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Seismic risk assessment of residential buildings in the Greater Accra Metropolitan Area using the OpenQuake Engine: 1939 earthquake scenario

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Abstract

Ghana faces a range of natural hazards, but one of the most significant and under-prioritised is seismic risk, particularly in the Greater Accra Metropolitan Area (GAMA), a densely populated urban centre exposed to a substantial yet underappreciated earthquake threat. This study assesses the seismic risk of GAMA's residential building stock to quantify the potential societal consequences of a major earthquake. Using the open-source OpenQuake Engine, an exposure model of residential buildings, classified by construction material and construction period, was integrated with deterministic seismic hazard scenarios based on the destructive 1939 Accra earthquake. Communities in coastal and western GAMA, characterised by soft soils that amplify ground shaking and a high concentration of vulnerable unreinforced masonry buildings, are identified as the most at risk. The analysis indicates that the current Ghana Building Code, when compared with ground-motion predictions from the Atkinson and Boore (2006, modified 2011; AB11) model, may significantly underestimate seismic input in these vulnerable areas, potentially leaving communities exposed to higher levels of risk. In contrast, the Pezeshk et al. (2011; PE11) ground-motion model produces estimates that are broadly consistent with the Ghana Building Code. The results translate into tangible societal impacts: widespread building damage and collapse in high-risk neighbourhoods could result in mass casualties, *large-scale displacement, and long-term socioeconomic disruption. This research provides a robust evidence base for decision-makers, underscoring the urgent need for targeted risk-reduction strategies. We conclude that enhancing Accra's earthquake resilience requires strengthened enforcement of building codes and the implementation of targeted retrofitting programmes in the most vulnerable communities to safeguard lives and livelihoods.*

Keywords: Seismic risk assessment, Greater Accra Metropolitan Area, Earthquakes, OpenQuake Engine, Ghana Building Code, Ground motion prediction equation.

1. Introduction

Disasters are powerful disruptors of sustainable development, capable of erasing decades of socio-economic progress in a single event. Their impacts, ranging from the collapse of critical infrastructure to mass displacement and loss of life, often trigger long-term humanitarian crises that hinder economic development and deepen social inequalities (Allotey et al., 2010). A hazard, however, becomes a disaster only when it intersects with a vulnerable and exposed society (Mulugeta et al., 2016). The severity of its impacts depends on the exposure of people and assets, as well as the vulnerability and resilience of the physical, social, and institutional systems intended to protect them.

Ghana faces a wide range of natural hazards, one of the most significant yet under-prioritised being seismic risk. Despite being located within a stable cratonic region, south-eastern Ghana, particularly the Greater Accra Metropolitan Area (GAMA), has experienced several destructive earthquakes, most notably the 1939 Accra earthquake (Amponsah et al., 2020). The region's complex geological setting and active fault systems indicate the potential for future earthquakes (Allotey et al., 2010; Amponsah et al., 2020). This geological reality intersects with a high level of societal vulnerability. GAMA is the nation's economic and administrative centre, home to more than four million inhabitants, critical government institutions, and major financial and commercial activities. Consequently, seismic risk is not merely a geological concern but a direct threat to national stability, economic resilience, and the well-being of a large urban population.

In this context, seismic risk assessment is more than a technical exercise; it is a fundamental tool for disaster risk reduction, social protection, and sustainable development. By quantifying potential human, social, and economic losses, such assessments transform an otherwise invisible threat into actionable knowledge for decision-making (Bendimerad, 2001). Although complex and data-intensive, they provide the essential evidence base for developing effective risk-reduction strategies, fully consistent with Priority 1 of the Sendai Framework for Disaster Risk Reduction: Understanding Disaster Risk.

This study presents a seismic risk assessment of residential buildings in GAMA. Residential buildings are the focus because they represent the foundation of community resilience: their widespread failure would not only result in substantial loss of life but also trigger large-scale displacement, disrupt social cohesion, and severely impair the functioning of the city. By identifying and quantifying the most vulnerable building types and the neighbourhoods at greatest risk, this research provides an evidence base to support informed decision-making. The aim is to move beyond a general characterization of seismic hazard towards a quantitative assessment of societal risk, thereby informing priorities for building code revision, emergency preparedness, and targeted retrofitting programmes to enhance the safety and resilience of communities in Accra.

2. Study area and geological setting

GAMA represents a compelling case study of urban seismic risk, where a densely populated metropolitan region and critical national assets are exposed to a significant seismic hazard. This section presents the geographical, geological, and socio-economic characteristics of the study area, together with its seismotectonic setting, providing the context for the seismic risk assessment undertaken in this study.

2.1. Urban and socioeconomic characteristics of GAMA

The Greater Accra Metropolitan Area (GAMA), centred on the capital city of Accra (5°30′ N, 0°10′ W), covers approximately 1,000 km², making it the smallest yet most densely populated region in Ghana (Allotey et al., 2010). With an estimated population of more than four million inhabitants (Ghana Statistical Service, 2021), GAMA comprises a rapidly expanding metropolitan area encompassing twenty-five administrative districts. It serves as Ghana's principal centre for commerce, finance, government, and education (Allotey et al., 2010).

Rapid urbanisation has outpaced formal planning and infrastructure development in many parts of the metropolitan area, resulting in the expansion of high-density informal settlements. Residential buildings in these communities are predominantly non-engineered structures, including unreinforced masonry buildings and informally constructed reinforced-concrete frames, many of which do not comply with seismic building codes. Moreover, this vulnerable building stock is unevenly distributed, being concentrated in economically disadvantaged areas, particularly along the coast and in zones underlain by soft soils. Consequently, physical vulnerability coincides with social vulnerability, substantially increasing the potential impacts of future earthquakes.

2.2. Seismic hazard and geology

The high societal exposure of GAMA is matched by a well-documented seismic hazard. The region lies within the South Ghana Seismic Zone, where seismicity is primarily controlled by the Akwapim Fault Zone, a major NE-SW-trending tectonic structure that constitutes the principal seismic source affecting the capital region (Amponsah et al., 2020). Historical earthquakes in GAMA have been shallow-focus, tectonic events associated with the reactivation of ancient regional faults. Many have been accompanied by significant foreshock and aftershock sequences, consistent with the behaviour of shallow crustal earthquakes (Junner et al., 1941; Kutu et al., 2013).
Local geological conditions further amplify the seismic hazard. Large areas of GAMA, including the central business district, the port city of Tema, and several coastal suburbs, are underlain by soft clays and unconsolidated sediments. These deposits are susceptible to liquefaction and, more importantly, to the amplification of seismic waves at bedrock, resulting in stronger and more prolonged ground shaking. Consequently, even moderate earthquakes occurring at some distance from the metropolitan area may produce locally severe damage, particularly where vulnerable buildings and critical infrastructure are founded on these soft soil deposits.
The significance of this seismic hazard is reflected in the region's historical record. The most destructive event in recent history, the 1939 Accra earthquake (Mw 6.5), resulted in 17 fatalities, injured 133 people, and caused extensive damage to buildings and infrastructures. More recent earthquakes, including those that occurred in 1964, 1997, and 2019, demonstrate that seismic activity remains an active and recurring threat rather than a historical phenomenon. Since 1939, GAMA has experienced rapid population growth, urban expansion, and substantial economic development. Consequently, an earthquake of comparable magnitude occurring today would be expected to produce far greater human, economic, and societal impacts.

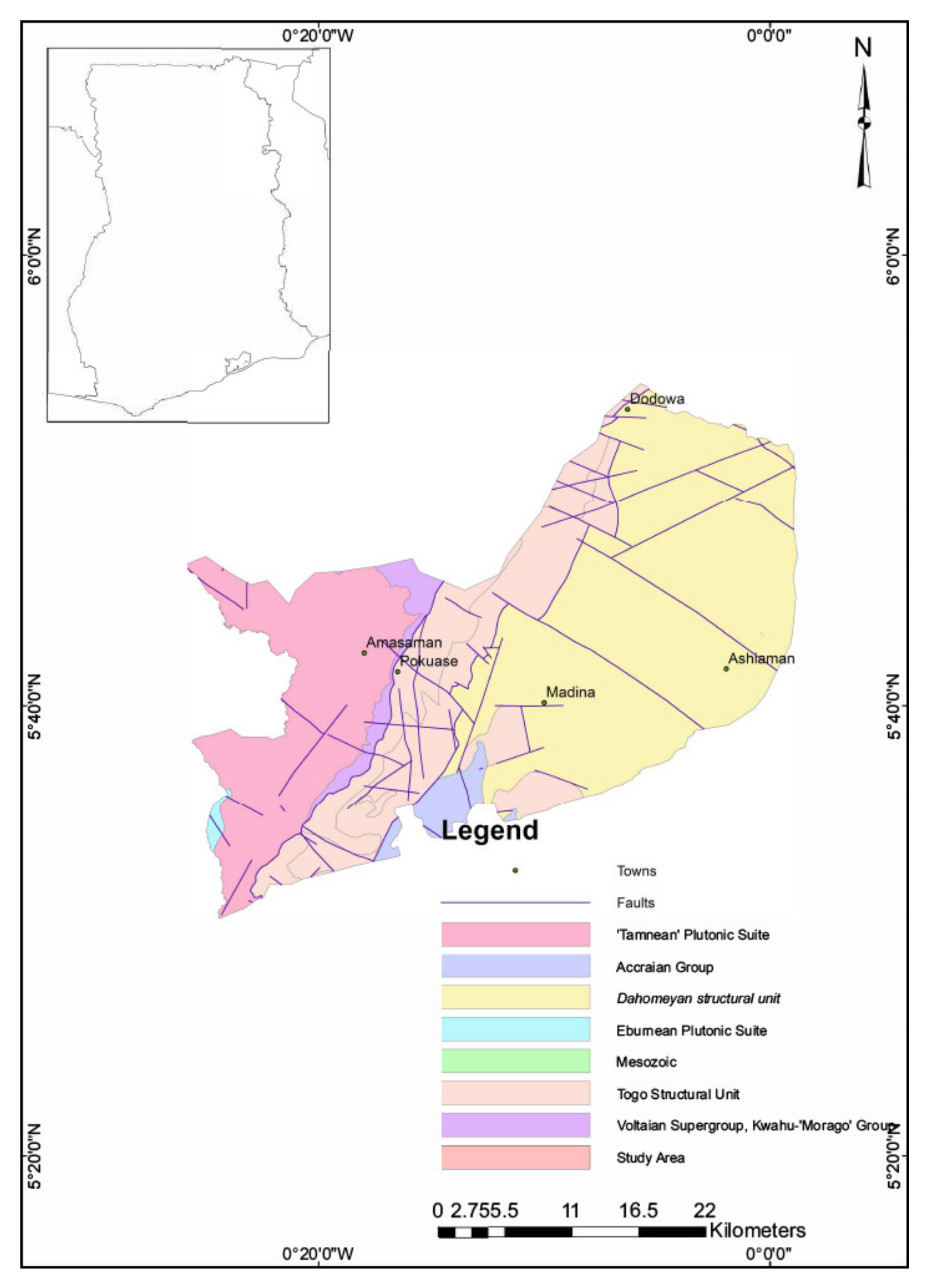

Figure 1. *Geology of GAMA (after Agyei-Duodu et al., 2009).*

Seismic risk in GAMA therefore arises from the interaction between a well-defined earthquake hazard and a densely populated metropolitan area characterised by widespread structural vulnerability. This convergence of hazard, exposure, and vulnerability makes comprehensive seismic risk assessment an essential prerequisite for effective disaster risk reduction and resilient urban planning.

Geologically, the study area is underlain predominantly by rocks of the Dahomeyide Belt, the Birimian Supergroup, and the Voltaian Supergroup (Agyei-Duodu et al., 2009; Anani et al., 2017; Kwayisi et al., 2024, 2025). A small southeastern portion of the area is occupied by the Palaeozoic and Tertiary coastal sedimentary basins (Figure 1; Agyei-Duodu et al., 2009).

The Dahomeyide Belt consists primarily of the crystalline basement rocks of the Dahomeyan Structural Unit, composed of mafic and felsic gneiss, together with the metasedimentary rocks of the overlying Togo Structural Unit. The felsic gneiss typically weathers into slightly permeable clayey sands, whereas the mafic gneiss weathers into relatively impermeable calcareous clays. The Birimian Supergroup comprises granitoids and granitoid gneisses belonging to the Eburnean and Tonian plutonic suites (Amponsah et al., 2023).

The Accra-Keta Basin, which forms part of Ghana's Palaeozoic-Tertiary coastal sedimentary basins, is dominated by Tertiary sands and Quaternary deposits (Figure 1). In the southern part of the study area, the Tertiary sediments consist predominantly of arenaceous and argillaceous deposits (Agyei-Duodu et al., 2009).

3. Methodology

The seismic risk assessment was conducted for residential buildings in GAMA using the OpenQuake Engine, an open-source software framework for probabilistic seismic hazard analysis and scenario-based seismic risk assessment (Silva et al., 2014; Pagani et al., 2024; Rao et al., 2025). The analysis integrated three fundamental components: a seismic hazard model, an exposure model of the residential building stock, and a vulnerability model describing the fragility of each building class. These components were combined within the OpenQuake Engine to estimate structural damage under a defined earthquake scenario.

3.1. Seismic hazard assessment

The selection of an earthquake scenario is a critical step in seismic risk assessment, requiring the definition of source parameters that realistically represent a plausible seismic event (Azizi et al., 2023). This study adopted a deterministic, scenario-based approach to simulate a high-impact earthquake comparable to the historically significant 22 June 1939 Accra earthquake. Accordingly, the seismic source parameters were derived from this event and are summarised in Table 1.

The scenario considered a Mw 6.5 earthquake generated by the Akwapim Fault Zone, identified as the principal seismic source affecting the study area. Rupture geometry was defined using the mapped fault trace together with assumptions regarding rupture length, strike, dip, rake, seismogenic depth, and faulting mechanism. These parameters were implemented in the OpenQuake Engine to simulate the spatial distribution and attenuation of ground motion generated by the scenario earthquake.

Parameter	Value
Magnitude M_W	6.5
Longitude	−0.1333°
Latitude	5.2000°
Depth	18 km
Strike	N 9° E
Dip	80°
Rake	3.1°

Table 1. *Seismic Source Parameters for the 1939 Earthquake Scenario (source: Quaah, 1980).*

Deterministic seismic hazard and ground-motion simulations were performed using the OpenQuake Engine. To account for epistemic uncertainty in ground-motion prediction, two Ground Motion Prediction Equations (GMPEs) appropriate for stable continental regions were incorporated into a logic-tree framework. The first branch employed the Atkinson and Boore (2006, modified 2011; AB11) model, while the second used the Pezeshk et al. (2011; PE11) model. Both GMPEs were originally developed for shallow crustal earthquakes in stable continental regions and are considered appropriate for the tectonic setting of the West African Craton. Because no prior evidence favoured one model over the other, equal logic-tree weights (0.5 each) were assigned to the two branches, resulting in two equiprobable logic-tree realizations. The two GMPEs are briefly described below:

1) AB11 – Developed for Eastern North America, this model incorporates a nonlinear site-amplification function based on the time-averaged shear-wave velocity in the upper 30 m (Vs30), with a reference value of 760 m/s. It was selected because of its applicability to stable continental tectonic environments such as the West African Craton.

2) PE11 – This hybrid GMPE was also developed for Eastern North America and is applicable to earthquakes with magnitudes between Mw 4.0 and 8.0 and rupture distances of up to 1,000 km. Its applicability to stable continental regions makes it suitable for modelling the expected seismicity of GAMA.

Ground Motion Fields (GMFs) were generated using the Scenario-Based Seismic Hazard Calculator implemented in the OpenQuake Engine. The simulated GMFs capture the variability associated with the selected ground-motion models and constitute the primary input for the subsequent scenario-based seismic risk assessment, enabling the estimation of building damage, economic losses, and human casualties.

3.2. Building inventory

The building exposure model was developed by integrating official census data with geospatial information and existing exposure datasets. The total number and distribution of residential buildings were obtained from the 2021 Population and Housing Census of the Ghana Statistical Service (GSS), which reports 1,076,556 residential buildings within GAMA (Ghana Statistical Service, 2021). This dataset provided the baseline building inventory for the exposure model.

To spatially distribute the census-derived building stock and classify structural typologies, the census data were combined with secondary geospatial datasets, including Google Earth satellite imagery and the Global Earthquake Model (GEM) exposure model (Paul et al., 2022). Satellite imagery was used to identify and verify the spatial distribution, density, and configuration of building footprints, distinguishing between compact urban settlements, dispersed residential areas, and sparsely developed zones. These observations were then used to allocate the census-derived building counts across the exposure grid.

The GEM global exposure model provided the prior distribution of structural characteristics for the building stock, including building typologies, construction materials, occupancy classes, and other vulnerability-related attributes. Where necessary, these attributes were refined using information derived from satellite-image interpretation and local knowledge of the dominant building types within the study area.

3.3. Site conditions

Local site conditions exert a significant influence on seismic hazard because near-surface geological materials can amplify or attenuate ground motions. GAMA is characterised by heterogeneous geological conditions, ranging from soft coastal sediments to bedrock. To account for this spatial variability in site response, the time-averaged shear-wave velocity in the upper 30 m (Vs30) was adopted as the principal site parameter.

Vs30 data were obtained from Nortey (2021), who conducted a comprehensive Multichannel Analysis of Surface Waves (MASW) survey across GAMA. MASW is a non-invasive geophysical technique that derives shear-wave velocity (Vs) profiles from the dispersion characteristics of Rayleigh waves, providing reliable estimates of Vs30 for site classification.

Based on measurements from 42 survey locations, the derived Vs30 values were classified according to the National Earthquake Hazard Reduction Program (NEHRP) site classification system. The analysis identified Site Classes D (Vs30 = 180-360 m/s) and C (Vs30 = 360-760 m/s) as the predominant ground conditions across GAMA (Nortey, 2021). Site Class D, characterised by relatively soft soils with a high potential for seismic-wave amplification, predominates in many coastal areas, whereas Site Class C generally exhibits lower amplification potential. These classifications were incorporated into the seismic hazard modelling to account for local site effects on ground-motion intensity.

3.4. Vulnerability

Building vulnerability describes the probability of damage resulting from a given level of seismic input. In this study, vulnerability was modelled using the vulnerability functions developed within the Global Earthquake Model (GEM) framework, specifically those presented by Martins and Silva (2021) for the GEM global vulnerability model. The principal structural typologies identified in GAMA are unreinforced masonry (URM), confined masonry (CM), and reinforced concrete (RC) buildings. Unreinforced masonry is the dominant construction type, accounting for approximately 65-68% of the residential building stock (Ghana Statistical Service, 2021), and therefore represents the region's greatest source of seismic vulnerability. Most URM buildings are constructed with cement-stabilized concrete blocks, while adobe buildings, although less common, are still present in older neighbourhoods and are particularly susceptible to deterioration under Accra's humid climatic conditions (Ghana Statistical Service, 2021; Paul et al., 2022).

Older reinforced concrete buildings also exhibit significant structural deficiencies, including inadequate shear reinforcement in columns and non-ductile beam-column joint detailing (Allotey et al., 2010). These deficiencies promote brittle failure mechanisms that substantially reduce seismic performance. Structural vulnerability is further aggravated by inadequate foundations, particularly in informal settlements, where many buildings were constructed without proper engineering design. This problem is especially critical in areas underlain by soft soils or affected by high groundwater levels, where differential settlement may further compromise structural stability. In addition, material deterioration associated with coastal environmental conditions, including reinforcement corrosion, concrete carbonation, and mortar weathering, progressively reduces the seismic resistance of ageing buildings.

For each building taxonomy (URM, CM, and RC), the corresponding GEM vulnerability function was selected from the publicly available OpenQuake Engine vulnerability database. These functions were derived through nonlinear time-history analyses of equivalent single-degree-of-freedom (SDOF) systems, in which the structural response of each building class is represented by a capacity (backbone) curve. For building types in which masonry infill walls significantly influence lateral behaviour, such as confined masonry and infilled reinforced concrete frames, quadrilinear capacity curves were adopted to represent the successive stages of infill cracking, frame yielding, and ultimate failure.

The resulting fragility functions express the probability of exceeding four damage states – Slight (DS1), Moderate (DS2), Extensive (DS3), and Complete/Collapse (DS4) – as a function of ground-motion intensity, represented by Peak Ground Acceleration (PGA). Following the GEM methodology, a composite vulnerability function was adopted for each building class, integrating structural damage, non-structural damage, and building contents into a single loss model. Damage ratios of 0.05, 0.20, 0.60, and 1.00 were assigned to the four damage states, respectively. Finally, the fragility functions were represented as lognormal cumulative distribution functions, exported in Natural Hazard Risk Markup Language (NRML) format, and implemented directly within OpenQuake Engine for the subsequent scenario-based seismic risk calculations.

3.5. Seismic risk calculation

The integrated seismic risk assessment was performed using the OpenQuake Engine (Pagani et al., 2024). The three fundamental components of the risk model – the seismic hazard model, the building exposure model (Yepes-Estrada et al., 2023), and the vulnerability (fragility) functions – were prepared using the OpenQuake Input Preparation Toolkit. The Scenario Damage and Loss Calculator was then used to perform the seismic risk analysis. This deterministic module simulated ground shaking generated by the defined Mw 6.5 earthquake scenario, applied the resulting ground-motion fields to the georeferenced building exposure model, and estimated the corresponding damage for each asset according to its assigned vulnerability function.

4. Results

The results quantify the potential impacts of a Mw 6.5 earthquake scenario simulated using the OpenQuake Engine. To evaluate the sensitivity of the results to the choice of ground-motion model, simulations were performed using two established Ground Motion Prediction Equations (GMPEs). For each GMPE, ten Ground Motion Field (GMF) realizations were generated to capture the aleatory variability inherent in ground-motion prediction. The comparison between the two GMPEs provides a first-order assessment of epistemic uncertainty associated with the choice of the ground-motion model; however, the analysis should be interpreted as a scenario-based sensitivity study rather than a comprehensive probabilistic uncertainty analysis. A fixed random seed was used to ensure reproducibility of the stochastic generation of the GMFs. Results are presented sequentially, beginning with Peak Ground Acceleration (PGA) and followed by the corresponding estimates of building damage.

4.1. Spatial distribution of PGA

Peak Ground Acceleration (PGA) for the Mw 6.5 earthquake scenario was simulated using two Ground Motion Prediction Equations (GMPEs). For each GMPE, ten Ground Motion Field (GMF) realizations were generated using the OpenQuake Engine to account for the inherent variability in ground-motion prediction. For comparison, the design PGA specified by the Ghana Building Code (GhBC, 2018) of 0.35 g was adopted as a reference value.

The resulting PGA maps reveal a clear spatial pattern, with the highest ground accelerations (0.35-0.58 g) concentrated in the coastal areas of GAMA, where soft soils amplify seismic waves. In contrast, lower PGA values are predicted in the northern part of the metropolitan area, which is predominantly underlain by stiffer geological formations. This spatial variability reflects the combined influence of source-to-site distance, fault geometry, and local site effects associated with variations in near-surface geological conditions.

A key finding is the discrepancy between the ground-motion estimates predicted by the GMPEs and the design acceleration specified in the Ghana Building Code (GhBC, 2018). The AB11 model predicts PGA values that exceed the code's design acceleration of 0.35 g by up to 60% in the most vulnerable coastal areas (Figure 2). In contrast, the PE11 model produces PGA estimates that are broadly consistent with the code provisions (Figure 3). These results suggest that buildings designed strictly in accordance with the current code may not achieve an adequate level of seismic safety if the higher ground motions predicted by the AB11 model are realised.

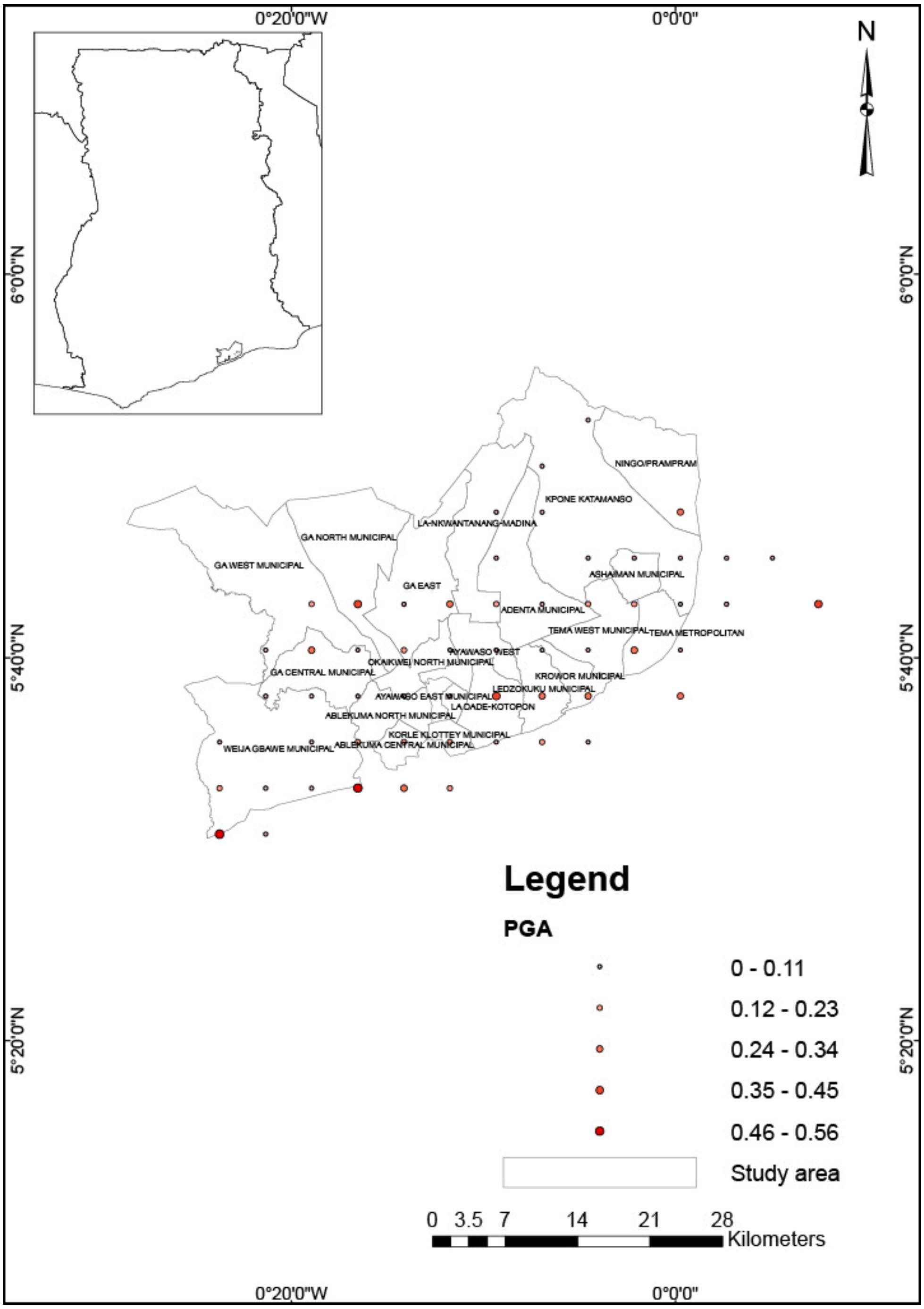

Figure 2. *Predicted PGA based on AB11 GMPE.*

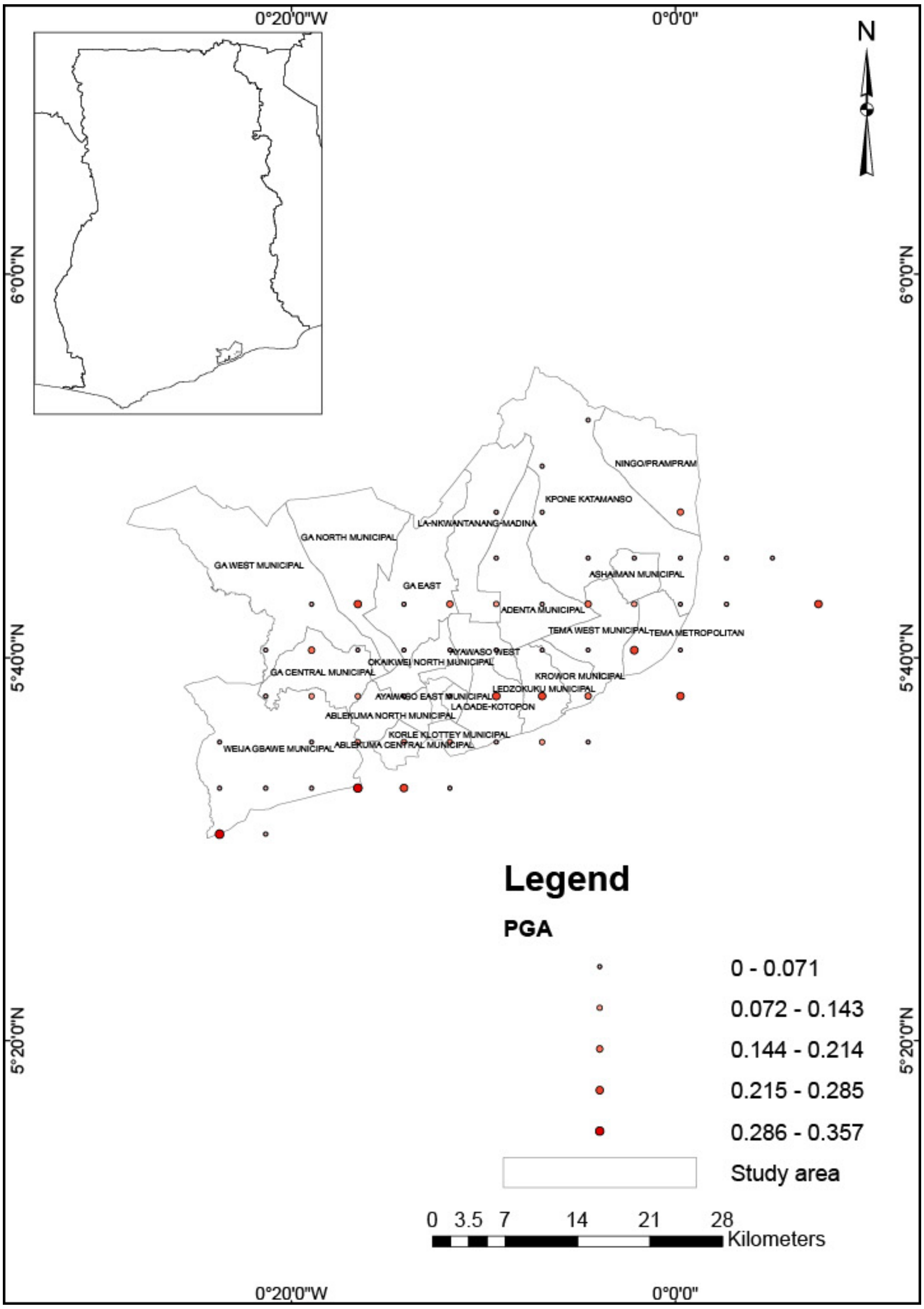

Figure 3. *Predicted PGA based on PE11 GMPE.*

When the two GMPE branches are combined with equal weights within the logic-tree framework, the mean PGA is approximately 0.32 g, slightly below the code reference value of 0.35 g, whereas the 84th-percentile PGA reaches approximately 0.44 g. This suggests that, although the mean scenario ground motion is broadly consistent with the design value prescribed by the Ghana Building Code, higher-end ground-motion estimates may exceed the current design level in some coastal areas.

Simulation No.	GMPE	Minimum PGA	Maximum PGA
1	AB11	0.073	0.364
2	AB11	0.08	0.398
3	AB11	0.074	0.369
4	AB11	0.11	0.56
5	AB11	0.093	0.467
6	AB11	0.067	0.333
7	AB11	0.041	0.206
8	AB11	0.097	0.486
9	AB11	0.089	0.445
10	AB11	0.051	0.255
11	PE11	0.051	0.253
12	PE11	0.052	0.26
13	PE11	0.052	0.262
14	PE11	0.071	0.357
15	PE11	0.062	0.308
16	PE11	0.047	0.235
17	PE11	0.032	0.16
18	PE11	0.061	0.305
19	PE11	0.053	0.264
20	PE11	0.038	0.189

Table 2. *Summary of the ten Ground Motion Field (GMF) realizations generated for each GMPE.*

4.2. Distribution of residential building damage

The spatial distribution of building damage reveals marked variations in seismic risk across GAMA. Overall, the AB11 ground-motion model predicts consistently higher levels of damage than the PE11 model across all damage states (Slight, Moderate, Extensive, and Complete). Damage is concentrated primarily in the coastal municipalities of Accra Metropolitan, Ledzokuku, Krowor, and La Dade-Kotopon. In these areas, the combined effects of proximity to the Akwapim and Coastal Boundary

Faults and the predominance of NEHRP Site Class D soils (Vs30 = 180-360 m/s) are expected to amplify ground motion, resulting in higher probabilities of structural damage. An additional inland hotspot is identified in the Ga East Municipality, where the combination of a dense and vulnerable building stock and potential ground instability associated with quarrying activities may further increase seismic risk.

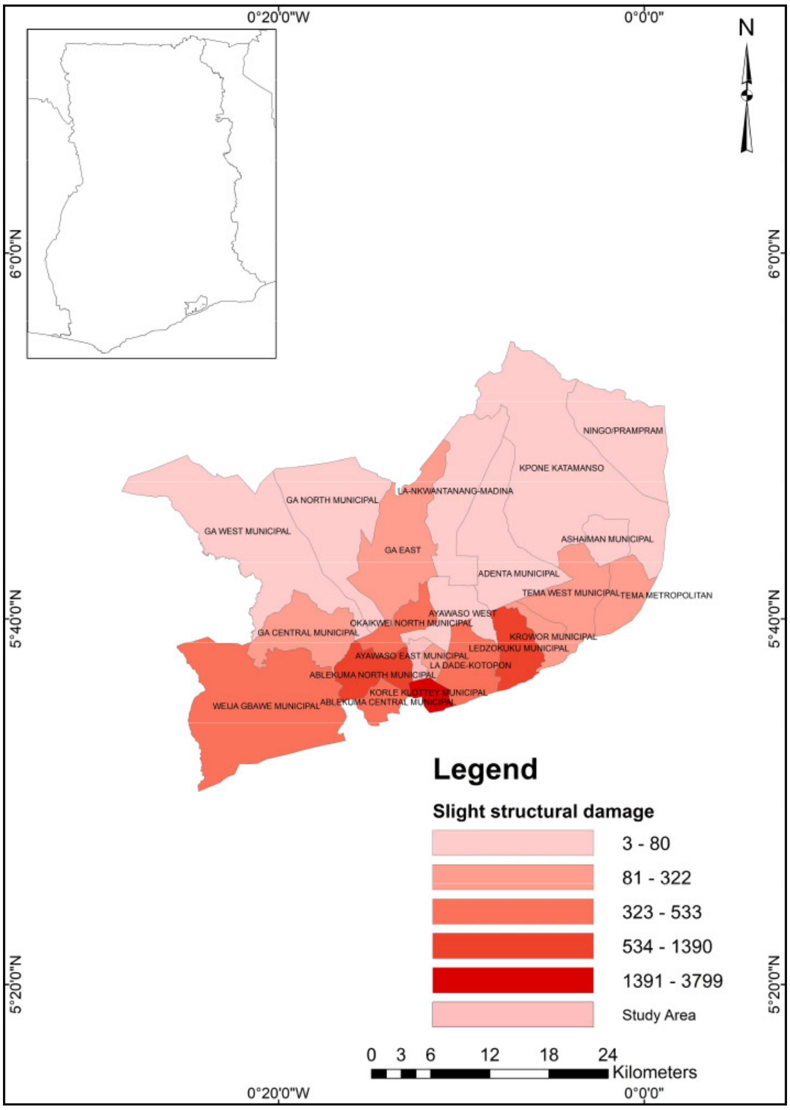

Figure 4. *Slight structural damage distribution in GAMA based on the AB11 GMPE.*

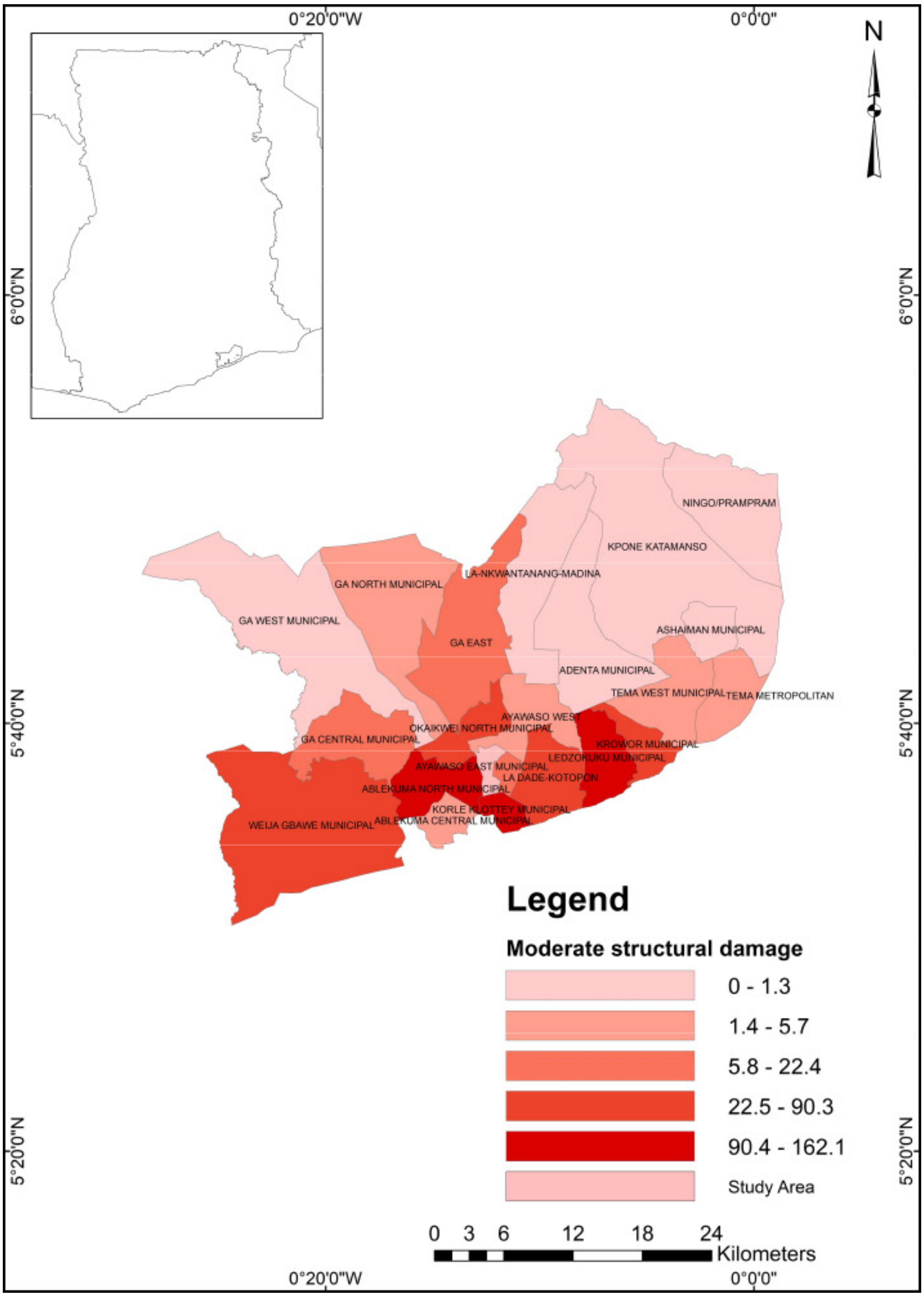

Figure 5. *Moderate structural damage distribution in GAMA based on the AB11 GMPE.*

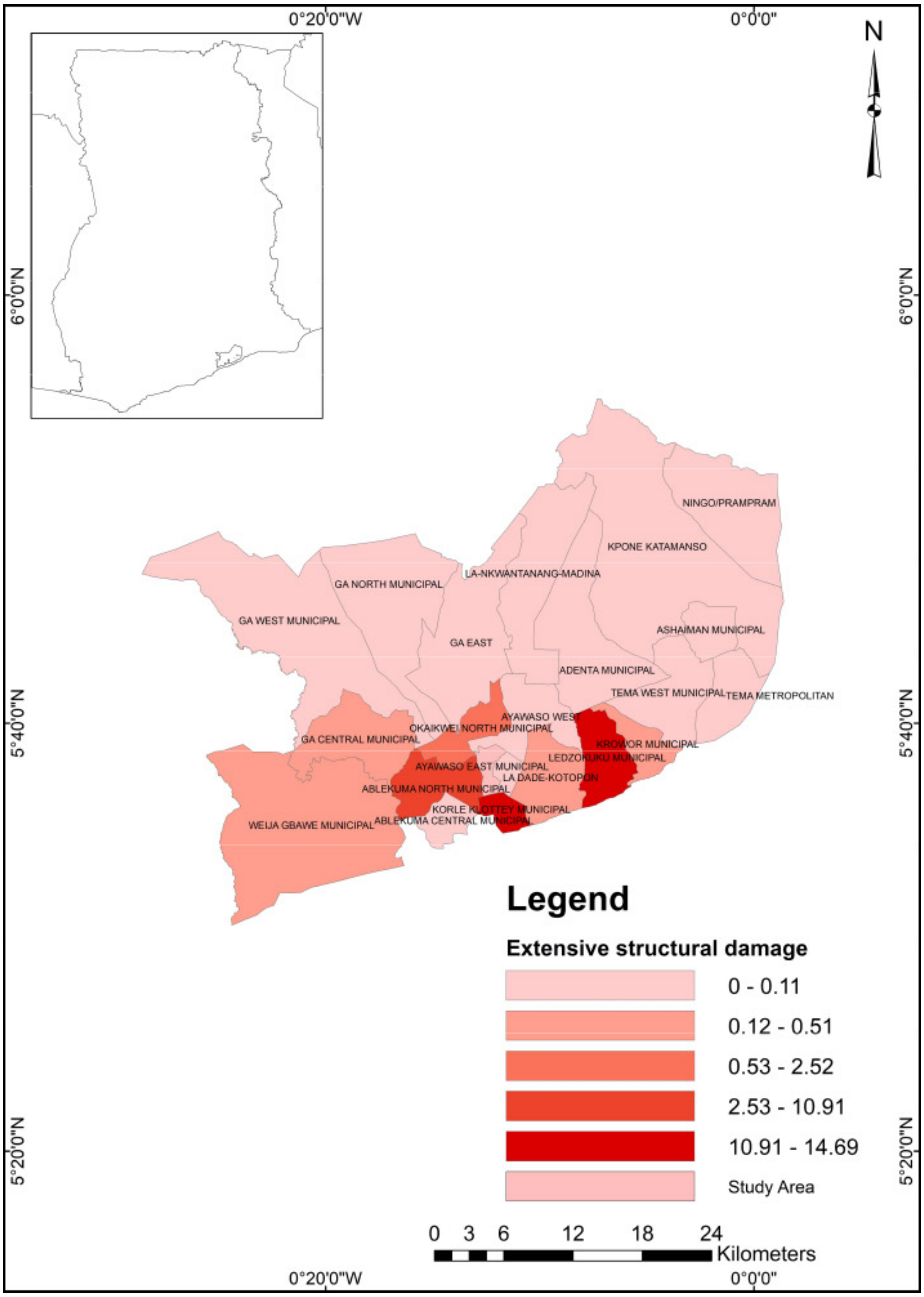

Figure 6. *Extensive structural damage distribution in GAMA based on the AB11 GMPE.*

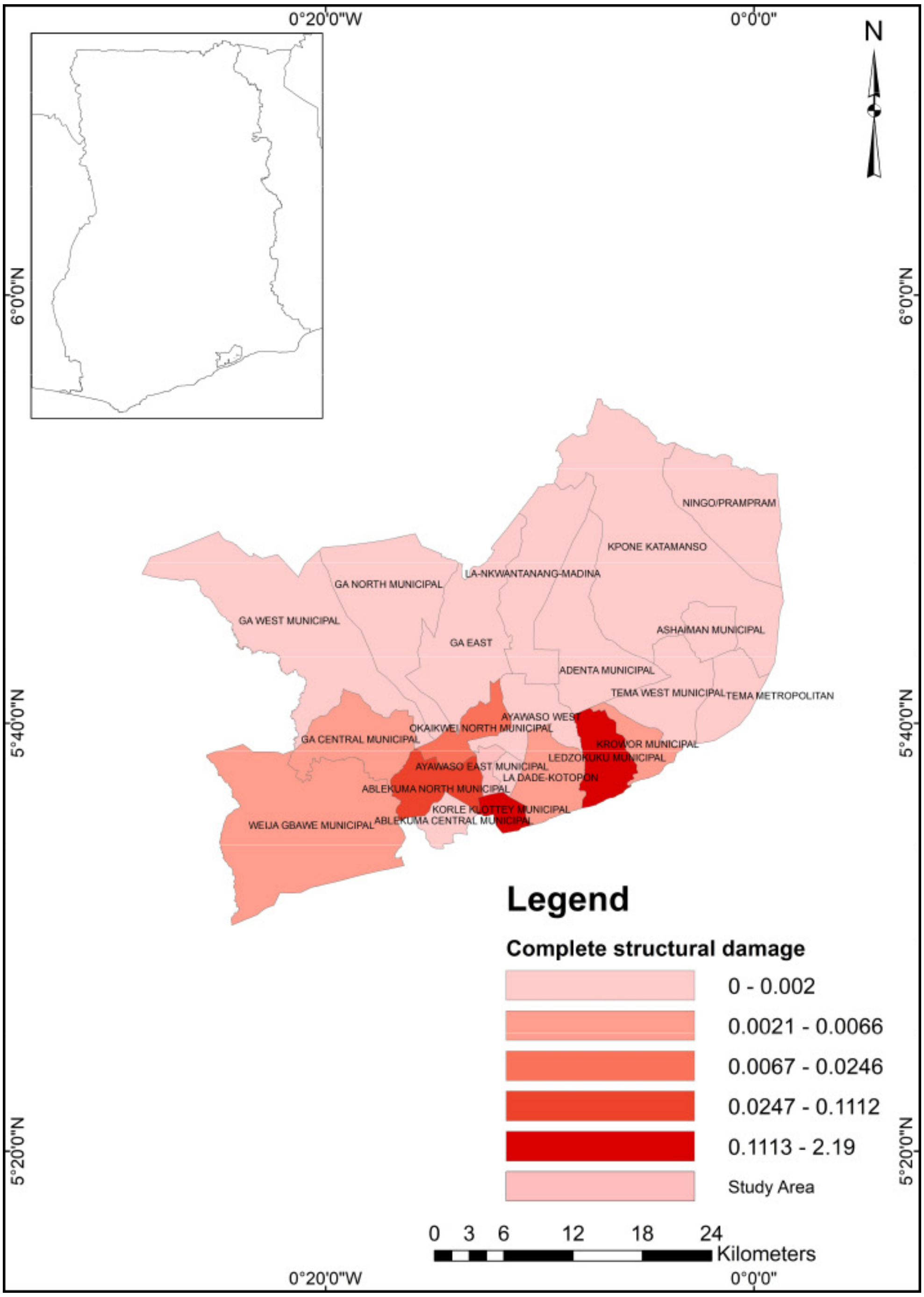

Figure 7. *Complete structural damage distribution in GAMA based on the AB11 GMPE.*

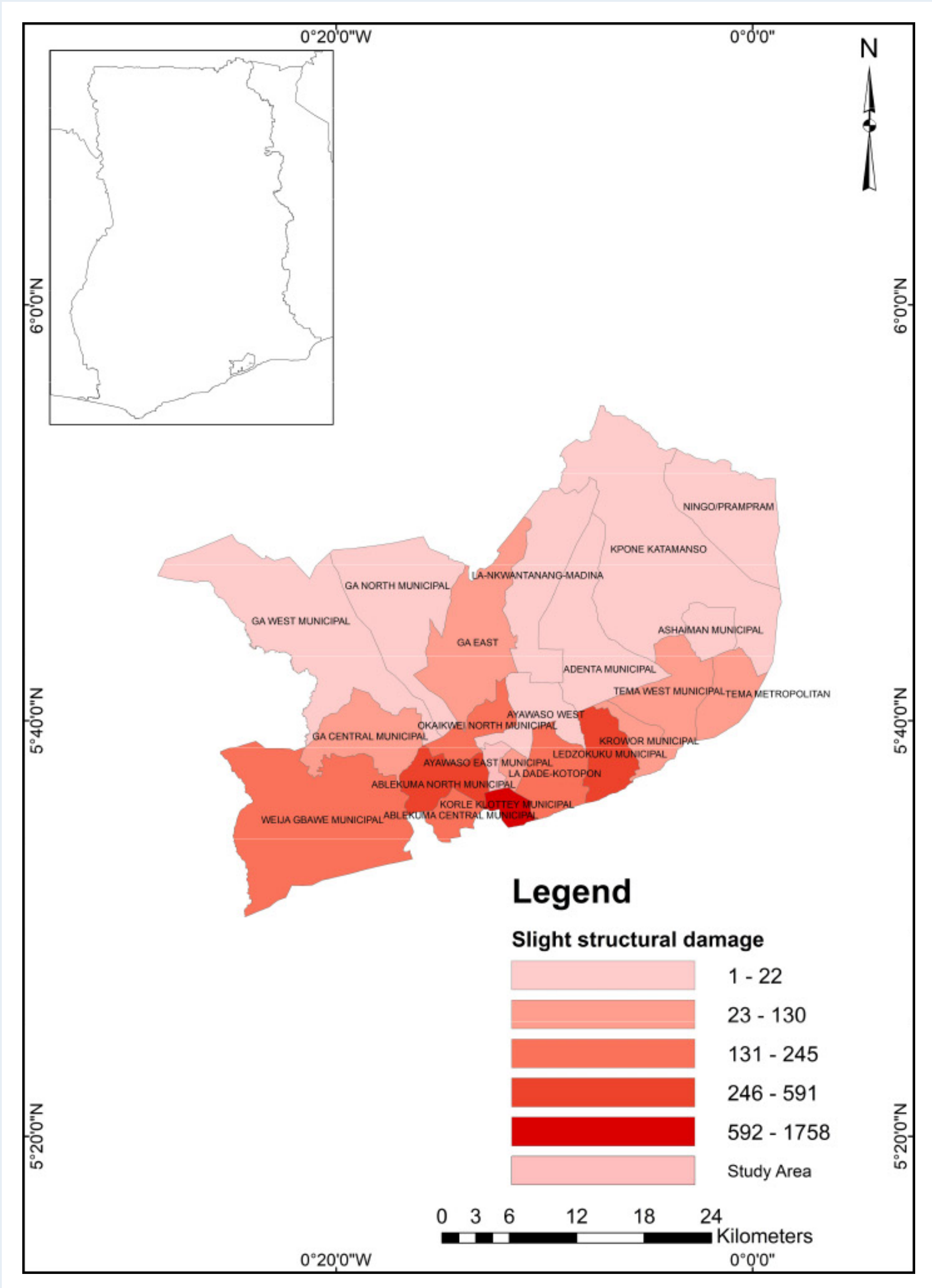

Figure 8. *Slight structural damage distribution in GAMA based on the PE11 GMPE*

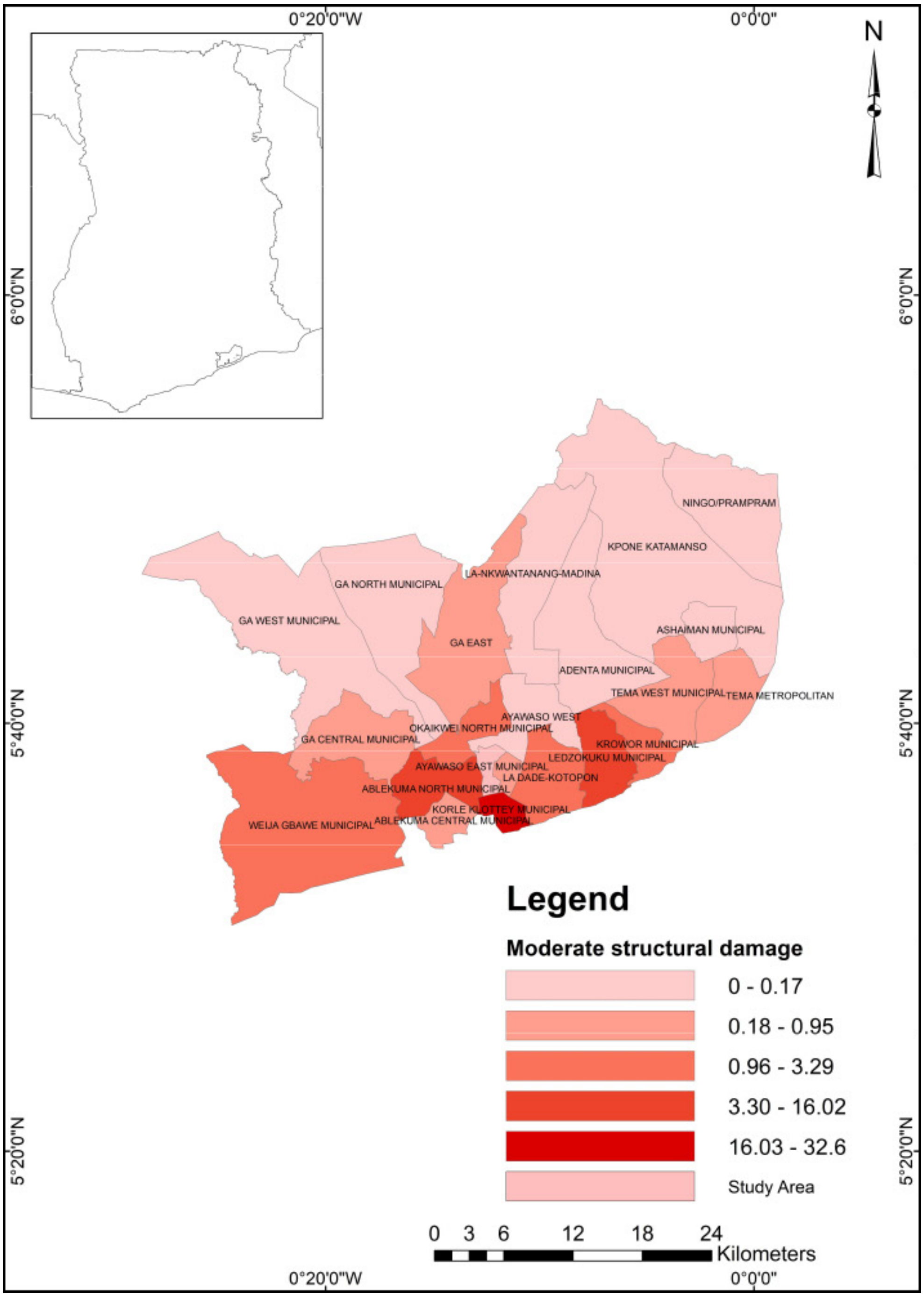

Figure 9. *Moderate structural damage distribution in GAMA based on the PE11 GMPE.*

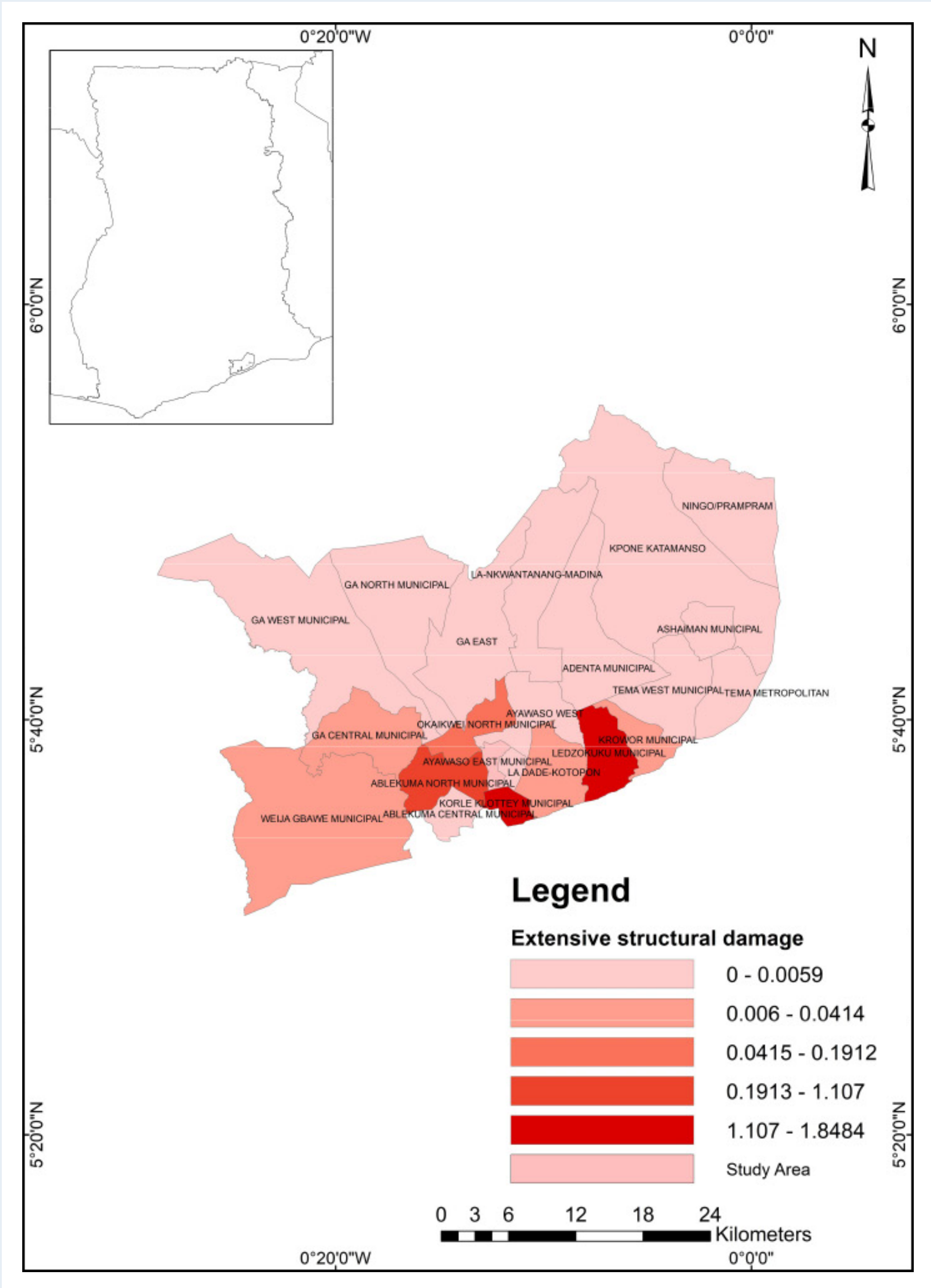

Figure 10. *Extensive structural damage distribution in GAMA based on the PE11 GMPE.*

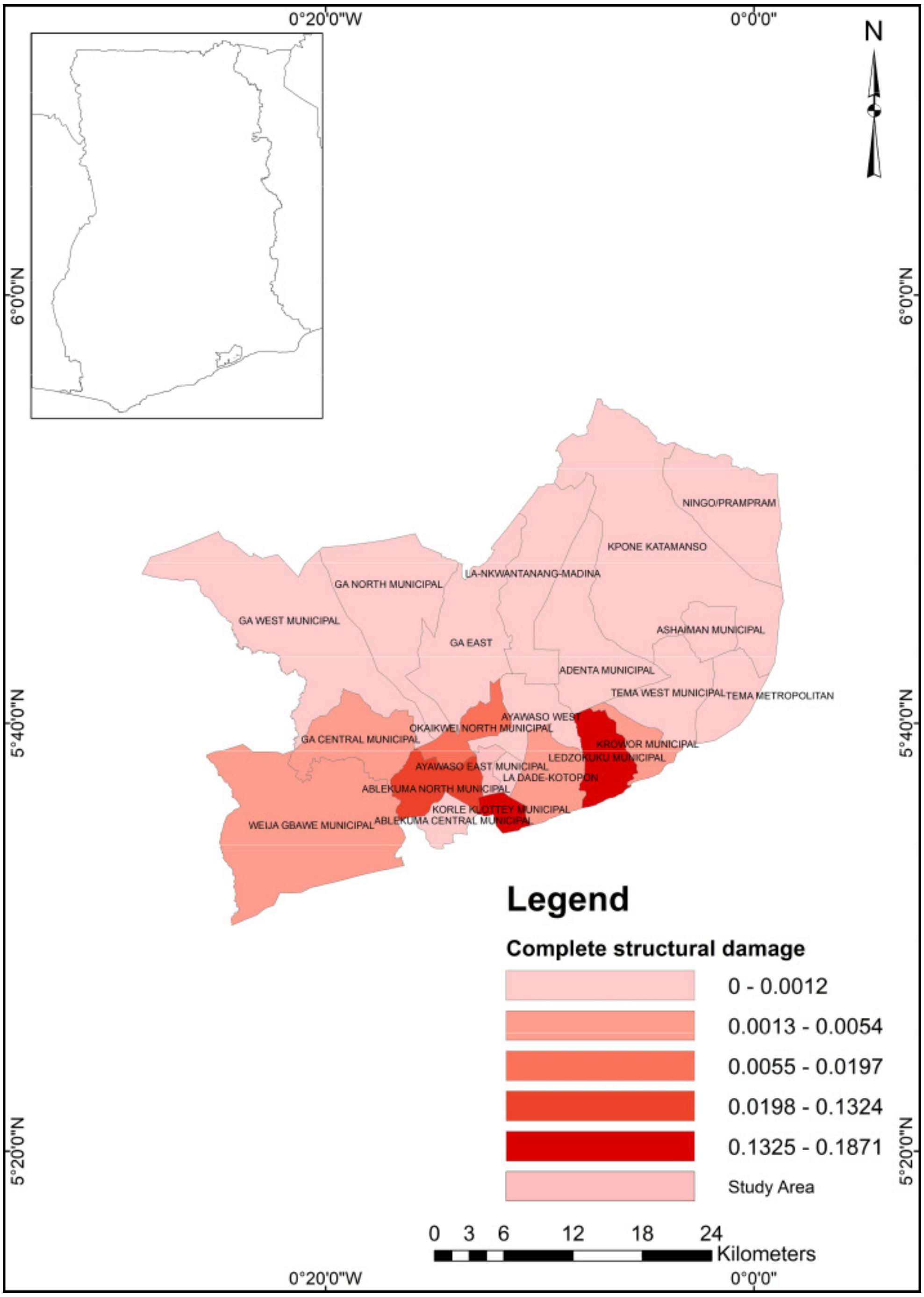

Figure 11. *Complete structural damage distribution in GAMA based on the PE11 GMPE.*

The overall distribution of predicted building damage reveals notable differences between the results obtained using the AB11 and PE11 GMPEs. Across all damage states (Slight, Moderate, Extensive, and Complete), the AB11 model consistently predicts higher levels of damage than the PE11 model, with the greatest concentration of severe damage occurring in coastal municipalities underlain by soft soils. Despite these differences, both GMPEs indicate that the majority of affected residential buildings are expected to experience either slight or moderate damage. This suggests that, although a Mw 6.5 earthquake would affect a large proportion of the residential building stock, the most probable outcome for most buildings would be repairable damage rather than extensive damage or complete collapse.

5. Conclusions

This study assessed the seismic risk of residential buildings in the Greater Accra Metropolitan Area (GAMA), providing important insights into the region's seismic hazard, building vulnerability, and potential earthquake impacts. The results confirm that GAMA's location within an active seismic zone, combined with rapid urbanization and a vulnerable building stock, underscores the need for proactive risk reduction. Scenario-based analyses performed with the OpenQuake Engine produced Peak Ground Acceleration (PGA) values ranging from 0.05 g to 0.40 g, identifying coastal areas underlain by soft Quaternary sediments as particularly susceptible to ground-motion amplification. The resulting damage scenarios highlight coastal communities, western suburbs, and parts of the Ga East Municipality as the areas most exposed to severe earthquake impacts.

The vulnerability assessment revealed substantial structural fragility, particularly among older buildings and non-engineered masonry constructions, which exhibit high probabilities of damage even under moderate levels of ground shaking. A key finding is that the Atkinson and Boore (2006, modified 2011) Ground Motion Prediction Equation (AB11) predicts ground motions that exceed the current Ghana Building Code design acceleration by up to 60% in some high-hazard areas. This suggests that the current design provisions may not provide an adequate level of seismic safety in the most vulnerable parts of GAMA.

These findings demonstrate that seismic risk in GAMA poses a significant threat to human life, infrastructure, and economic activities. Reducing this risk will require an integrated approach combining effective urban planning, strengthened enforcement and periodic revision of building codes, targeted retrofitting of vulnerable structures, enhanced emergency preparedness, and sustained public awareness.

Beyond its technical implications, this study highlights that seismic risk is also an ethical challenge involving the protection of human life, social equity, and responsible governance. The identification of communities disproportionately exposed to seismic hazard underscores the shared responsibility of scientists, engineers, policymakers, and public authorities to translate scientific knowledge into effective risk-reduction measures. From a geoethical perspective, the production of reliable hazard and risk assessments carries a responsibility to ensure that this knowledge informs building regulations, urban planning, emergency preparedness, and public awareness. Integrating scientific evidence into decision-making is essential for reducing vulnerability, strengthening societal resilience, and promoting sustainable and equitable urban development.

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References

Agyei Duodu J., Loh G.K., Hirdes W., Boamah K.O., Baba M., et al., (2009). Geological Map of Ghana 1:1000000. Ghana Geological Survey/Bundesanstalt für Geowissenschaften und Rohstoffe, Accra, Ghana/Hannover, Germany.

Allotey N.K., Arku G., and Amponsah P.E., (2010). Earthquake-disaster preparedness: the case of Accra. International Journal of Disaster Resilience in the Built Environment, 1(2), 140-156. https://doi.org/10.1108/17595901011056613.

Amponsah P., Opoku-Ntim I., and Nortey G., (2020). Seismic risk in Ghana: efforts and challenges. Arabian Journal of Geosciences, 13. https://doi.org/10.1007/s12517-020-05665-4.

Amponsah P.O., Kwayisi D., Awunyo E.K., Sapah M.S., Sakyi P.A., et al., (2023). New evidence for crustal reworking and juvenile arc-magmatism during the Paleoproterozoic Eburnean events in the Suhum Basin, South-east Ghana. Geological Journal, 58(10), 3734-3755. https://doi.org/10.1002/gj.4790.

Anani C.Y., Mahamuda A., Kwayisi D., and Asiedu D.K., (2017). Provenance of sandstones from the Neoproterozoic Bombouka Group of the Volta Bain, northeastern Ghana. Arabian Journal of Geosciences, 10. https://doi.org/10.1007/s12517-017-3243-2.

Atkinson G.M., and Boore D.M., (2011). Modifications to existing ground-motion prediction equations in light of new data. Bulletin of the Seismological Society of America, 101(3), 1121-1135. https://doi.org/10.1785/0120100270.

Azizi A., Yaghoobi M., and Kamel R., (2023). Earthquake risk assessment using OpenQuake and GIS: A case study of Cyprus. https://doi.org/10.21203/rs.3.rs-3140149/v1.

Bendimerad F., (2001). Loss estimation: a powerful tool for risk assessment and mitigation. Soil Dynamics and Earthquake Engineering, 21(5), 467-472. https://doi.org/10.1016/S0267-7261(01)00022-7.

Ghana Statistical Service (2021). Population and Housing Census (2021 PHC), Version 1.0 of the public use dataset (August 2022), provided by the National Data Archive. Retrieved from https://www.statsghana.gov.gh/census-surveys/population-housing-census (accessed 14 July 2026).

Junner N. R. (1941). The Accra earthquake of June 1939. Gold Coast Geological Survey Bulletin 13, 3-41.

Kutu J.M., Anani C.Y., Asiedu D.K., Manu J., Hayford E., et al., (2013). Recent seismicity of southern Ghana and re-interpretation of the 1939 Accra earthquake: implications for recurrence of major earthquake. International Journal of Basic and Applied Sciences, 2(4), 322-331. https://doi.org/10.14419/ijbas.v2i4.1120.

Kwayisi D., Amponsah P.O., Agra N.A., Nunoo S., Thompson J., et al., (2024). Neoproterozoic passive margin formation and evolution during the Rodinia-Gondwana supercontinent cycle at the eastern margin of the West African Craton. Geological Magazine, 161, e14. https://doi.org/10.1017/S001675682400027X.

Kwayisi D., Amponsah P.O., Awunyo E.K., Sapah M.S., Sakyi P.A., et al., (2025). Petrology and geochemistry of the Suhum Basin granitoid complex, Ghana: Implications for the crustal growth during the Rhyacian orogeny of the West African Craton. Journal of African Earth Sciences, 222. https://doi.org/10.1016/j.jafrearsci.2024.105475.

Martins L., and Silva V., (2021). Development of a fragility and vulnerability model for global seismic risk analyses. Bulletin of Earthquake Engineering, 19, 6719-6745. https://doi.org/10.1007/s10518-020-00885-1.

Mulugeta G., Amponsah P.E., Ayonghe S.N., Benouar D., Durrheim R., et al., (2016). Africa Science Plan: Natural and Human-induced Hazards and Disasters. ICSU Regional Office for Africa, ISBN 978-0620745741, https://council.science/wp-content/uploads/2017/05/ICSU-ROA-Science-Plan-Hazards-and-Disasters.pdf (accessed 14 July 2026).

Nortey G., (2021). Site-Specific Soil Classification Of Seismic Site Effects For The Greater Accra Metropolitan Area Of Ghana Using Multichannel Analysis Of Surface Waves. PhD Earth Science Thesis, University of Ghana. Retrieved from https://ugspace.ug.edu.gh/items/a6a52754-cc28-4417-b7c1-611c37e8dbc8 (accessed 14 July 2026).

Pagani M., Silva V., Rao A., Simionato M., and Johnson K., (2024). OpenQuake Engine manual – Release 3.16.7, https://docs.openquake.org/oq-engine/3.16/PDF/OpenQuake%20Manual%203.16.pdf (accessed 14 July 2026).

Paul N., Silva V., and Amo-Oduro D., (2022). Development of a uniform exposure model for the African continent for use in disaster risk assessment. International Journal of Disaster Risk Reduction, 71. https://doi.org/10.1016/j.ijdrr.2022.102823.

Pezeshk S., Zandieh A., and Tavakoli B., (2011). Hybrid Empirical Ground-Motion Prediction Equations for Eastern North America Using NGA models and Updated Seismological Parameters. Bulletin of the Seismological Society of America, 101(4), 1859-1870. https://doi.org/10.1785/0120100144.

Quaah A.O., (1980). Microseismicity, past seismic activity and seismic risk in Southern Ghana. PhD Thesis, University of London.

Rao A., Yepes-Estrada C., Johnson K., Todorović L., Pagani M., et al., (2025). Evolution of the OpenQuake Engine: Enhanced capabilities, collaborative development, and global adoption. Earthquake Spectra, 41(5), 3299-3336. https://doi.org/10.1177/87552930251378157.

Silva V., Crowley H., Pagani M., Monelli D., and Pinho R., (2014). Development of the OpenQuake engine, the Global Earthquake Model's open-source software for seismic risk assessment. Natural Hazards, 72, 1409-1427. https://doi.org/10.1007/s11069-013-0618-x.

Yepes-Estrada C., Calderon A., Costa C., Crowley H., Dabbeek J., et al., (2023). Global building exposure model for earthquake risk assessment. Earthquake Spectra, 39(4) 2212-2235. https://doi.org/10.1177/87552930231194048.

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