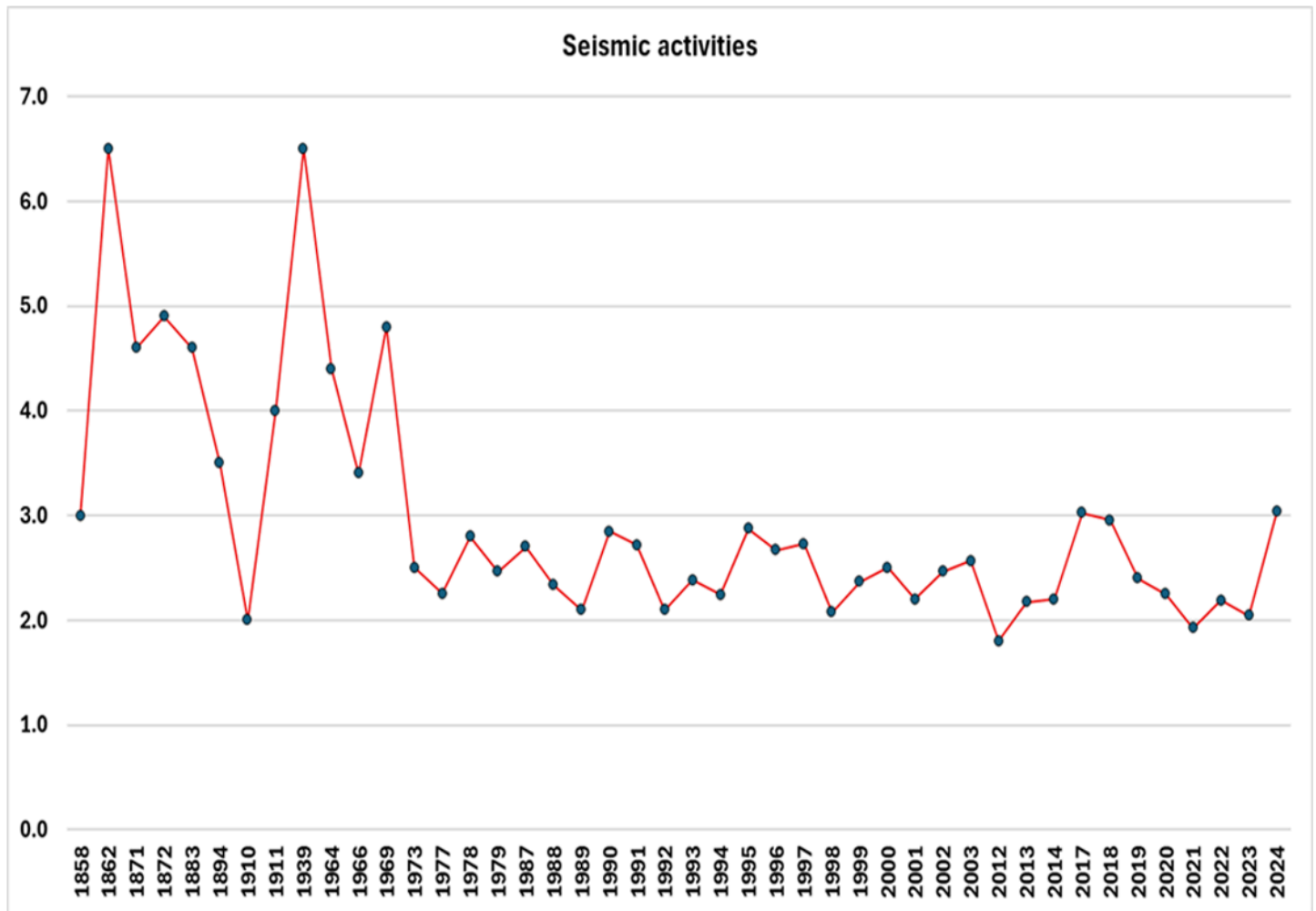


Figure 2

Graphical Representation of Earthquake Magnitudes and Frequencies in GAMA (1858–2024).

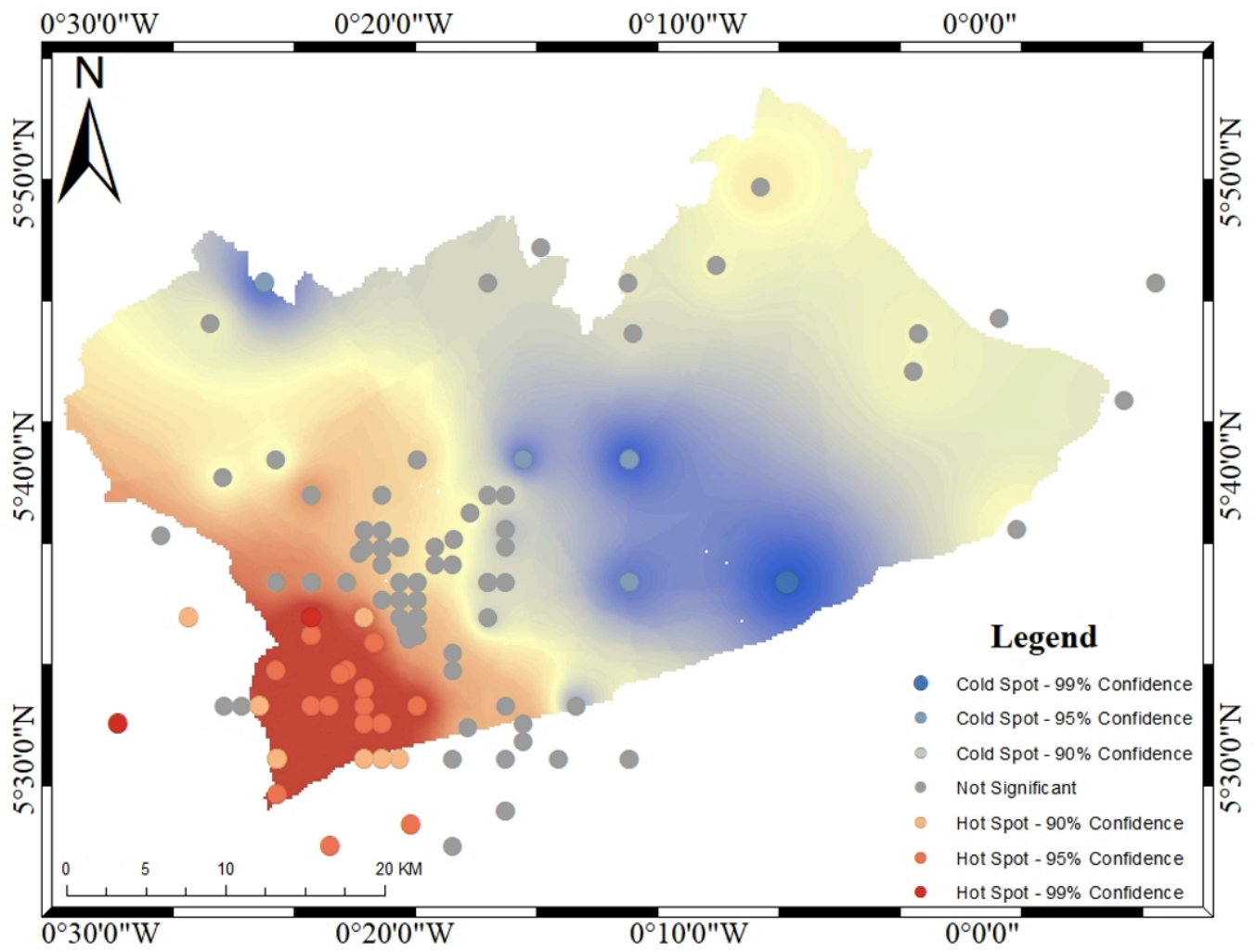
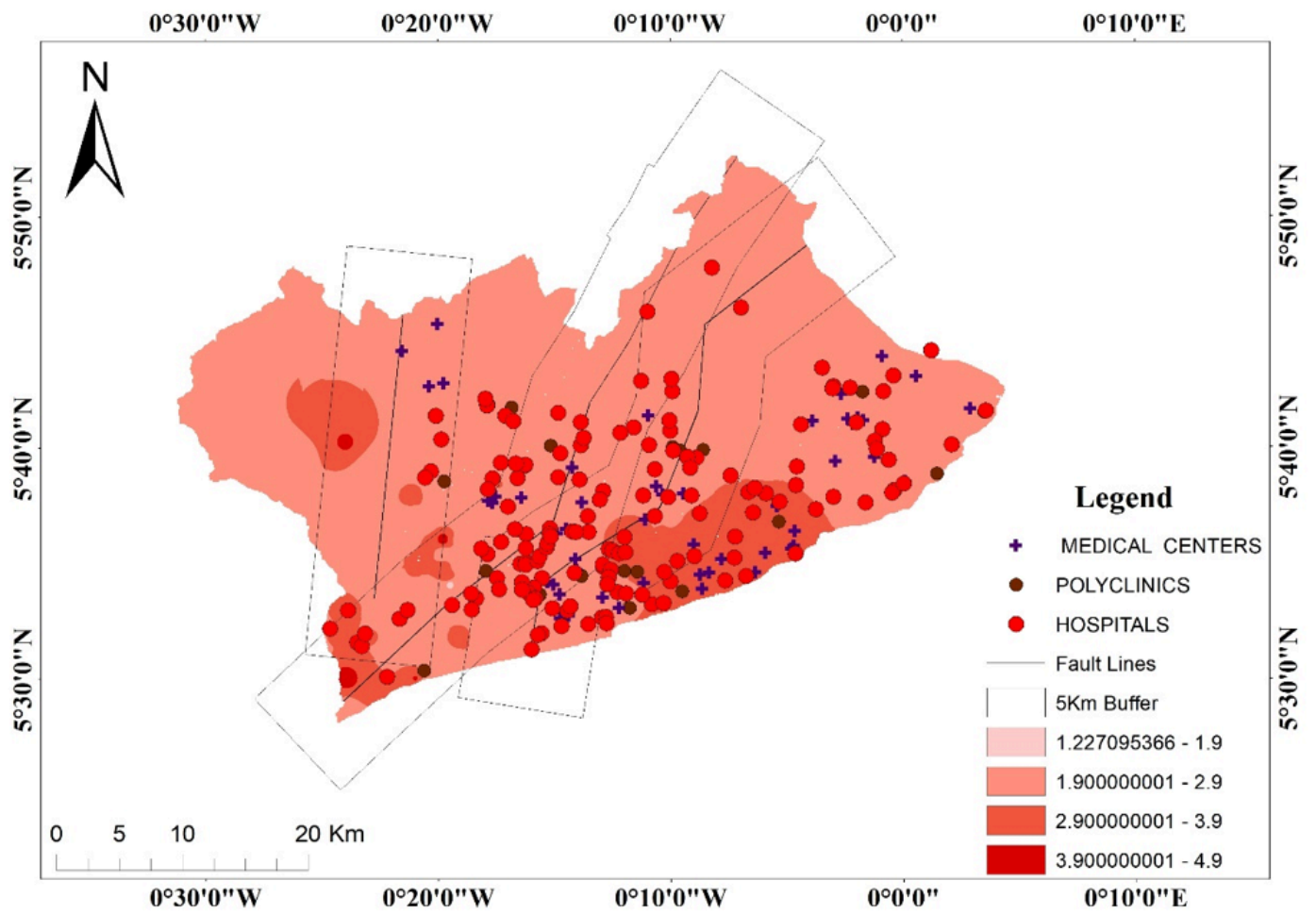


Figure 3

hotspots and cold spots of seismic zones and activities in GAMA



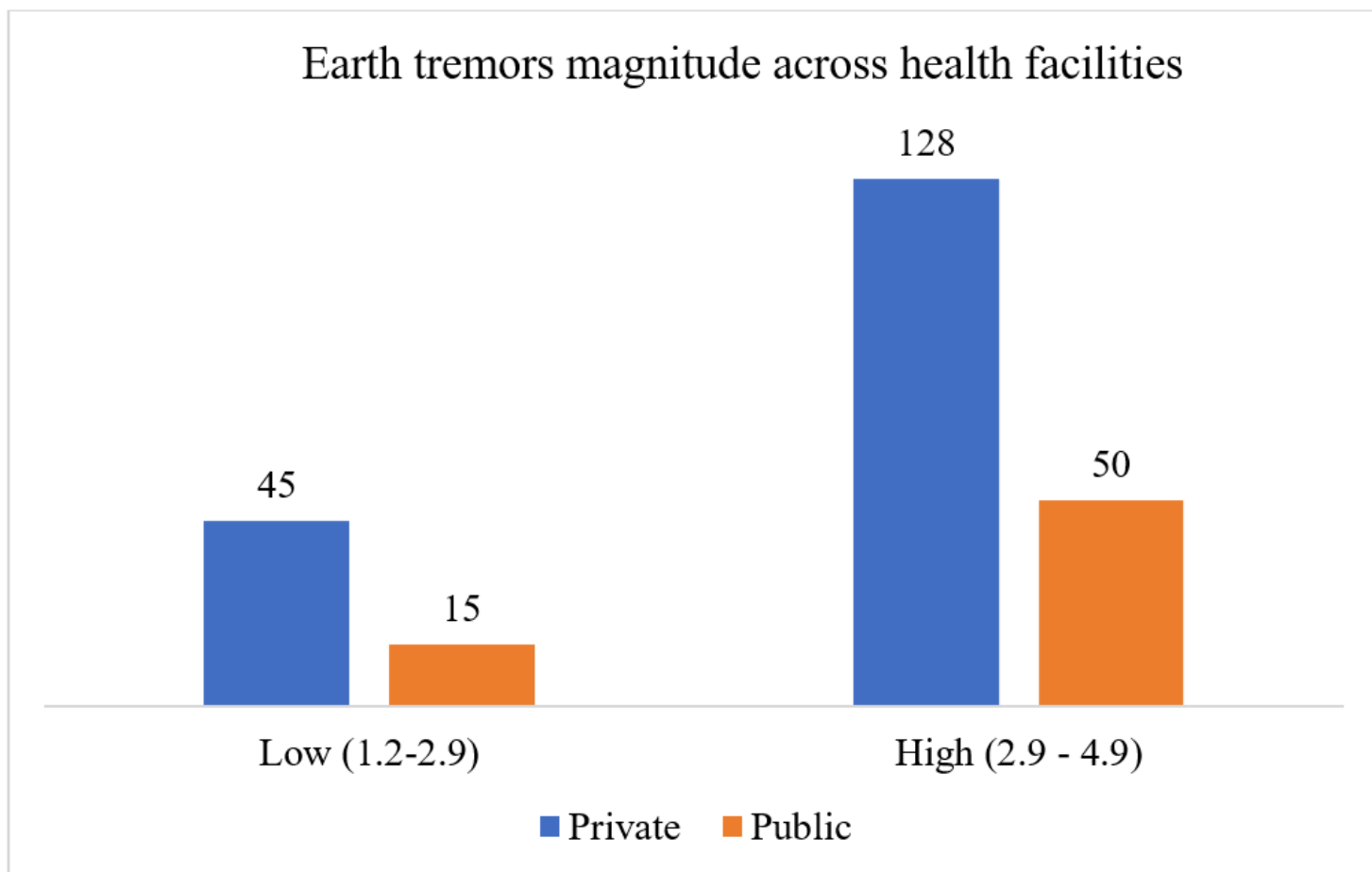


Figure 5

Earthquake magnitude across public and private health facilities