

PROBABILISTIC EARTHQUAKE RISK ASSESSMENT FRAMEWORK FOR UGANDA: EVENT-BASED MODELLING APPROACH

Morris Oleng¹, Zuhail Ozdemir² and Kypros Pilakoutas³

¹ Doctoral Researcher, University of Sheffield, UK, MOleng1@sheffield.ac.uk, wotamuko@gmail.com

² Lecturer, University of Sheffield, UK

³ Professor, University of Sheffield, UK

Abstract: Uganda's geology, tectonics and morphology exposes most of its territory to earthquakes of low to moderate intensities. Past earthquakes such as the 1966 Toro, 1994 Kisomoro and 2016 Bukoba events have had detrimental consequences on the socio-economic welfare and resilience of communities across Uganda. Despite earlier efforts in predicting seismic hazard in Uganda, there is no comprehensive study published on earthquake-related risks across the country. Whilst losses during the previous earthquakes were still comparatively low, damage due to future earthquakes are likely to escalate considerably because of the proliferation of a largely substandard building stock coupled with rapid population growth and urbanisation. As a first step towards building an earthquake risk and resilience framework for Uganda, this work employs the probabilistic event-based risk calculator of OpenQuake-engine to holistically assess potential losses resulting from future earthquakes. Using a fault-oriented spatially distributed seismicity approach, a logic tree is implemented to minimise the associated epistemic uncertainties and site conditions are modelled using the shear wave velocity in the upper 30m of soil across Uganda. The building stock is largely inferred and projected from the 2014 national population and housing census and analytical vulnerability curves are selected from the GEM global database. The analysis of earthquake ruptures, hazard maps, loss exceedance curves, mean annual loss maps and aggregated asset loss statistics indicate that western Uganda is prone to the highest risk. These findings will be a huge step towards the urgent need to update the Uganda Seismic Design Code, strategically plan land use patterns, optimise earthquake insurance pricing and improve the National Policy for Disaster Preparedness and Management.

Keywords: Building exposure; Probabilistic seismic hazard analysis; Probabilistic seismic risk assessment; Stochastic event-based modelling; Structural vulnerability; Uganda

1 Introduction

Earthquakes can potentially cause widespread and devastating damage to the built and natural environment, eventually affecting the safety of communities (Baker et al., 2021; Daniell et al., 2011). The socio-economic welfare and resilience of communities, particularly in developing countries like Uganda, can be affected by the catastrophic impacts of earthquakes. Uganda is located between the two seismically active arms of the East African Rift System (EARS), a tectonic environment that exposes most of the country's territory to earthquakes with moment magnitude (M_w) between 5.5 and 7.2. Moreover, many seismic events with $M_w < 5.5$ have been recorded across the country (Midzi et al., 1999; Oleng et al., 2024; Twesigomwe, 1997). Following the major earthquakes across Uganda, many structures have been damaged in addition to the numerous deaths and

injuries ([Balikuddembe and Sinclair, 2018](#); [Maasha, 1975](#); [Midzi and Manzunzu, 2014](#)). For instance western Uganda incurred economic loss worth US\$ 60 million when the 1994 Kisomoro earthquake of surface-wave magnitude (M_s) 6.2 struck Kabarole, Bundibugyo and Kasese districts. Moreover, 8 people were killed and several injuries registered ([Kahuma et al., 2006](#); [NEDC, 1994](#)). More recently, the 2016 Bukoba earthquake of 5.9 M_w generated an estimated economic loss of US\$ 458 million, with 11 deaths and over 440 injuries in Kagera region ([Balikuddembe and Sinclair, 2018](#)).

Earthquake damage to structures, injuries and fatalities in future events are likely to escalate due to the rapidly increasing population growth and urbanisation. Over the past few decades, Uganda's population has grown at an average annual rate of 3% and the current population of the country is estimated at over 44.2 million ([UBoS, 2022](#)). Although majority of earthquake epicentres are largely less populated compared to the rest of the country, the growing economic activity and rapid urbanization are likely to spike the population in these areas thereby posing an increased seismic risk. Furthermore, the largest proportion of Uganda's building stock is substandard and more than half of the stock comprises masonry buildings. Moreover, this construction typology poses a significant risk because it is typically more vulnerable to earthquakes ([Brzev et al., 2013](#); [Silva et al., 2015](#); [Vicente et al., 2011](#)). In this regard, seismic risk in Uganda ought to be comprehensively evaluated in order to develop a reliable national risk mitigation strategy for the country. Such remedies include reinstating and enforcing standards and regulations towards design and construction of earthquake resistant structures, strengthening/retrofitting existing buildings in earthquake prone areas, and adequate planning of emergency response, and transfer of the financial cost of reconstruction and repair through creation of insurance and reinsurance schemes ([Baker et al., 2021](#); [Gkimpraxis et al., 2021](#); [Salgado-Gálvez et al., 2017](#)).

However, many African countries suffer from the substantial lack of data required for a comprehensive seismic risk analysis. Subsequently, global earthquake risk assessment approaches which rely on readily available information can be employed to assess the associated seismic risks. A case in point is the study by [Guettiche et al. \(2017\)](#) which utilised Association Rule Learning Technique ([Riedel et al., 2014](#)) to assess the seismic risk of Constantine region in Algeria. Except for Malawi which has a national exposure model ([Kloukinas et al., 2020](#); [Ngoma et al., 2019](#)), many countries within Sub-Saharan Africa rely on national census data from global databases ([De Bono and Chatenoux, 2015](#); [Gamba et al., 2012](#); [Jaiswal et al., 2010](#); [Jaiswal and Wald, 2008](#)) to perform seismic risk analyses. Inasmuch as the efficacy of seismic management and mitigation strategies is undermined by the absence of a reliable and comprehensive seismic risk framework, this study presents the first probabilistic seismic risk assessment framework for Uganda by combining the existing exposure and earthquake hazard models with the seismic vulnerability of the building inventory.

2 Methodology: Event-based probabilistic seismic risk

In this work, a novel earthquake risk assessment (ERA) framework which employs a stochastic event-based modelling approach in *OpenQuake* engine ([Pagani et al., 2014](#); [Silva et al., 2014](#)) is proposed. Using the event-based calculator for probabilistic seismic hazard analysis (PSHA) over a given investigation time, stochastic event sets (SES) representing the seismicity of the region are generated following the Monte Carlo (MC) procedure. The number of event occurrences is then simulated by sampling the corresponding probability distribution for each rupture created by seismic sources. Whilst taking into account the inter-event variability of ground motion and the intra-event residuals, spatially correlated ground motion realisations are generated for each rupture in the SES. Epistemic uncertainties associated with the seismic source and ground motion prediction equations (GMPEs) are included in the model through a logic tree approach. Using fragility/vulnerability curves of different assets in the exposure, loss ratios are sampled for each ground motion realisation prior to the computation of loss exceedance curves for each asset. The probability of exceedance (POE) of different loss levels over the specified time period is described by loss exceedance curves while loss maps for the region of interest show the loss values that have a given POE over the investigation period.

In addition to the total loss across the portfolio for each earthquake event in the SES summarised in the event loss table, aggregate loss exceedance curves describing the POE of different loss levels for all assets in the portfolio are produced. Although the classical PSHA ([Cornell, 1968](#); [McGuire, 2004](#)) can be employed to compute hazard curves at the sites of interest, this work uses the event-based approach in which probability of losses for a stochastic set of assets is calculated per event. Despite the computational cost and complexity of MC simulations, it is adopted with the view of allowing model flexibility especially when physic-based GMPEs are applied to simulate site response ([Graves et al., 2011](#)). Moreover reliable estimates of the total loss value

at high return periods is determined when the spatial variability with intra-event residuals is considered in MC simulations (Jayaram and Baker, 2009).

3 Probabilistic seismic hazard model

3.1 Catalogue compilation and refinement

To quantify earthquake hazard across Uganda, earthquake catalogues from numerous sources (e.g., Albini *et al.*, 2013; Ambraseys and Adams, 1991; DGSM, 2022; Di Giacomo *et al.*, 2018; ISC, 2022; Maasha, 1975; Storchak *et al.*, 2013; Storchak *et al.*, 2015 and USGS, 2022) are compiled, merged and refined using the GEM catalogue toolkit (Weatherill, 2014). Starting from the 20th century, the earthquake catalogue comprises 744 major events that occurred within the region (Fig. 1a). As a conservative approach to estimating seismicity parameters, non-Poissonian events are removed using the modified Knopoff (2000) declustering space and time windows (Aldama Bustos, 2009). Subsequently, the ZMAP (2022) algorithm of Wiemer (2001) is executed to statistically assess completeness thresholds using *b-value* stability (Cao and Gao, 2002) approach and maximum curvature method (Wiemer and Wyss, 2000). As shown in Fig. 1b, catalogue completeness thresholds are in good agreement with the fact that the completeness periods for larger magnitude events start from earlier time periods whilst smaller magnitude events are complete for recent dates (Oleng *et al.*, 2024).

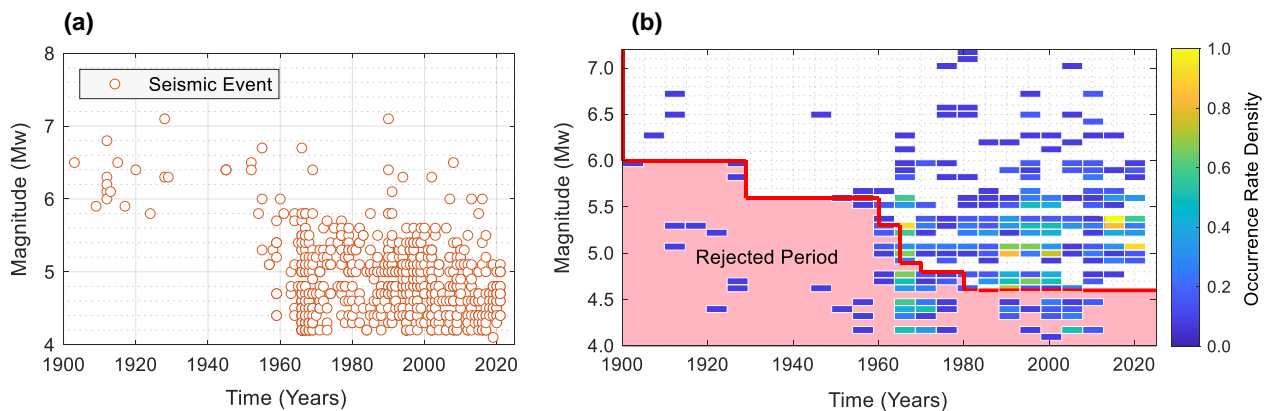


Figure 1. (a) Distribution of seismicity over time for the events in the homogenised, non-declustered earthquake catalogue for Uganda; and (b) Magnitude-time-density plot of the Uganda earthquake catalogue, with normalised rates computed for a 0.1 magnitude bin and a fixed time window of 5 years.

3.2 Seismic source characterisation

Delineation of source zones is based on a fault-oriented spatially distributed seismicity strategy which involves dividing the region on the basis of its geology (Baker *et al.*, 1972; Schlüter, 2008; Westerhof *et al.*, 2014) and tectonic domains (Chorowicz, 2005; Macgregor, 2015; Yang and Chen, 2010), defining source geometries and typologies, and assigning seismicity parameters to each seismic source (Vilanova *et al.*, 2014). The zonation adopted in this work constitutes 13 area source zones (ASZs) from which ASZs of similar geological and tectonic settings are categorised into four gross sources as shown in Fig. 2. Calibrated seismicity parameters (*a*- and *b*-values shown in Fig. 2) and their associated standard deviations are defined using the Weichert (1980) maximum likelihood method. Due to lack of source-scaling relationships for Uganda (Oleng *et al.*, 2024), realistic maximum magnitude values are arbitrarily estimated by adding a conservative increment of 0.5 magnitude units to the maximum observed magnitude for each ASZ as shown in Fig. 2.

3.3 Selection of ground motion prediction equations

In PSHA, suitable GMPEs are required to predict the distribution of site response arising from possible ruptures. Unfortunately, there is a substantial lack of GMPEs developed based on strong ground motion records for Uganda (Bwambale *et al.*, 2015; Oleng *et al.*, 2024; Poggi *et al.*, 2017). In this study, suitable GMPEs for each tectonic regime are selected using the functionalities of GEM Ground Motion Toolkit (Weatherill *et al.*, 2014). While the GMPEs of Akkar *et al.* (2014) and Chiou and Youngs (2014) are used to model ground motion in active shallow crust (ASC) regimes, the response of stable continental crustal (SCC) formations is predicted using GMPEs of Atkinson and Boore (2006) and Pezeshk *et al.* (2011). A logic tree is implemented to minimise epistemic uncertainties associated with the model.

3.4 Site conditions

Many modern seismic design codes (e.g., BSSC, 2004 and CEN, 2004) characterise local site conditions using the average velocity of seismic shear waves in the upper 30 m layer of soil ($V_{s,30}$) value (Silva et al., 2015). Moreover, several fundamental GMPEs summarised by Douglas (2021) are calibrated against $V_{s,30}$ values of the corresponding seismic station (Bommer, 2022). In this work, site conditions are first modelled using the $V_{s,30}$ reference values for Uganda obtained from USGS database of Allen and Wald (2007). For each location where seismic hazard and risk is computed, the appropriate or nearest $V_{s,30}$ value is defined within the GMPE used. In addition to site-specific hazard outputs, more representative earthquake hazard estimates are derived for free rock conditions (with a fixed $V_{s,30} = 760$ m/s) assumed for each site of the investigation grid.

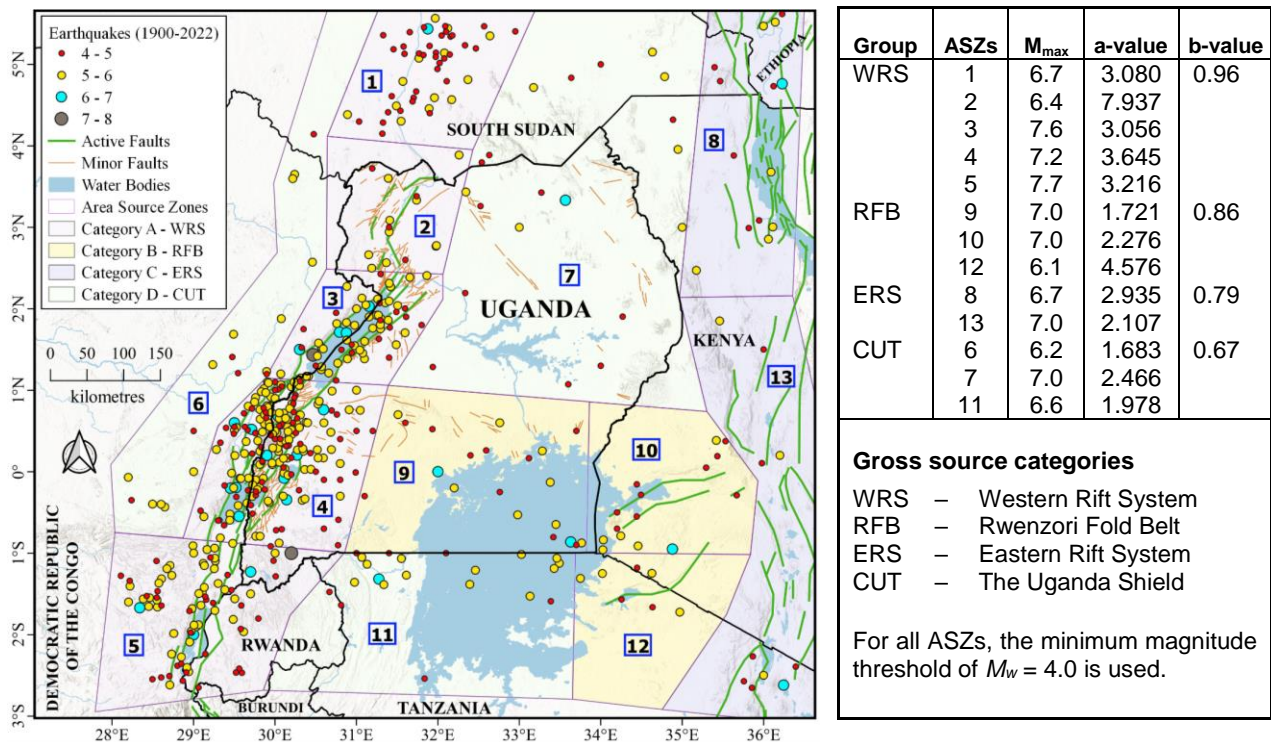


Figure 2. Earthquake epicentres of major events which occurred within and around Uganda, active fault system, area source zonation model and calibrated seismicity parameters used in MC-based PSHA for Uganda

4 Exposure model

4.1 Uganda building stock

For each exposed asset in the portfolio, the degree of damage caused by an earthquake is a major parameter controlling seismic risk in the region of interest (Bommer, 2022). In this work, information regarding Uganda’s building stock is obtained from the uniform exposure model for the African continent (Paul et al., 2022). The data herein is largely inferred and projected from the national population census (UBoS, 2016) from which buildings located in each region have been classified according to residential, commercial and industrial occupancy categories as shown in Table 1.

Despite the rising number and fast growing population of Uganda’s building stock, this study uses the data for a baseline year of 2024. Out of the total buildings estimated, approximately 27.8, 26.1, 20.6 and 25.5% are located in the central, eastern, northern and western parts of the country respectively. However, it’s worth noting that Uganda’s residential buildings constitute over 97% of the country’s building stock, with only about 3% falling into the commercial and industrial building occupancy categories. Furthermore, residential buildings mostly comprise reinforced concrete, unreinforced masonry, confined masonry, wooden/timber, wooden wattle and daub, vegetative exterior walls, and metals except structural steel. The attributes (encoded in condensed strings) adopted in this work utilise building typology nomenclature defined in the GEM building taxonomy (Brzev et al., 2013; Silva et al., 2018). For instance, a coded taxonomy CR/LFINF+CDM/H:2 represents a moderately ductile (DCM) two storey (H:2) reinforced concrete (RC) moment frame structure with infilled unreinforced masonry (LFINF) as the lateral load resisting system.

Table 1. Distribution of the estimated building stock across the four regions of Uganda.

Building category	Number of buildings ('000) located in each region				Total ('000)
	Central	Eastern	Northern	Western	
Residential	2,675	2,514	1,982	2,450	9,621
Commercial	55	52	41	50	198
Industrial	24	22	18	22	86
Total ('000)	2,754	2,588	2,041	2,522	9,905

4.2 Estimated economic value of buildings

This study adopts total replacement costs of Uganda's building stock estimated in the uniform exposure model for the African continent. The estimates were based on national statistical building cost datasets and a review of independent international cost books (Paul et al., 2022; Yepes-Estrada et al., 2023). Then, unit costs are normalized for the baseline year of 2024 and all currency values converted to US\$. For each asset, the total replacement cost is taken as the monetary value of constructing a building of similar characteristics based on the associated current costs. A summary of the total replacement cost for each settlement type is presented in Fig. 3. Across the country, RC and confined masonry buildings are predominantly situated in urban centres and the two typologies are the most expensive, with over US\$ 400 per square metre. The cost per square metre of unreinforced masonry, which constitutes the majority Uganda's housing stock, ranges US\$ 240-275 in both rural and urban areas. The costs of other building typologies in urban and rural settlements are fairly uniform across the country. Overall, the exposure model estimates approximately 9.62 million residential buildings valued at over US\$ 171.45 billion. In addition, the building stock includes more than 198000 commercial and 85000 industrial facilities valued in excess of US\$ 11.9 billion and US\$ 6.6 billion, respectively. As per Uganda's nominal gross domestic product (GDP), estimated at US\$ 40.53 billion in June 2022 (UBoS, 2022), the three occupancy classes amounts to approximately 4.7 times the national GDP.

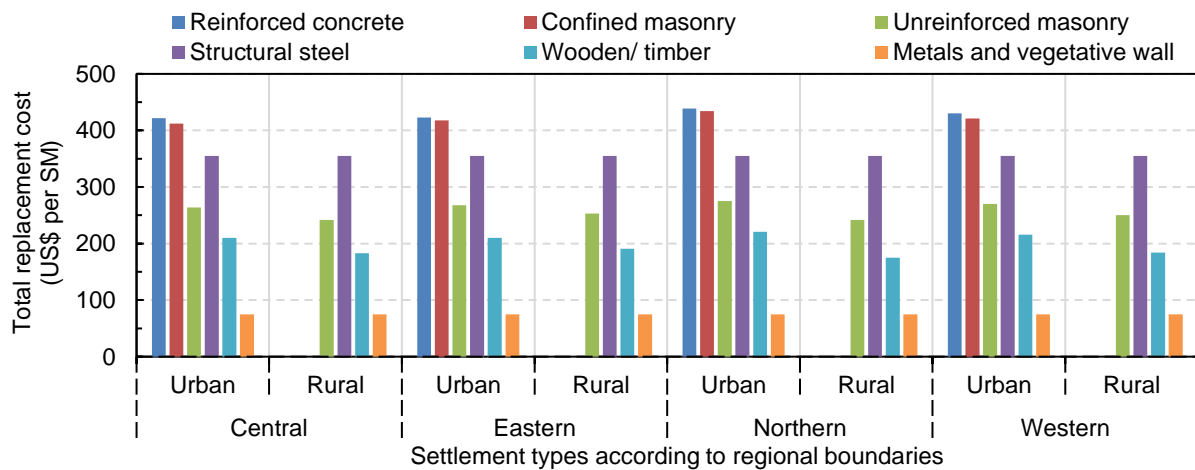


Figure 3. Average total replacement cost per unit area in urban and rural settlements for different structural types located in each of the four regions of Uganda.

5 Vulnerability model

Fragility curves which are benchmarked against post-earthquake damage data and specifically developed for the region of interest should be considered for a reliable and more accurate assessment of seismic risk (Sianko et al., 2023; Villar-Vega and Silva, 2017). Unfortunately, the substantial lack of fragility models developed with a holistic consideration of the building stock in many Sub-Saharan African countries is still a challenge. However, there are a few fragility/vulnerability curves explicitly developed for particular African countries e.g., Ghana (Adom-Asamoah, 2012) and Malawi (Giordano et al., 2021). More recently, analytical fragility curves shown in Fig. 4a-b for informal and code-conforming unreinforced fired brick masonry buildings constituting the Malawian housing stock have been proposed (Giordano et al., 2023). Although the building stock could be similar across the majority of Sub-Saharan African countries, post-earthquake damage on various building typologies may vary extensively. Therefore, employing specific fragility curves for a particular region can give an ameliorate estimate.

Unfortunately, distinct fragility curves for Uganda are non-existent in published literature. In such cases, analytical vulnerability functions derived for equivalent single degree of freedom (SDOF) models of several building typologies in various tectonic regimes using non-linear time history analyses (D'ayala *et al.*, 2014; Martins and Silva, 2021; Rao *et al.*, 2020) can be used. Hence, this study utilises globally calibrated curves found in the fragility/vulnerability database of GEM Foundation (Martins and Silva, 2018; Martins and Silva, 2021) in which the uncertainty in loss ratio defined by the set of vulnerability curves is modelled with either lognormal or beta distribution.

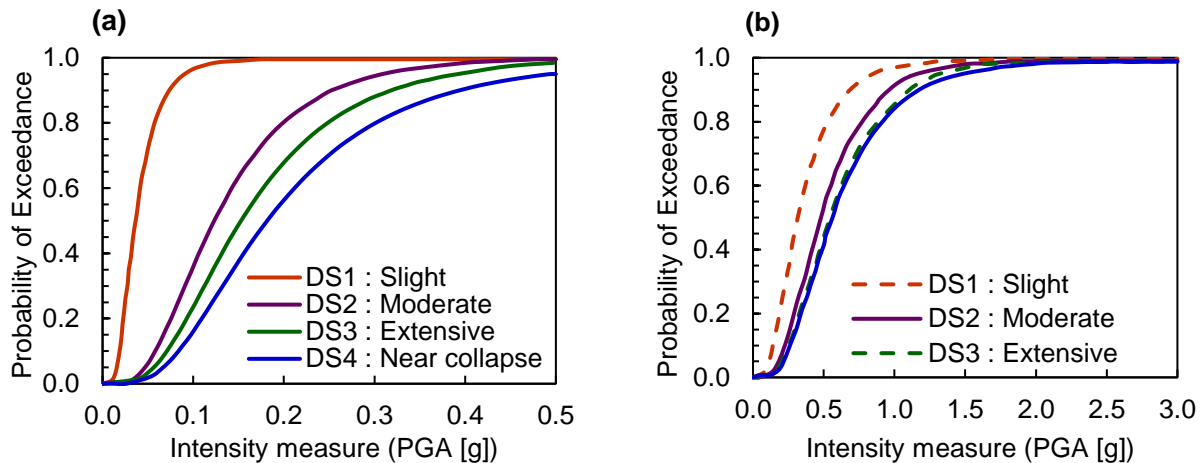


Figure 4. Fragility curves proposed by Giordano *et al.* (2023), derived for unreinforced fired brick masonry buildings in Malawi: (a) Non-code-conforming or informal, and (b) Code-conforming buildings.

6 Results and discussion

6.1 Seismic hazard

6.1.1 Earthquake ruptures generated for tectonic sub-regions

In this work, 100 terminal branches are sampled from the overall logic tree (shown in (Fig. 5a) and 100 stochastic event sets are simulated for each logic tree path; giving a total of 10000 stochastic events which are simulated and their corresponding rupture geometries (as shown in Fig. 5b) generated by sampling ground motion intensity values using GMPEs assigned for each tectonic sub-region. As expected, the largest earthquake ruptures strike along the two geo-tectonic and seismically active branches of the EARS. Whereas the Precambrian basement of Uganda is largely stable and inactive, a number of earthquake ruptures have been recorded along the Rwenzori fold belt; especially around the Lake Victoria basin, Utimbere, Nyanza and Speke rifts at the Uganda-Kenya-Tanzania border.

6.1.2 Earthquake hazard maps

With consideration for 5% damped response spectral acceleration (RSA) investigated over 50 years, the site-specific and bedrock mean earthquake hazard map of Uganda estimating 10 % POE, corresponding to a 475-year return period, are shown in Fig. 6a-b. However, the evaluation of seismic risks associated with earthquake hazard was investigated on an annual basis. The calculations are performed with ± 3 conservative truncation level applied to ground motion distribution. As indicated in previous studies (Bwambale *et al.*, 2015; Cheriberi and Yee, 2022; Poggi *et al.*, 2017; Twesigomwe, 1997), the findings in this study further confirm that the country is prone to seismic hazard of varying degrees. For instance considering bedrock conditions, areas around Arua, Kampala, Lira, Soroti and Mbale cities can expect PGA values raising to 0.1g over a 475-year return period. Higher PGA values ranging between 0.1 and 0.2g are predicted across Hoima, Masaka and Mbarara for the same return period. Although the hazard model in this work predicts Soroti to be least prone to seismic hazard, the largest PGA across Uganda (between 0.22 and 0.27g) is observed within the Rwenzori and Kigezi regions. For instance considering a 10% annual exceedance rate in 50 years, the site-dependent hazard model shown in Fig. 6a predicts a maximum PGA of 0.34g in Fort Portal city. On the other hand, the same city can expect maximum PGA values raising to 0.255g on Type A (rock) ground as indicated in Fig. 6b (Oleng *et al.*, 2024). The earthquake hazard model presented in this work can be used as a starting point for the update and continuous improvement of a more robust seismic design code for Uganda.

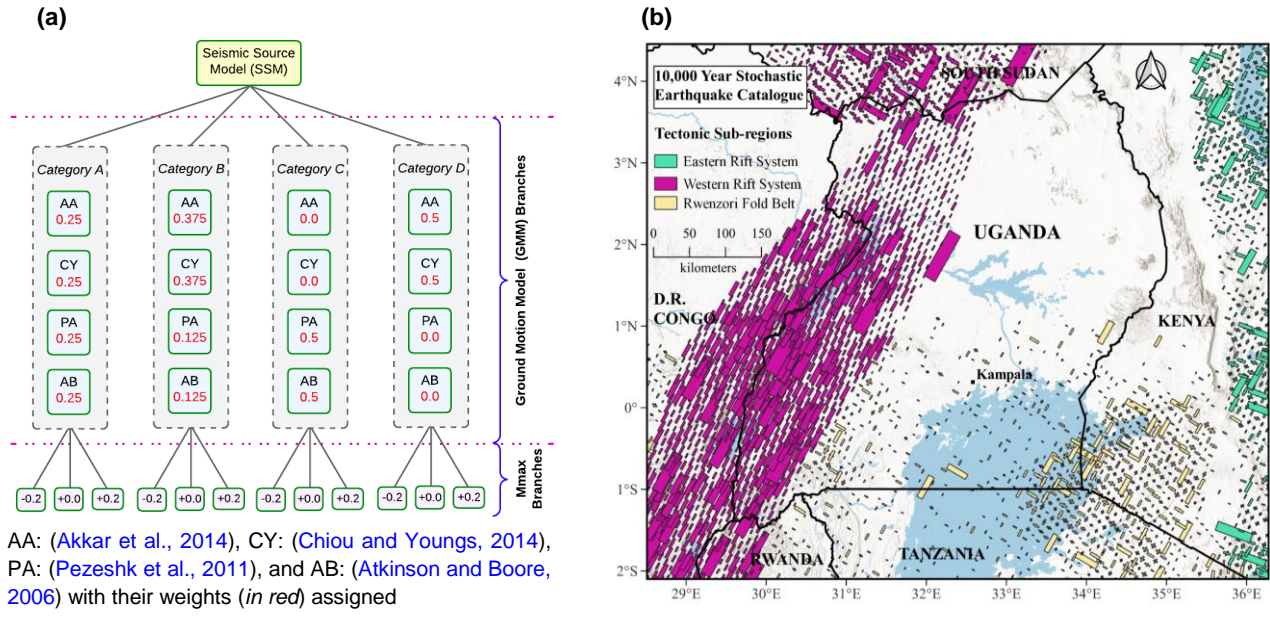


Figure 5. (a) Schematic diagram showing the logic tree implemented in the stochastic event-based PSHA for Uganda, and (b) Rupture geometries illustrated for a 10,000-year subset of the stochastic earthquake catalogue, displaying only seismic events of magnitude $M_w \geq 4.0$.

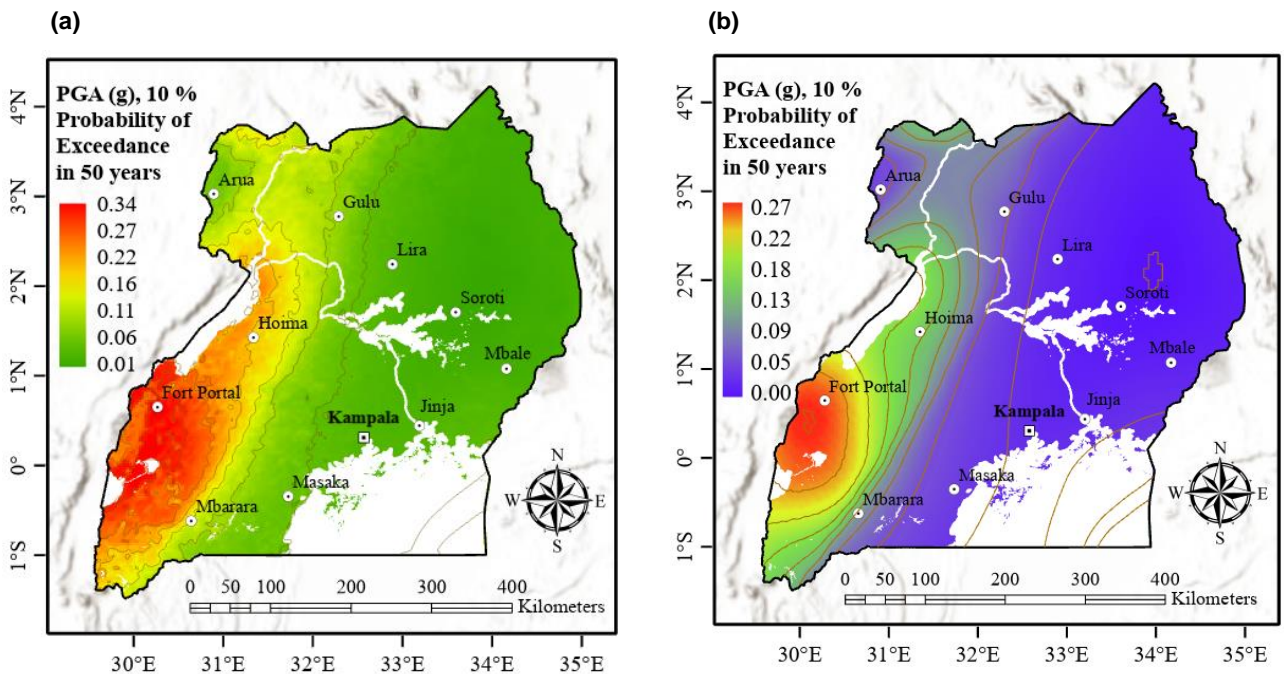


Figure 6. Earthquake hazard maps of Uganda investigated in terms of PGA (g) and computed for a 475-year return period (10 % POE in 50 years) considering: (a) site-specific conditions with 0.05 g contour interval, and (b) bedrock conditions with 0.03 g contour interval (Oleung et al., 2024).

6.2 Earthquake risk

6.2.1 Loss exceedance curve

For a set of loss values, loss exceedance curves can be used to describe exceedance probabilities within a given investigation time. Alongside the Uganda's nominal GDP estimate of US\$ 40.53 billion (UBoS, 2022) which is used to display loss values relative to the national GDP on the secondary vertical axis, mean and quantile loss exceedance curves estimating economic losses are presented in Fig. 7. The seismic risk model predicts mean economic losses for 10, 50 and 100-year return periods to be in excess of US\$ 147.78 million (0.36% GDP), US\$ 1.12 billion (2.72% GDP) and US\$ 2.04 billion (4.94% GDP) respectively.

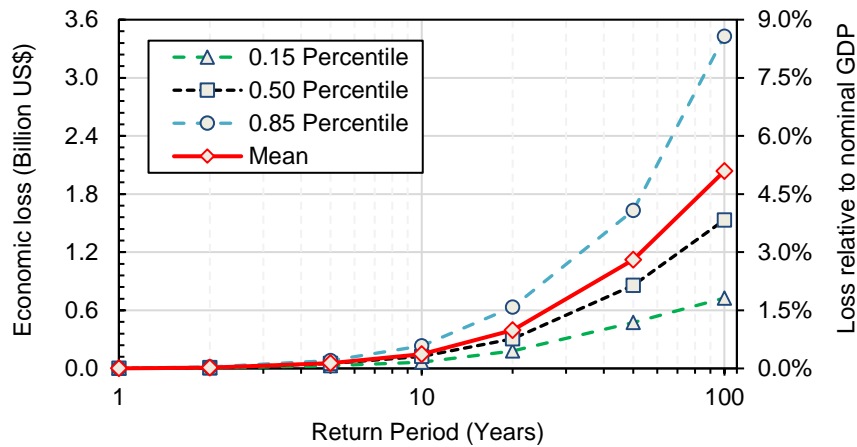


Figure 7. Mean and quantile economic loss exceedance curves showing the losses relative to nominal GDP.

6.2.2 Mean annual loss maps

The economic loss map of Uganda showing mean annual loss values aggregated at municipality/county and sub-county levels is presented in Fig. 8a-b. The estimated economic loss is largely concentrated in western Uganda (Kigezi, Rwenzori and Albertine regions), where for instance a maximum average annual loss worth US\$ 12.7 million can be incurred at a given county or municipality. In terms of the average annual population affected by earthquakes, the districts (Kasese, Mbarara, Hoima, Ntoroko, Kabarole, Mbarara, and Bundibugyo) located near the western arm of the EARS have the largest contribution to seismic risk across Uganda.

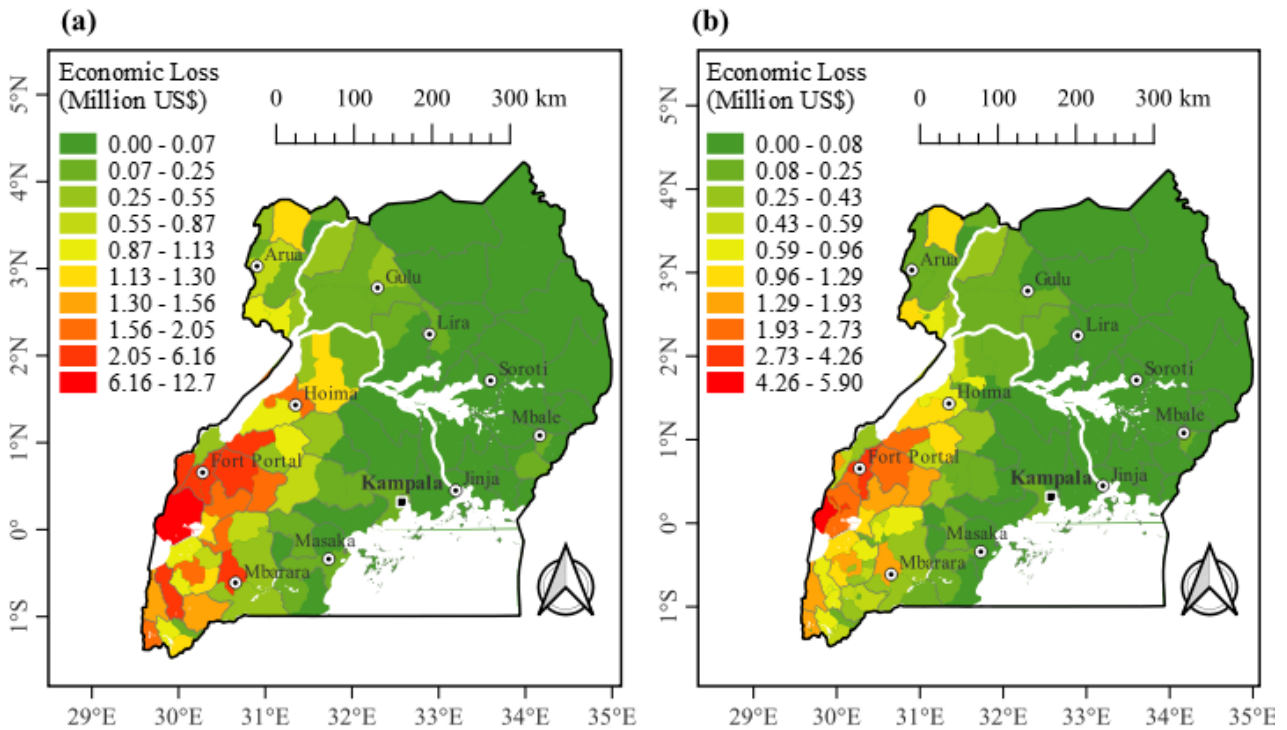


Figure 8. Economic loss maps of Uganda indicating the average annual loss values aggregated for major administrative units: (a) municipality/county (district boundary), and (b) sub-county level

On the other hand, the capital city (Kampala) and its surrounding environs (especially Wakiso district) can expect average annual losses in excess of US\$ 1 million. Although Kampala is situated in an area of low-moderate seismicity, the associated relatively high absolute damage costs can be attributed to the concentration of exposed assets (Mujugumbya et al., 2006). Despite low seismic hazard across the rest of Uganda, substantial economic losses are still expected owing to the presence of many substandard buildings located in soft soils, notwithstanding the already high rate of urbanisation and population growth in the region. By and

large, the earthquake risk model for Uganda presented in this work estimates an overall mean annual economic loss of about US\$ 74.722 million across the whole country. This value is fairly realistic compared with economic losses indicated in previous damage reports (Balikuddembe and Sinclair, 2018; Kahuma *et al.*, 2006; USGS, 2016). For instance economic losses worth US\$ 60 million were incurred when the 1994 Kisoro earthquake struck Kabarole, Bundibugyo and Kasese districts (NEDC, 1994).

In addition, the distribution of average annual human losses (fatalities) due to ground shaking is computed for night time occupancy in all residential buildings comprising Uganda's building stock is computed and aggregated at municipality/county and sub-county levels as respectively shown in Fig. 9a-b. Within a county/municipality, up to 11.4 deaths could be incurred on average per year in western Uganda. The mean annual death toll across the whole country is estimated to increase to a maximum value of 71.3 persons.

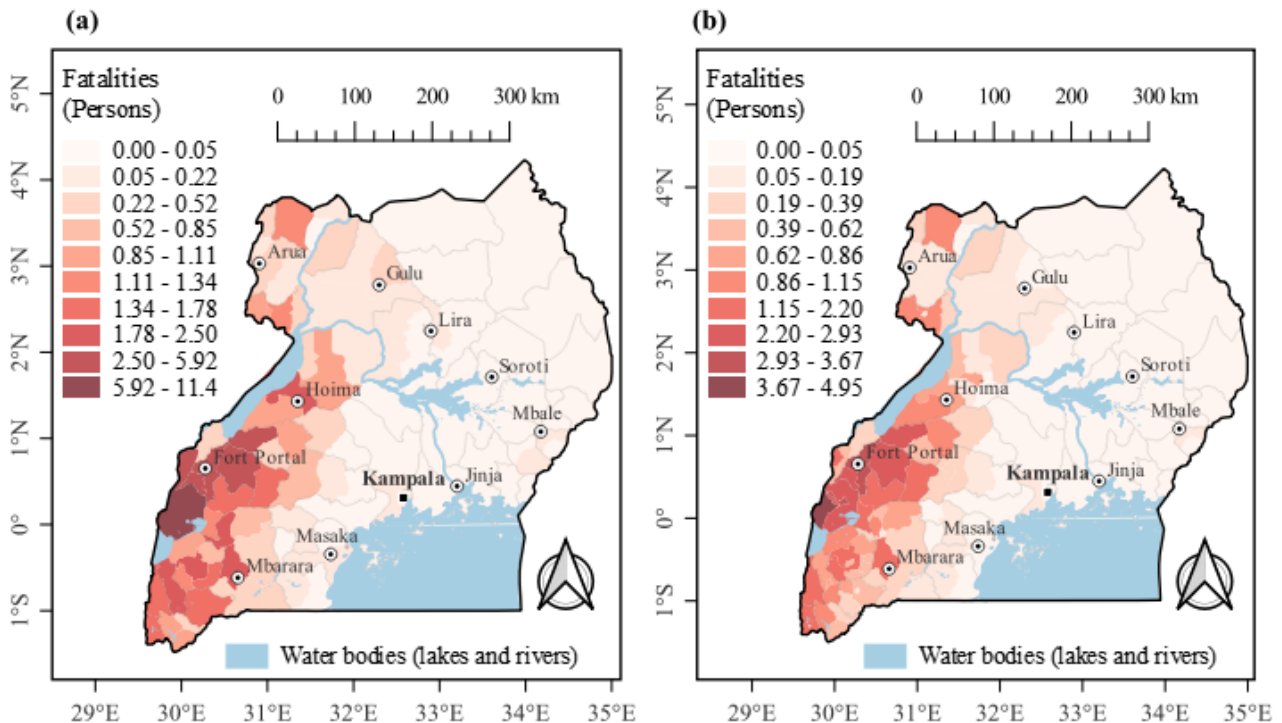
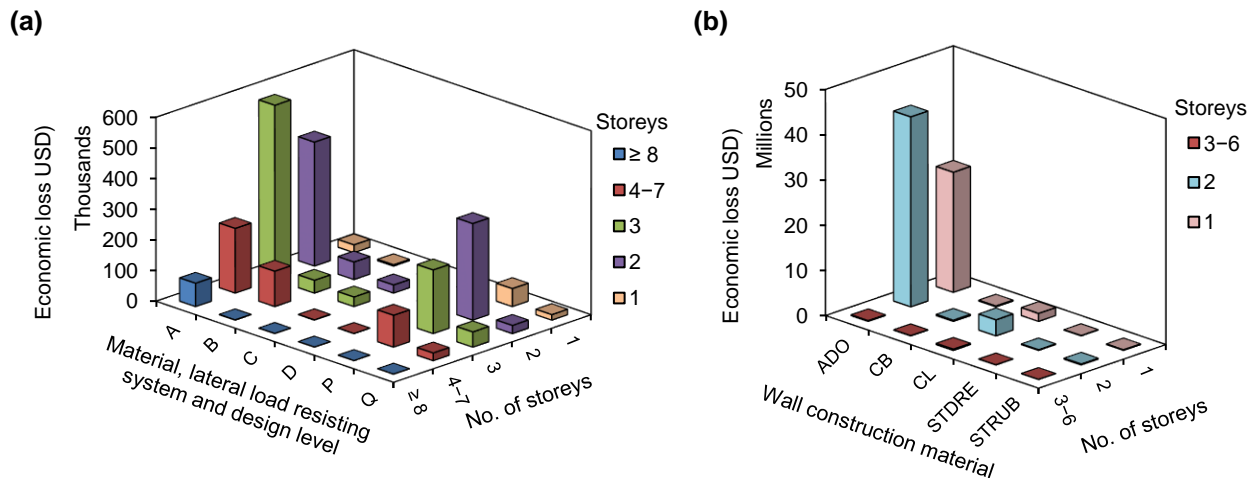


Figure 9. Loss maps of Uganda showing the mean annual fatalities for night-time occupancy in residential buildings, aggregated according to: (a) municipality/county boundaries, (b) sub-county level,

6.2.3 Aggregated asset loss statistics

Mean annual economic losses per building taxonomy are aggregated in order to understand the contribution of each building type to the overall economic loss incurred based on Uganda's exposure model as shown in Fig. 10a-b. As depicted in Fig. 10a, low ductility reinforced concrete buildings which rely on infilled walls for resisting lateral loads can suffer mean annual economic losses in excess of US\$ 400000, US\$ 560000, and US\$ 200000 for 2, 3, and 4-7 storeys respectively. On the other hand, economic losses of over US\$ 315000 and US\$ 200000 are calculated for two and three storeyed confined masonry buildings respectively. In addition, Fig. 10b correspondingly indicates higher mean annual economic losses in excess of US\$ 260000 and US\$ 420000 for single and double storeyed masonry buildings comprising adobe block walls. The other building typologies present reduced losses, possibly due to their lower likelihood of damage due to ground shaking. In addition, reduced losses for these building typologies can be attributed to the fact that they represent only a small fraction of Uganda's building stock. It is worth noting that the results presented herein only account for the direct losses due to structural damage. Future studies will consider determining the associated eventual indirect losses due to business interruption and/or losses resulting from damage in the non-structural components and contents of Uganda's building stock.



Legend: (A) and (B) denote reinforced concrete with infill unreinforced masonry wall for resisting lateral loads in low and medium ductility buildings respectively; (C) and (D) denote reinforced concrete buildings with shear wall lateral load resisting systems of low and medium ductility classes respectively; (P) and (Q) denote confined masonry with shear wall lateral load resisting systems of low and medium ductility classes respectively. (ADO) Adobe blocks, (CB) Concrete blocks, (CL) Fired clay bricks, (STDRE) Dressed stone masonry, (STRUB) Rubble or semi-dressed stone masonry

Figure 10. Average annual economic loss values for the whole of Uganda considering: (a) reinforced concrete and confined masonry depicted according to lateral load resisting system, level of ductility and number of storeys; and (b) non-ductile unreinforced masonry categorised according to wall construction material and number of storeys.

7 Conclusions

Seismic risks in Uganda are fast increasing due to the rapidly rising population, urbanisation, and vulnerable building stock caused by a lack of building control and out-of-date seismic design guidelines. As a precursor towards building an earthquake risk and resilience framework for Uganda, this work employs the probabilistic event-based risk calculator of OpenQuake-engine to holistically assess potential losses resulting from future earthquakes. To perform a PSHA for Uganda, data on seismicity, seismo-tectonics and geology of the country is collected in addition to earthquake catalogues starting from the twentieth century. Despite the non-existence of GMPEs specifically developed based on actual strong ground motion data for Uganda, a logic-tree approach is implemented to predict ground motion response using four selected GMPEs developed for regions of similar geology and seismo-tectonics. In addition to the site-dependent hazard map produced, an additional bedrock hazard map is derived by assuming free rock conditions with a fixed 30-metre average shear-wave velocity reference of 760 m/s assigned to each site of the investigation mesh. Herein, data regarding Uganda's building stock is taken from the uniform exposure model for the African continent; from which total replacement costs are estimated from national statistical building cost datasets and a review of independent international cost books. This study utilises globally calibrated curves found in the fragility/vulnerability database of global earthquake model. Site-specific and bedrock earthquake hazard maps investigated in terms of PGA (g) and computed for a 475-year return period are produced and results indicate that western Uganda can reach a reference PGA of 0.27 g on rock ground. For a set of loss values, mean and quantile loss exceedance curves describing the average annual losses in terms of total loss for all assets in the grid-based exposure model are derived. By and large, the earthquake risk model presented in this work estimates an overall average annual economic loss of about US\$ 74.522 million and average annual fatalities totalling to 71.3 persons likely to be incurred across Uganda. The findings of this work will be a big step towards the urgent need to update the Uganda Seismic Design Code, strategically plan land use patterns, optimise earthquake insurance pricing and improve the National Policy for Disaster Preparedness and Management. The ERA framework presented in this work aims at providing practitioners, policymakers, insurance companies and government stakeholders with practical seismic risk appraisal techniques; subsequently leading to sustainable growth and development owing to reduced earthquake-related losses in the country.

Statements and Declarations

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Author Contributions

All authors contributed to the study conception and design. Data collection was performed by MO. The development of codes and analyses were done by MO. Outputs were checked by Dr ZO and Professor KP. MO wrote the first draft of the paper, and Dr ZO and Professor KP commented on previous versions. All authors read and approved the final manuscript.

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