METEOR Definition of taxonomy for multi-peril vulnerability

Report Number: M5.1/P

25 October 2018

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UK SPACE AGENCY

Document Verification

Project	METEOR: Modelling Exposure Through Earth Observation Routines
Report Title	METEOR: Definition of taxonomy for multi-peril vulnerability
Related Milestone	M5.1
Reference as	V. Silva, T. Tatar, P. Henshaw (2018) METEOR: Definition of taxonomy for multi-peril vulnerability. Report 5.1/P
Release Type	Public / ~~Confidential~~ / ~~Confidential with Embargo Period~~

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Approved by: UKSA IPP Project Officer		
Name:	Signature:	Date:

Date	Version	Alterations	Editor

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Acronyms

BGS	- The British Geological Survey
CGI	- Corrugated Galvanized Iron
DfiD	- Department for International Development
DMD	- Disaster Management Department
DRM	- Disaster Risk Management
DRR	- Disaster Risk Reduction
EDP	- Engineering Demand Parameter
GEM	- The Global Earthquake Model
GLOF	- Glacial Lake Outburst Flood
HOT	- The Humanitarian OpenStreetMap Team
IDF	- Insurance Development Forum
IM	- Intensity Measure
IPP	- International Partnership Programme
KPI	- Key Performance Indicator
LDC	- Least Developed Country
M&E	- Monitoring and Evaluation
M&E	- Monitoring & Evaluation
METEOR	- Modelling Exposure Through Earth Observation Routines
MOVER	- Multi-Hazard Open Vulnerability Platform for Evaluating Risk
MRT	- Mandatory Rules of Thumb
NBC	- Nepal National Building Code
NGO	- Non-Governmental Organisation
NSET	- National Society for Earthquake Technology
ODA	- Official Development Aid
OPM	- Oxford Policy Management Limited
PGA	- Peak Ground Acceleration
QA	- Quality Assurance
SDGs	- United Nations Sustainable Development Goals
UKSA	- United Kingdom Space Agency

UNICEF	-	United Nations Children's Emergency Fund
UNISDR	-	United Nations Office for Disaster Risk Reduction
URM	-	Unreinforced masonry

1. METEOR Project

Project Title	Modelling Exposure Through Earth Observation Routines (METEOR): EO-based Exposure, Nepal and Tanzania
Starting Date	08/02/2018
Duration	36 months
Partners	UK Partners: The British Geological Survey (BGS) (Lead), Oxford Policy Management Limited (OPM), SSBN Limited International Partners: The Disaster Management Department, Office of the Prime Minister – Tanzania, The Global Earthquake Model (GEM) Foundation, The Humanitarian OpenStreetMap Team (HOT), ImageCat, National Society for Earthquake Technology (NSET) – Nepal
Target Countries	Nepal and Tanzania for “level 2” results and all 47 Least Developed ODA countries for “level 1” data
IPP Project	IPPC2_07_BGS_METEOR

At present, there is a poor understanding of population exposure in some ODA countries, which causes major challenges when making Disaster Risk Management decisions. METEOR (Modelling Exposure Through Earth Observation Routines) takes a step-change in the application of Earth Observation exposure data by developing and delivering more accurate levels of population exposure to natural hazards. Providing new consistent data to governments, town planners and insurance providers will promote welfare and economic development in these countries and better enable them to respond to the hazards when they do occur.

METEOR is funded through the second iterations of the UK Space Agency’s International Partnership Programme, which uses space expertise to deliver innovative solutions to real world problems across the globe. The funding helps to build sustainable development while building effective partnerships that can lead to growth opportunities for British companies.

2. Introduction

Every year catastrophic events such as floods, cyclones and earthquakes cause hundreds of fatalities and billions in economic losses. Such disasters require an immediate assessment of the impact in the affected region to deploy rescue teams, a short-term loss and damage evaluation to initiate public or private financial support, and a long-term monitoring of the region to support the recovery process. However, such activities require the availability of detailed, up-to-date and reliable hazard, exposure and vulnerability datasets. The latter component assumes special importance in the process of reducing disaster risk, as a reduction in disaster vulnerability can cause a direct minimization of the potential for economic and human losses.

This component of the METEOR project aims at establishing a uniform system to define the required elements to characterize the vulnerability of the exposed elements to natural hazards. These elements include fragility curves, vulnerability functions and damage-to-loss to models. We leverage on the outcomes of past initiatives regarding the classification of vulnerability models, in particular the OpenQuake platform (vulnerability module) and the MOVER project led by the University College of London (developed within the scope of the Global Facility for Disaster Reduction and Recovery Challenge Fund 2). This approach aims at ensuring that the outcomes of METEOR will be compatible with on-going and well-established initiatives, thus increasing the likelihood that the outcomes will be usable and used.

The definition of the vulnerability taxonomy was performed considering the application to two example countries: Nepal and Tanzania. Therefore, we performed a review of past disasters in the country, available hazard and vulnerability datasets, and existing types of construction. This initial assessment provided critical information regarding the most common intensity measures used to define the demand from earthquakes, floods, landslides or floods, or the main structural attributes that have to be featured by the vulnerability models. Finally, since the vulnerability taxonomy establishes the link between the hazard and exposure datasets, we also liaised with the other partners from METEOR to ensure that all of the components and interoperable and compatible.

This report is organized in three main chapters: description of existing datasets for 1) Nepal and 2) Tanzania, and 3) definition of the vulnerability taxonomy. An example of an existing fragility functions applicable to Tanzania is also presented, as well as the interface of a platform that can be used to display these functions.

3. Natural hazards and built environment in Nepal

Nepal is a country in South Asia, largely located in Himalaya Mountains and bordered by India and Tibet (China). Almost one third of the Himalayan range which is around 2400 km long lies throughout the country. Hence, the environment eventuates very diverse because of its steep topography.

The total population of the country was around 28 million in 2016 with 1.1% annual growth rate. (World Bank). The urban population is 19% of the country. The Kathmandu city is the most compactly populated area with the population density of more than 29,000 people per km^2 while the national average population density is 197 people per km^2. Nepal stays between latitudes 26° and 31°N, and longitudes 80° and 89°E.

The country can be topographically separated by five main regions, they are roughly parallel to each other: (i) High Himalayas/Tethyan which ranges from 4000 m to above 8000 m and embraces the highest peak and deepest gorge in the world, (ii) High Mountains which varies from 2200 m to 4000 m elevations and consists of phyllite, schist and quartzite. The soil is generally sallow and resistant to weathering, (iii) the elevations in Middle Mountains (Mahabharat ranges) differ from 1500 m to 2700 m and contains many rivers, (iv) Siwalik (Churia Hills) ranges from 700 m to 1500 m and (v) Terai which is very fertile and around 50% of the population lives in the region. The average elevation is below 750 m and consists of alluvial plains and extensive alluvial fans (Lizundia, et al., 2016).

3.1. Natural Disasters in Nepal

Nepal faces several natural hazards every year including earthquakes, landslides, floods, wildfires, and storms. Table 1 displays the reported average annual loss (AAL) of the country by the selected natural hazards containing the data since 1934. The country shows a high vulnerable profile in terms of human loss; by only three hazards, annually average human loss is 458 fatalities. In addition, most of the average annual monetary loss is due to flooding which plays the most devastating hazard role in the country.

Table 1: Average annual losses (GAR 2015)

Hazard	Absolute [million US$]	Death Toll [person/year]
Earthquake	0.35	225
Flood	16.13	124
Landslide	0.70	109
Multi-Hazard	17.18	458

3.1.1. Earthquakes

Nepal is located in a highly seismic region and most of the country is placed on the Indian tectonic plate, close to the boundary between the northward moving Indian Plate and The Tibetan Plateau on the Eurasian Plate. The impact of those two landmasses has produced the Himalayan mountain range more than 65 Ma years ago which lays along the country is bounded by the Chaman Fault in the west which is a sinistral fault and the Sagaing Fault in the east which is a dextral fault. The Indian and the Eurasian plates are converging at a relative rate of 40-50 mm per year, which results in a net uplift of Himalayan mountain ranges by approximately 18 mm per year due to series of thrusts (northward under-thrusting of India beneath Eurasia) (Lizundia, et al., 2016). Around 92 small and active faults are distributed around the three main fault systems parallel to the Himalaya mountain range, among the major tectonic boundaries, result of continental collision between the Eurasian and Indian plates and produce great potential to yield large earthquakes in future (NAKATA & KUMAHARA, 2002), (Parajuli, Kiyono, Taniguchi, Toki, & Maskey, 2010).

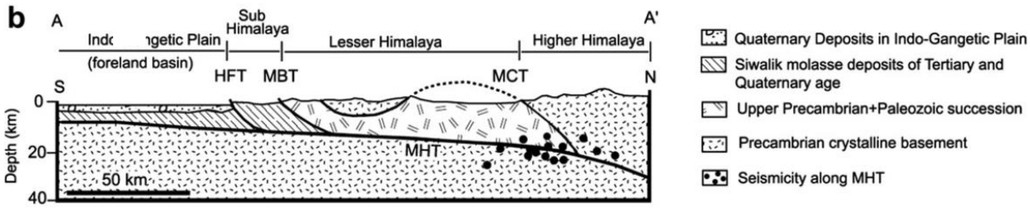


Figure 1: HFT – Himalayan Frontal Thrust, MBT – Main Boundary Thrust, MCT – Main Central Thrust, MHT – Main Himalayan Thrust (Malik, Sahoo, Shah, Shinde, Juyal, & Singhvi, 2010)

Earthquake in Nepal shows the most devastating hazard profile in terms of human loss and Table 2 lists relevant past earthquakes in the country since 1934, which caused 18,972 fatalities and over 13 billion US$ in monetary loss.

Table 2: List of past earthquakes in Nepal (DesInventar), (EM-DAT)

Year	Death toll	Affected people	Total damage ('000 US$)
1934	9040	-	-
1966	80	20000	1000
1980	125	200000	245000
1988	744	300000	60000
1993	1	230	-
2001	2	-	70000
2003	1	-	-
2011	9	167860	7750000
2012	1	-	-
2015	8969	5621790	5174000
Total	18972	6309880	13300000

Zhang et al. produced seismic hazard map of continent Asia as a part of Global Seismic Hazard Assessment Program (GSHAP). Within the work, the earthquake catalogue includes 14302 event with moment magnitude is greater than 5 in Asia between 7670 BC and 1996. The Huo and Hu (1992) attenuation model was employed while the seismic site condition is assumed rock. Figure 2 shows seismic hazard map of Asia based on peak ground acceleration (PGA) with a 10% probability of exceedance in 50 years. The entire country demonstrates high seismic hazard from 0.2g to 0.5g, including the Kathmandu Valley and the north-western provinces.

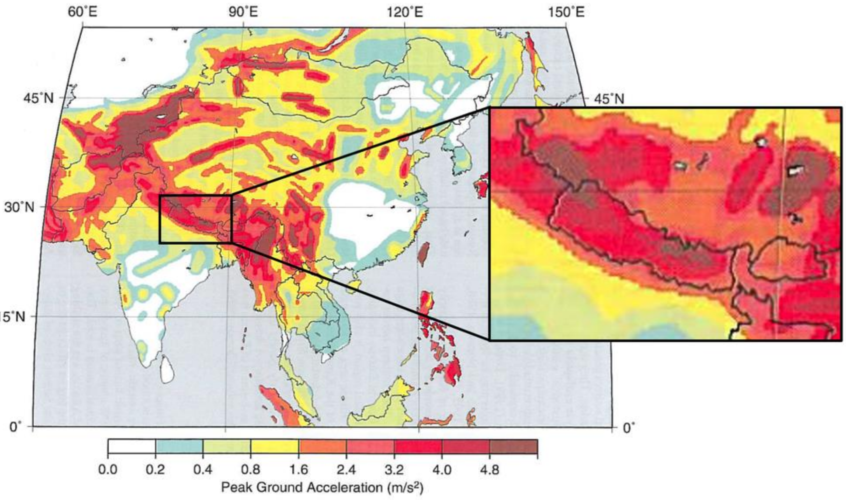


Figure 2: Seismic hazard map for Asia with 10% chance of exceedence in 50 years in terms of peak ground acceleration (Zhang, Yang, Gupta, Bhatia, & Shedlock, 1999)

Parajuli et al. computed probabilistic seismic hazard maps in terms of peak ground acceleration (PGA) for soft soil with 10 % probability of exceedance in 50 years (Parajuli, Kiyono, Taniguchi, Toki, & Maskey, 2010). Figure 3 presents the seismic risk map for the country in terms of peak ground acceleration. It can be observed around Kathmandu Valley approximately 0.5 g, the Far West Region also displays high seismic hazard which is around 0.4 g.

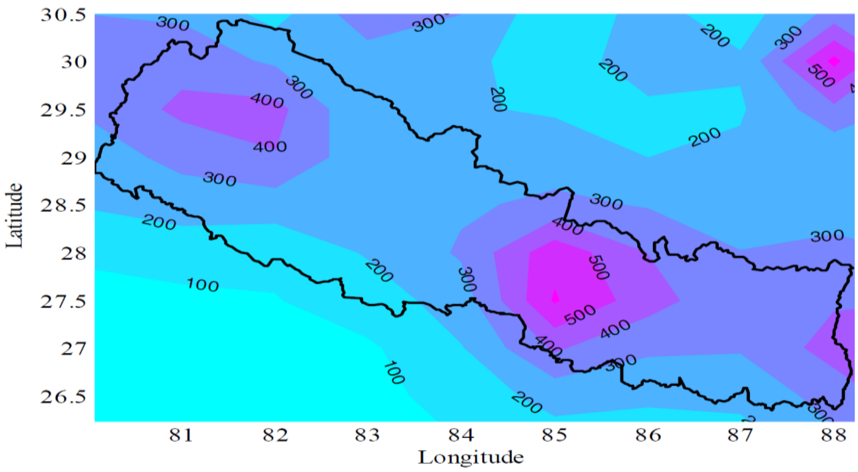


Figure 3: Probabilistic seismic hazard with 5% damping 10 % probability of exceedance in 50 years

Chaulagain et. al. studied on assessment of seismic risk in Nepal while combining probabilistic seismic hazard, structural vulnerability, and exposure data (Chaulagain, Rodrigues, Silva, Spacone, & Varum, 2015). Figure 4 displays the seismic hazard map of the country which demonstrates ground shaking in terms of peak ground acceleration with 10% probability of exceedance in 50 years. The central zone (Gandaki District) and southern east part (Mechi and Rapti districts) demonstrate higher seismic hazard in the country.

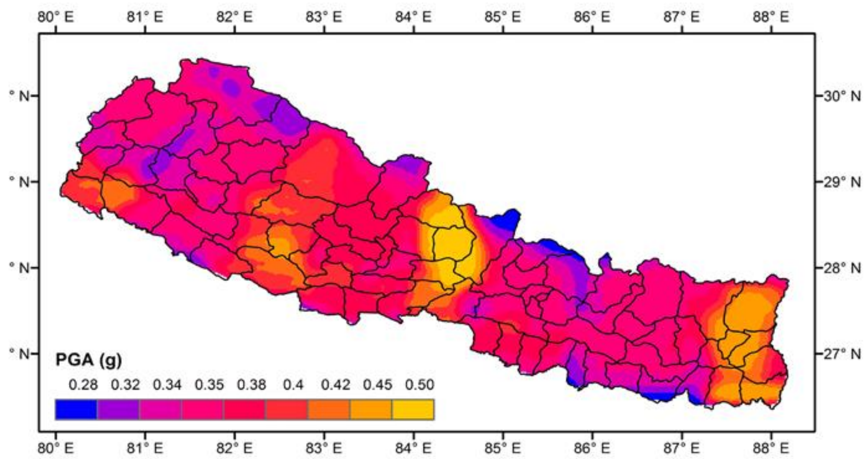


Figure 4: Seismic hazard maps showing the peak ground acceleration distribution with 10 % probability of exceedance in 50 years [5]

3.1.2. Floods

Nepal is one of the richest countries in terms of natural water and there are around 6000 rivers all over the country in different sizes. The large rivers are snow-fed from the Himalayas, the medium rivers are fed by rain from middle mountains and small rivers are originated in the southern slopes of the middle hills and the Siwaliks hills (Siwaliks zone) and have little or no flow during the dry seasons. These small rivers are the ones that contribute to flood damage significantly because of carrying great amount of sediment from degraded Siwaliks hills and depositing them on Terai region. The Siwaliks zone demonstrates high degradation because of weathered and deformed rocks, high topographic variation, high rate of deforestation and encroachment and unpredicted extreme rainfalls. Hence, the many communities of the region are located below the river bed due to sedimentation and flood causes significant human and monetary loss each year (Shrestha, Heggen, Thapa, Ghimire, & Shakya, 2004), (Dhakal, 2014).

In addition, effects of global warming in the country result in high rate of glacial melting and of formation of glacial lakes. Those lakes are in danger of rupturing resulting of Glacial Lake Outburst Flood (GLOF) hazard. At least 14 GLOF events have been identified as originating in the Nepal Himalayas in the past (Khanal, et al., 2015).

In Nepal, flood repeated reportedly 1074 times between 1954-2017 and caused a total of 7841 fatalities, as presented in Figure 5. The total economic loss is more than 10 Billion USD. The trend of the hazard is upward and the predicted effects of potential flood in the context of climate change are also visible in the country. The hazard occurrence shows strong mirroring the periodicity in summer monsoon in South Asia.

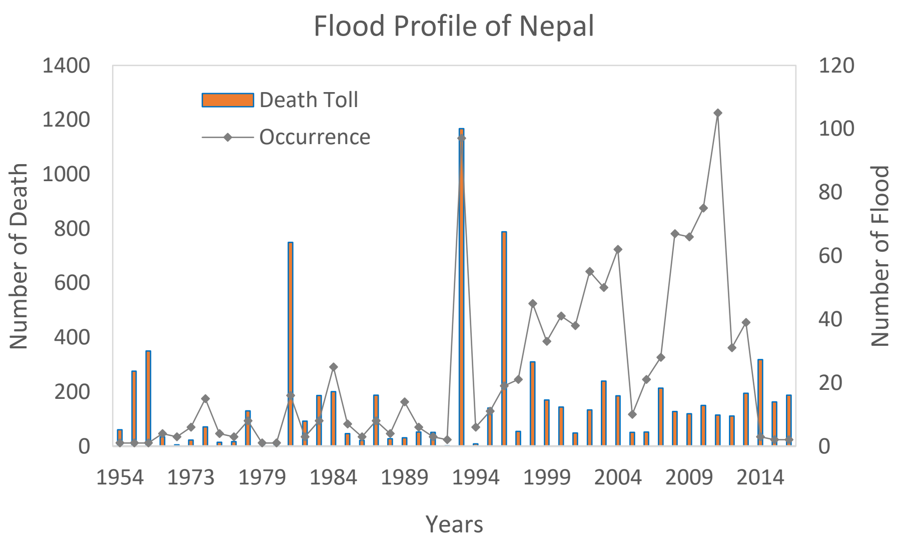


Figure 5: Flood profile of Nepal between 1954-2017

3.1.3. Landslides

The fast uplift on the terrain due to high collision rate of the Indian and the Eurasian plates and rapid riverine erosion form a very diverse landscape in the Middle Mountains, and produce landslides in the country. The terrain mainly consists of steeped-sloping terraces used for agricultural purposes and villages. Landslide itself is often categorized as a secondary hazard of earthquake, flood and one the major causes of loss of life and damage to the structures in Nepal. For instance, after the Gorkha earthquake in 2015 and its aftershocks, at least 25,000 landslides throughout the steep Himalayan Mountains were reported (Roback, Clark, West, Zekkos, G., & Godt, 2018).

Parameters that contribute to landslides in Nepal can be categorized into four parts: (1) geological sources (weak, weathered, sheared materials, and contrast in permeability of materials); (2) morphological sources (fluvial, erosion of slope toe, tectonic uplift, erosion of marginal sides); (3) physical sources (intense rainfall, prolong or exceptional precipitation, earthquake, and snowmelt); (4) human sources (deforestation, irrigation, mining, road construction, artificial vibration, water leakage, land use changes) (Dahal, 2010).

Figure 6 illustrates the reported landslide profile of the country between 1971 and 2014 which occurred 1204 times and caused loss of 5240 lives. Total economic loss due to landslides is over 12 Million US Dollar (DesInventar). The graph demonstrates also that the occurrence in variety year by year despite of that fact that the trend is upward in general.

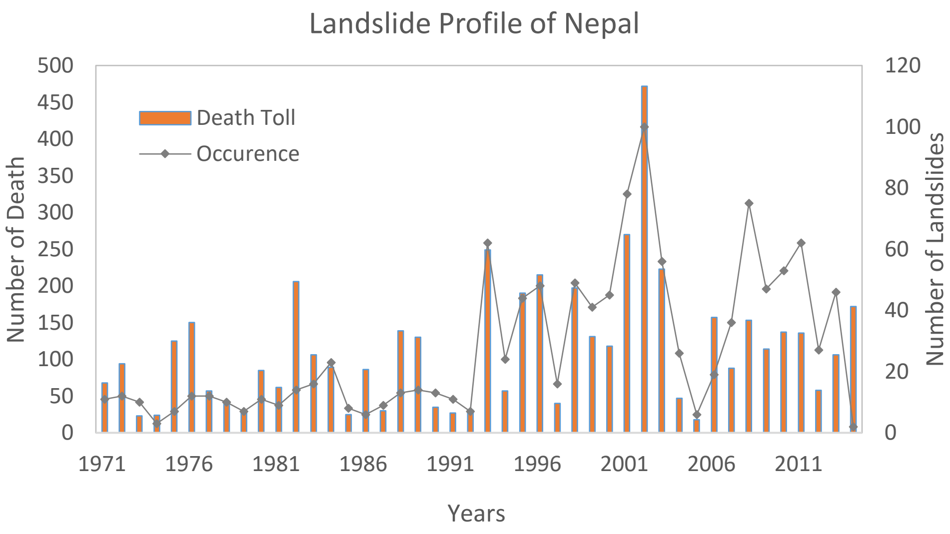


Figure 6: Landslide profile of Nepal between 1971-2014.

3.2. Common construction types in Nepal

The Nepal National Building Code (NBC) is a standard for guidance of the construction of new buildings while covering the typical and most common building types constructed in Nepal. The NBC was established in 1994 by the Government of Nepal, following the 1988 M6.9 Bihar earthquake. The code has been released under several provisions including the improvement of the level of hazard and development of design calculation referred to the Indian code. In 2006, the adaptation of the code became mandatory for all the government buildings and recommended for use in all municipalities. After the 2015 Gorkha Earthquake, the Department of Urban Development and Building Construction (DUDBC) became the responsible government department for formulation, updating, and implementation of building code in Nepal and it has proposed some changes in the provisions under the Mandatory Rules of Thumb (MRT) and Guidelines sections of the NBC. Despite of all the facts, a very high portion of buildings are constructed by owner or/and local craftsmen or/and do not fulfill many of the requirements in the code. In urban areas, over 80% of the structures are constructed by owners or local masons. In rural areas, that number increases over 95% and only 5% of them has professional engineering design and supervision (Dixit, 2008). Since a great amount of the building stock in the country is located in remote areas due to its topography and built using indigenous construction techniques, the NCB offers a ‘Guidelines’ to ensure a level of some standard design and detailing practice on the remote rural structures. The standard design details have been recommended in the 'Mandatory Rules of Thumb' (MRT) for the most common semi-urban and urban residential houses in which the main structural systems as load bearing masonry walls and reinforced concrete frame with infill walls.

The most common building typologies in Nepal are unreinforced masonry bearing wall structures, wooden structures and reinforced concrete structures with infill walls. The majority of those buildings is non-engineered construction and they indicate very high vulnerability to the natural hazards. Moreover, the National Population and Housing Census 2011/12 revealed that main material of walls are cement bonded bricks/stones (29%), mud bonded bricks/stones (41%) baked bricks (26.3%) and wood/planks/bamboo (25%) among of around 5.5 million households (National Population and Housing Census 2011 (National Report), 2012).

3.2.1. Unreinforced masonry (URM) bearing wall structures

Unreinforced masonry structures in Nepal are made of varying materials depend on availability on the location constructed such as adobe brick, baked bricks, stones or concrete blocks with several mortar types like lime, mud, mud mixed with cow dung or cement. The thickness of the masonry walls ranges from 500 mm to 750 mm with three layers in a single cross-section, internal walls are commonly one half brick thick. In the case of roof construction practice, most of all the roofs are one way predominantly sloped at around 10°. Construction of roofs is generally with timber rafter covered with tiles laid over mud mortar or metal sheet. (Shakya & Kawan, 2016). Baked clay bricks are commonly used as masonry infill walls. URM bearing wall buildings are generally two to four stories high. Different mortar known as Vajra (a mix of lime and brick dust) is also observed in some of the old buildings. These buildings have either wooden or reinforced concrete flooring. A hybrid type of construction also prevails in semi-urban and rural areas, where wood frames are used in the ground story front façade, and rest of the house is made of unreinforced masonry bearing walls (Lizundia, et al., 2016). Older masonry structures are used at least three generations without any strengthening procedures; thus, they incur massive damage of life and properties (Gautam, Rodrigues, Bhetwal, Neupane, & Sanada, 2016).

Adobe structures require simple construction technology, demanding low cost, showing great thermal and acoustic properties and this material can be seen for construction of early monuments, temples, palaces and residential buildings in the country (Seismic Retrofitting Guidlines of Buildings in Nepal, 2016). They, however, accomplish poor performance to the natural hazards, such as earthquake, flood and heavy rain. These buildings are built with locally available sundried bricks (earthen) bonded with mud mortar/mixture of cow dung and mud or stones without mortar for the construction of structural walls. Adobe bricks are usually used in a case of absence of stones in the area. In case of lock of presence of mud mortar, the voids in between masonry units are filled with stone chips or aggregates [7]. The irregular heavy rubble stones can be bearing walls, however, there are no cornerstones and even the shape of stone units is irregular leading to heavy damage with stone chips or aggregates in majority of houses. This type of structures can be seen in mountain and hill areas namely Mustang, Dang, Bardiya, Banke and the story height is low, around 1.8 to 2.1 m. They are typically isolated construction and commonly found as two stories excluding the loft story. Floors are made of timber or bamboo covered by mud. Roofs are mostly of timber or bamboo covered with tiles, slate (heavy stone slices), shingles or corrugated galvanized iron (CGI) sheets (Group, 2013). Walls tend to be very thick, depending upon the type of walling units but not more than 350 mm and openings are very limited (Group, Seismic Vulnerability Assessment Project, 2013). The seismic capacity of these buildings is very low, limited by the integrity of structural components and strength of walls and lack of elements tying the structure together (ring beams at wall or roof level). Vertical and horizontal wooden elements are sometimes embedded in walls, providing some level of earthquake resistance, but this is very uncommon.

GEM Taxonomy string: MUR+ADO+MON

MUR+STRUB+MON

3.2.2. Mud mortared masonry buildings with stone/bricks

The houses are formed by dressed or undressed stone walls with mud mortar or baked bricks walls with mud mortar. They are commonly observed in mountain and hill areas as well as in urban areas. The walls of 17% of the houses in urban areas and of the 47% of the houses in rural area are made of mud mortared stones/bricks in Nepal (National Population and Housing Census 2011 (National Report), 2012).

GEM Taxonomy string: MUR+STRUB+MOM

MUR+CLBRS+MOM

(Langenbach, 2015)

3.2.3. Cement mortared masonry buildings with stone/bricks/concrete blocks

This type of buildings has walls of fired brick, concrete block or stone in cement-sand mortar and they are typically up to three stories. Floors and roofs are commonly of reinforced concrete or reinforced brick concrete. The 69% of the walls in urban area and the 19% of the walls in rural areas are made of cement mortared stones/bricks (National Population and Housing Census 2011 (National Report), 2012). Establishment of some earthquake resistant features is not common in these buildings and despite using comparatively higher quality materials, these buildings suffer from lack of construction practices (NEPAL EARTHQUAKE POST DISASTER NEEDS ASSESSMENT, 2015).

GEM Taxonomy string: MUR+CBS+MOC
MUR+CLBRS+MOC
MUR+STRUB+MOC

(Study of habitat typologies and Solutions for their seismic reinforcement Nepal – Avril , 2016)

3.2.4. Wooden structures

Typically, these houses are constructed of timber or bamboo with wooden plank, thatch or bamboo strip walling materials with flexible floor and roof. Wooden frame houses are built in rural areas of Terai especially in Kanchanpur, Kailali, Surkhet, Bara, Rautahat, Morang, Sunsari where the material for such construction is easily available and they are generally two to three stories tall. Majority of this type of houses are used for residential purposes. These housing types have traditional system of bamboo/wooden posts. Bamboo posts are implanted into the ground to behave as compression members and are tied with horizontal bamboo/wooden girders with the help of bamboo ropes (cane) to give a proper shape and framing action. However, there is no protection of bamboo/wooden posts against decaying/termites or any other natural causes. The performance of these houses during the past earthquakes is unknown. However, according to the local communities, the performance of these houses in the past major earthquakes is comparatively well and the majority of houses survived under severe earthquake loading due to their light weight (Khan, 2008).

GEM Taxonomy string: W+WBB

W+WLI

3.2.5. Reinforced concrete (RC) structures with infill walls

RC frame buildings with masonry infill walls are commonly constructed in urban and semi-urban areas throughout Nepal to conduct rapidly increasing settlement of the region and they consist of cast-in-situ concrete frames with masonry partition and infill walls (brick, block or stone masonry). The height of most of the buildings is three to five stories, however much taller buildings up to 20 stories have been observed in greater cities, they are often non-engineered and mainly owned by the household. Most of the governmental buildings and a large number of newly constructed private buildings can be categorized into this type. The common practice to build a house in Nepal is following those steps which is (1) the owner/contractor has to submit the architectural drawing to the local government which shall fulfill all the criteria under architectural norms. (2) If the architectural drawings accomplish all the criteria, the concern authority approve the drawings and (3) the owner/contractor can proceed the construction (Shakya & Kawan, 2016). Nevertheless, most of the private built buildings are non-engineered and show some lack of basic earthquake resistant features.

The RC frame buildings with masonry infills suffered extensive damage during the Gorkha earthquake in 2015 and the majority of these buildings face deficient construction practices despite of using high quality materials. While seismic detailing has become more common in recent years, older buildings have no ductile detailing. The reinforced concrete buildings constructed before the design code share some common deficiencies which are low concrete quality, poor workmanship, inadequate beam and column sizes, insufficient longitudinal reinforcement, large stirrup spacing, weak beam-column joints (Varum, Dumaru, Furtado, Barbosa, Gautam, & Rodrigues, 2018).

GEM Taxonomy string: CR/LFM
CR/LFINF

(Group, Seismic Vulnerability Assessment Project, 2013)

(Gautam, Rodrigues, Bhetwal, Neupane, & Sanada, 2016) (1806)

4. Natural hazards and built environment in Tanzania

Tanzania is located in coastal East Africa, neighbouring Kenya, Uganda, Rwanda, Burundi, the Democratic Republic of the Congo, Zambia, Malawi, and Mozambique. The total population of the country is 55,572,201 in 2016 (World Bank). Even though the urbanization rate is higher in the cities of Dar es Salaam, Dodoma, Arush, the 68% of the total population lives in rural areas (World Bank). The population density of Dar es Salaam was over 2,700 people per km^2 in 2012. The mainland Tanzania (excluding Zanzibar) is formed of a large central plateau covered with grasslands, plains and rolling hills. The country is also bordered the largest lakes in Africa, Lake Nyasa, Lake Victoria, and Lake Tanganyika and contains large rivers such as Nile, River Congo, River Rufiji, and River Ruvuma. Tanzania appears one of the fastest population growing countries by 3.1% annually in 2016. The economy of the country depends on the agricultural sector, which accounts for more than 32% of the GDP (World Bank).

Due to economic and cultural reasons, the urbanization rate has reached to the unexpected rate following by informal settlement and non-engineered structures. As a result of those factors, the exposure to the natural hazard threats is in a rapid increase in the country.

Tanzania faces several natural hazards every year including drought, earthquake, landslide, flood and storms. Table 3 shows the reported average annual loss of the country by hazards containing the data since 1964. Thus, 85% of the average annual monetary loss is due to flood which plays the most devastating hazard role in the country before earthquake. Within those years, total monetary loss is over 6.5 Million USD and flood shows the most dangerous and frequent peril in the country. The average monetary loss due to multi-hazards is over 10 million USD per year.

Table 3: Average annual losses (GAR 2015 Data Source)

Hazard	Absolute [Million USD]	Death Toll [person/year]
Earthquake	8.64	0.75
Flood	1.53	15.25
Volcano	-	-
Multi-Hazard	10.17	16.00

4.1. Earthquakes

Tanzania is located along the Western Rift Valley of the East African rift system which is 3000 km long Cenozoic age continental rift. Rifting and deformation in the East Africa Rift System is interpreted to be more broadly distributed than along a single linear feature. Figure 7 shows past earthquakes in the region.

In the East African Rift, seismicity is widespread, but demonstrates a distinct pattern and it is characterized by mainly shallow (<40 km) normal faults (earthquakes rupturing as a direct result of extension of the crust), and volcano-tectonic earthquakes (Hayes, et al., 2014). Although the seismicity level of divergent, plate boundary can be described as moderate; several damaging earthquakes have been reported in historical times, and the seismic risk is exacerbated by the high vulnerability of the local buildings and structures (Poggi, Durrheim, & Tuluka, 2017).

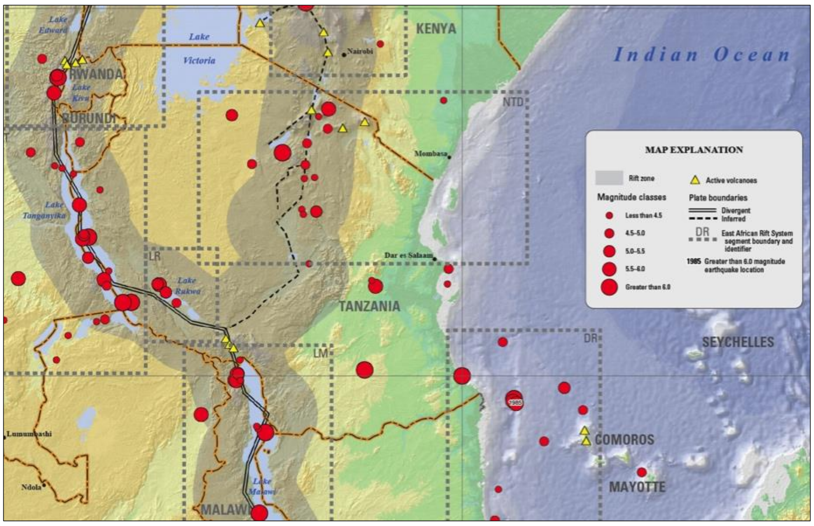


Figure 7: Location of past earthquakes in the East African Rift (Hayes, et al., 2014)

The earthquakes in Tanzania show moderate seismicity and Table 4 lists the past earthquakes in the country which caused 38 fatalities since 1964.

Table 4: List of past earthquakes in Tanzania (EM-DAT)

Time	Region	Depth	Magnitude (Richter Scale)	Death toll
05/07/1964	Tanzania	-	6.0	4
10/02/2000	Nkansi, Rukwa	31 km	6.5	1 (Tanzania - Earthquake OCHA Situation Report, 2000)
05/18/2002	Bunda	8 km	5.5	2
09/10/2016	Lake Victoria	33 km	5.9	20 (Emergency Plan of Action (EPoA) Tanzania: Earthquake, 2016)
05/25/2017	Mwanza	35 km	4.4	1
***26/12/2004**	Sumatra, Indonesia	-	9.1	10

*The epicenter of the earthquake is located out of the country.

Midzi et al. calculated a seismic hazard map for East and South African regions using a probabilistic approach. The earthquakes in the region between 627-1994 collected and homogenized using different sources. Figure 8 presents a seismic hazard map in terms of peak ground acceleration for 10% probability of exceedance in 50 year in cm/s^2. The map indicates that the Arusha region and Lake Tanganyika demonstrate higher seismic hazard in the country (approximately 200 cm/s^2).

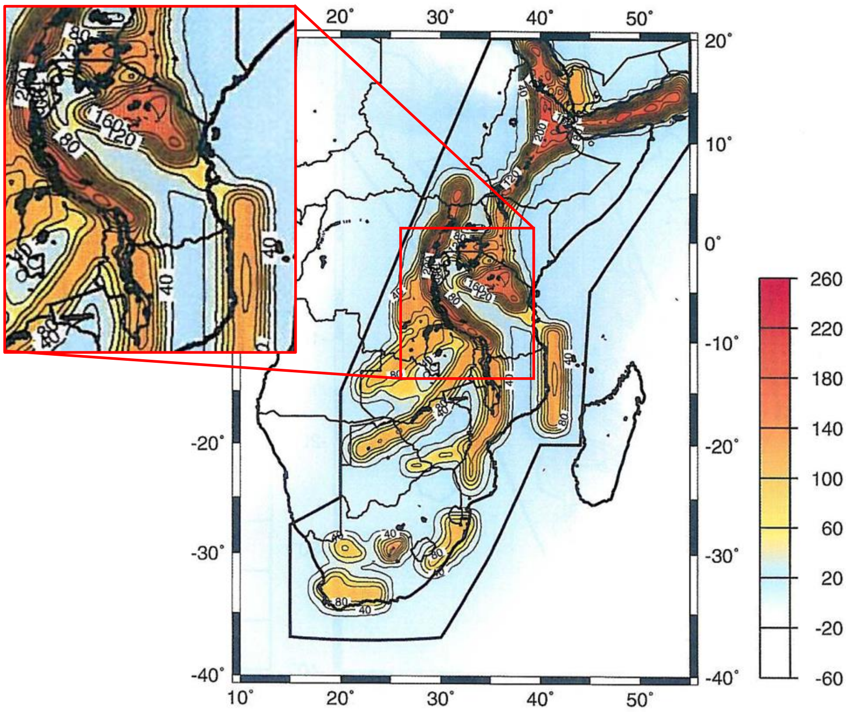


Figure 8: Distribution of mean peak ground acceleration values for 10% probability of exceedance in 50 years (Midzi, et al., 1999)

Poggi et. al. studied the seismic hazard along the East African countries as depicted in Figure 9. The map was created using the OpenQuake-engine while assuming the soil conditions as rock. The map indicates that western Tanzania along the border with Congo and Zambia and the Arusha region are characterized by high seismic hazard, approximately 0.25 g for 10% probability of exceedance in 50 years.

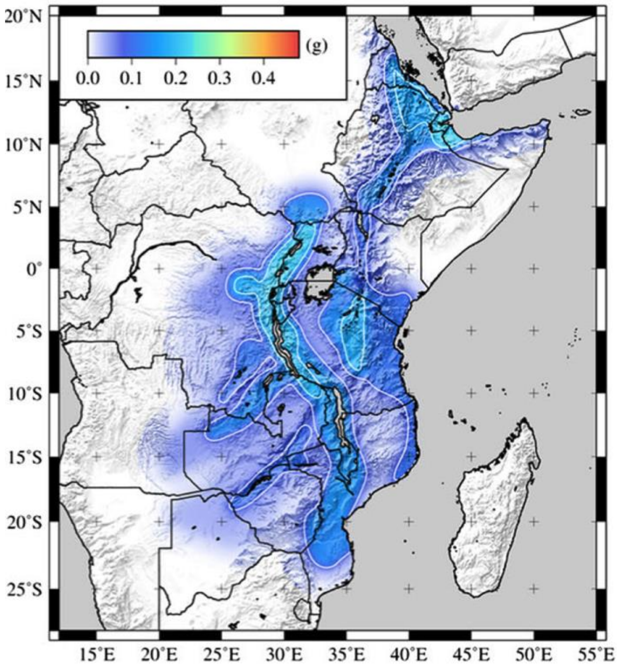


Figure 9: Seismic hazard map of spectral acceleration (g) for 10% probability of exceedance in 50 years

4.2. Floods

Since 1954, Tanzania faced floods 44 times, causing 886 fatalities, affected more than 5.5 million people and resulted in significant monetary loss for the country (EM-DAT).

Figure 10 displays the reported flood profile of the country which is in increasing trend in terms of the frequency of the peril and the death toll by the time.

The total rainfall amounts for stations in Tanzania vary from year-to-year as well as having large seasonal variations. The country has two rain seasons; one is from March to May, the other one is from October to December. Flood, mostly riverine, is the most frequent and unprepared disaster in the country due to water source anomalies. Heavy rains causes strong floods, devastating homes, bridges, and crops. Due to vulnerable housing conditions and informal settlement, the peril becomes the most devastating natural hazard in the country. Figure 11 shows the past floods according to the regions and the flood mostly seen in Mbeya, Pwani, Arusha and Morogoro regions while Dar es Salaam city (Pwani region) and Kiyela (Mbeya region) show particularly vulnerable profile.

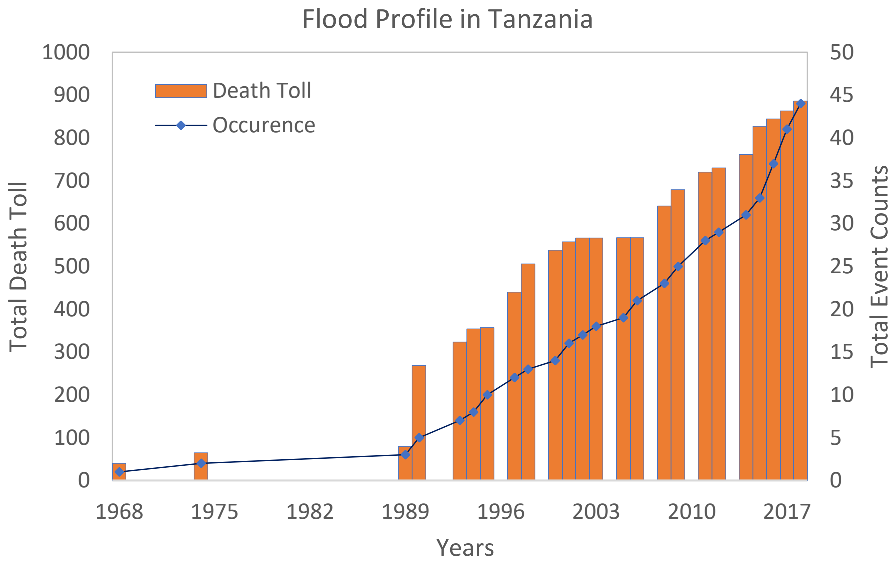


Figure 10: Flood profile of Tanzania (EM-DAT)

The Meteorological Agency (TMA) of Tanzania does provide a warning to the people about the rain intensity and possible flooding. Moreover, The Ministry of Water and Dar es-Salaam University have been developing flood modelling capabilities for the country and organized different research about flood simulations by the regions but have not introduced those results into practice (Mikova & Makupa).

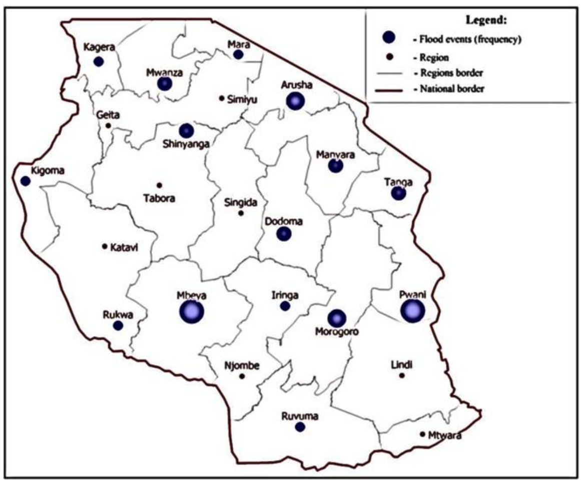


Figure 11: Flood frequency map of Tanzania (1964-2014) (Mikova & Makupa)

4.3. Volcanoes

In Tanzania, there are 10 Holocene volcanoes, but only one is active. The Ol Doinyo Lengai Mountain is the only volcano in the country associated with a hazard levels PEI-3 (PEI: Population Exposure Index). Due to lack of volcano monitoring, the remaining ones, however, may be unrest and may have potential eruptions. Of these unclassified volcanoes, five have no confirmed Holocene eruptions; two have Holocene activity records and Meru and Kyejo have historic activity as recently as 1910. Meru, Rungwe and Ngozi have Holocene records of large magnitude eruptions of VEI ≥4 (VEI: Volcanic Explosivity Index) (Jonathan, Sparks, Cashman, & Brown, 2015). *Figure 12* demonstrates the location of volcanoes, ports, airports and major cities with an extent of the 100 km zone surrounding them. The potential number of people living within a 30 km zone of Holocene volcano effect is calculated 2,604,862 (GAR 2015 Data Source).

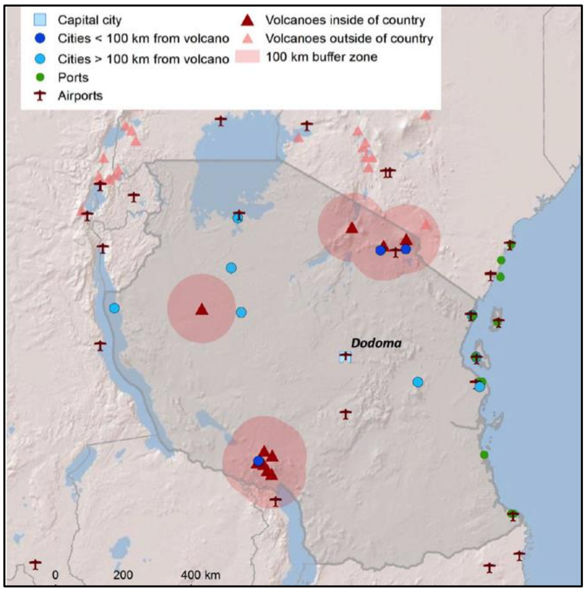


Figure 12: Volcano hazard map of Tanzania (Jonathan, Sparks, Cashman, & Brown, 2015)

4.4. Common construction types in Tanzania

In Tanzania, most of the population, about 80% cannot afford to have an earthquake resilient household due to expensive cost of materials, labour and technical know-how (Kwanama, 3–4 December 2015). Buildings in rural areas are still based on self-help or/and community-help approaches particularly when traditional housing knowledge is concerned. It has been observed that low quality housing is prevalent in rural areas while the situation in urban areas is that of low quality houses for low income groups, inadequacy and scarcity of dwelling space hence overpopulation and inability to access descent housing because of income poverty.

Most of the houses are non-engineered and informal settlement has been a great issue in the country. In the big cities, such as Dar es Salaam, construction regulatory authorities involved in regulating construction activities are the Engineers Registration Board, the Architects and Quantity Surveyors Registration Board, Contractors registration Board, Public Procurement Regulatory Authority (for public constructions), and the Municipal Councils (Ignas, 2013). The National Population and Housing Census 2011/12 revealed that main material of walls are cement bricks (20.3%), sundried bricks (26.3%), baked bricks (26.3%) and pole and mud (23.5%) among of over 9 million households (The Housing Condition, Household Amenities and Assets , 2015).

The most common building typologies in Tanzania are traditional houses, unreinforced masonry structures with adobe bricks, unreinforced masonry with baked bricks/concrete blocks and reinforced concrete structures. Since the majority of those buildings is non-engineered construction, they indicate very high vulnerability to the natural hazards.

4.4.1. Traditional houses

The traditional houses can be categorized as structures without lateral load resisting system and built using the local materials, for instance collecting eligible poles from the area or nearest forest and assembling them. The height range of poles is from 90-150 cm, commonly around 120 cm and they are horizontally tied together. The outer surface is plastered with a mix of mud, sticks, grass, cow dung and human urine. Roof is usually cover by straw/thatch or metal sheet (rarely) (De Risi, et al., 2013). In Tanzania, the 23.5% of the outer walls is made of pole and mud and 1.6% of them is assembled by grass (The Housing Condition, Household Amenities and Assets , 2015). Mostly the roof of those houses can be made of earth as well or straw/thatch.

GEM Taxonomy string: W/LN
EU/LN

4.4.2. Unreinforced masonry structures with adobe bricks

Unreinforced masonry with adobe brick display the most common structure type in Tanzania, especially in rural areas. Those structures differ in size and features depending on weather and traditions of the location that they are built in. The walls are made of sun dried adobe bricks joined with mud mortar or mud plaster. Mostly they are constructed in rectangular shape in plan with a single door (around 0.6 mx1.2 m) and small windows. Because the average height of the building is less than 2 m, some have excavated floors, below than ground level around 0.3 m in order to increase the headroom. Most of adobe buildings investigated in Dodoma region have shallow foundations about 160 mm below ground level and were constructed by adobe bricks with adobe mortar and adobe flat roofs. In many regions, most of the roofs are constructed using adobe flat roofs with around 0.4 m thickness in addition to adobe walls, except in Shinyanga and Mwanza regions where most of the roofs are made of thatched grass material. Mostly, timber poles have been added to assist the load bearing walls to support the heavy adobe roof. To improve the roof durability, cow dung is mixed with soil from ant hills in a ratio of about 1:2 hence produce the adobe material for the roof. After some time, grass is allowed to grow on top of the roof because of reducing erosion/wearing of the roof. Recent adobe constructed roofs are being replaced by corrugated iron roofing sheets which are kept in position by placing stones or other heavy objects on top. The placing of stones on top is necessary by the fact that most of the adobe constructed in buildings in rural areas lack strong roof structure to hold in place roofing sheets especially against wind loads (Rubaratuka, 2012).

GEM Taxonomy string: MUR+ADO+MOM


https://pixabay.com/en/home-hut-brick-clay-thatched-roof-216581/ (Rubaratuka, 2012)

4.4.3. Unreinforced masonry structures with baked bricks/concrete blocks

The walls are the main structural component to resist lateral loads in those buildings. The walls can be formed by baked bricks or concrete blocks. This type of household is the most common structure in the urban area, especially Dar es Salaam. 20% of the walls are made of concrete blocks and 26% of the walls are built with baked bricks in the whole country (The Housing Condition, Household Amenities and Assets , 2015). Mostly they are not reinforced nor confined masonries. The bricks/blocks can be attached using mud mortar, lime mortar or cement mortar. Commonly, the buildings in Dar es Salaam are built with 460x230x125 mm cement blocks, wooden or iron beams are used as roof beams covered by corrugated iron sheets (De Risi, et al., 2013).

GEM Taxonomy string: MUR+CLBRS+MOM

MUR+CBS+MOC

(Mrema)

4.4.4. Reinforced concrete structures

Reinforced concrete became a popular structural material, especially in large cities, such as Dar es Salaam, in which about 98% of storied buildings are constructed using reinforced concrete (Ignas, 2013). Due to absence of the national design code/regularization/guideline in the country, the design of the constructions is integrated following some foreign code, mostly British Standards. In Dar es Salaam, 95% of walls are made of concrete blocks according to the Population and Housing Census Survey in 2012 (The Housing Condition, Household Amenities and Assets , 2015). Nonetheless, they demonstrate great problems due to design deficiencies such as lack of design detailing, unsatisfactory quality of concrete mixture, inappropriate construction technology, lack of quality control measures and inadequate supervision on construction sites.

GEM Taxonomy string:	CR/LFINF
	CR/LFM

5. Definition of the vulnerability taxonomy

To ensure compatibility with the outcomes of the GFDRR-DFID Challenge Fund (hazard, exposure and vulnerability) schema, as well as with the associated web-based platform (http://det-dev.geo-solutions.it), the vulnerability taxonomy closely follows the MOVER classification system. MOVER is an open multi-hazard vulnerability schema created by University College London. The MOVER data schema comprises 4 separate modules: 1) Vulnerability, Fragility, and Damage-to-Loss Function module, 2) the Physical Indicators module, 3) the Social Indicator module and 4) the Physical, Social and Hybrid Indices module. Each one consists of one or more base tables in which the main information of the functions indicators and indices are portrayed.

Module 1, the Vulnerability, the Fragility and the Damage to Loss Function, which is the interest of this work is formed of three base tables and six supporting tables. The base tables are vf_table (vulnerability functions table), ff_table (fragility functions table) and dtl_table (damage-to-loss functions table). The supporting tables are independent from the remaining three modules and those are edp (engineering demand parameters), loss_parameter, damage_scale, ff_scoring_table, vf_scoring table and im_table (intersity measure table). In addition, Module 1 is linked to the Hazard, Asset, Reference and Data tables which allow interconnecting all the four modules.

5.1. Vulnerability Functions Table

Table VF5 exemplifies a part of the Vulnerability Function table (vf_table) which is characterized by the data types and their descriptions. Besides, the Vulnerability Function table is the only table that connects to the Loss Parameters supporting table.

Table VF5: Schema of the Vulnerability Function base table

Column name	Type	Description
id	Identifier (ID)	Unique identifier of the vulnerability function
hazard_type	Hazard Type	Enumerated field with possible entries of: Earthquake, Tsunami, Flood, Wind, Landslide, Storm surge, Volcanic ash, Drought
asset		Enumerated field with possible entries of: Buildings, Lifelines, People, Crop
taxonomy		GEM taxonomy
country_iso		List of the countries that the function can be applied to
approach		Enumerated type inclines the possible forms of vulnerability function. Those include: Empirical, Analytical, Judgement, Hybrid-Analytical/Empirical, Hybrid-Analytical/Judgement, Hybrid-

		Empirical/Judgement and Hybrid-Analytical High Fidelity/Low Fidelity
reference		Reference study of the vulnerability function
vf_math_model	Vulnerability Function Mathematical Model	Enumerated field. Possible entries include: Cumulative lognormal, cumulative normal, exponential, Bespoke
lp_name	Loss Parameter Name	Enumerated type. Possible entries include: Relative loss, Fatality Rate, Total fatalities, Economic loss total, Annual average loss, Downtime, Mean damage ratio, Economic loss ratio, Damage Index.
im_name_f	Intensity Measure Name	The field specifies the name of the intensity measure. The field is enumerated and indexed so that the entries are predefined and allow for the associative discovery of the VF and FF function using a specific intensity measure. The field is also constrained to allow only for unique entries, so as to avoid that multiple user can input the same intensity measure, associating for instance two different definitions to the same intensity measure.

5.2. Fragility Functions Table

Table VF6 partially displays the schema of the Fragility Function table (ff_table) which shares the similar structure to the Vulnerability Functions table. Meanwhile the fragility functions are engaged to specific damage states, a number of entry of a set of fragility functions on the table is related with the number of the damage states defined on the corresponding study. Also, the Fragility Function table is the only table linking with the EDP table.

Table VF6: Partially schema of the Fragility Function base table

Column name	Type	Description
id	Identifier (ID)	Unique identifier of the vulnerability function
hazard_type	Hazard Type	Enumerated field with possible entries of: Earthquake, Tsunami, Flood, Wind, Landslide, Storm surge, Volcanic ash, Drought

asset		Enumerated field with possible entries of: Buildings, Lifelines, People, Crop
taxonomy		GEM taxonomy
country_iso		List of the countries that the function can be applied to
approach		Enumerated type inclines the possible forms of vulnerability function. Those include: Empirical, Analytical, Judgement, Hybrid-Analytical/Empirical, Hybrid-Analytical/Judgement, Hybrid-Empirical/Judgement and Hybrid-Analytical High Fidelity/Low Fidelity
reference		Reference study of the vulnerability function
ff_math_model	Fragility Function Mathematical Model	Enumerated field. Possible entries include: Cumulative lognormal, cumulative normal, exponential, Bespoke
dm_state_f_name	Damage State Names	Name of the specific damage state studied by the function.
im_name_f	Intensity Measure Name	The field specifies the name of the intensity measure. The field is enumerated and indexed so that the entries are predefined and allow for the associative discovery of the VF and FF function using a specific intensity measure. The field is also constrained to allow only for unique entries, so as to avoid that multiple user can input the same intensity measure, associating for instance two different definitions to the same intensity measure.

5.3. Damage to Loss Functions Table

Table VF7 shows the Damage to Loss Functions base table (dtl_table). The DtL functions employ as a conversion function to obtain indirect vulnerability function through fragility functions. Thus, contrarily to the Vulnerability and Fragility base tables, the DtL base table does not include an associated scoring table. In addition, *Damage scale name* is a unique identifier for the entries of the *Damage scale table* which is a supporting table linked to both the Fragility Function and Damage to Loss Function base tables.

Table VF7: Schema of the Damage to Loss Functions base table

Column name	Type	Description
id	Identifier (ID)	Unique identifier of the vulnerability function
hazard_type	Hazard Type	Enumerated field with possible entries of: Earthquake, Tsunami, Flood, Wind, Landslide, Storm surge, Volcanic ash, Drought
asset		Enumerated field with possible entries of: Buildings, Lifelines, People, Crop
taxonomy		GEM taxonomy
country_iso		List of the countries that the function can be applied to
dm_states_name	Damage states names in the original reference	Names of damage states studied in the reference study of the function, listed using the exact names used in the reference damage scale.

5.4. Supporting Tables

The supporting tables engage supplementary information as digital dictionaries when a user wishes to assess on selecting entries of the main base table. Module 1 contains six supporting tables and they will be explained briefly below. In addition to the supporting tables, Reference, Data and Scoring tables will be briefly discussed.

5.4.1. Hazard table

The Hazard table is employed to specify the hazard type which leads the users to the specific functions, indicators or indices. As a main parameter for the risk assessment, this supporting table is linked to all the base tables of the four modules of the MOVER data schema and additionally to the damage scale table.

5.4.2. Asset table

The Asset table creates the integration of the MOVER data schema with the Exposure. Similar to the Hazard table, this supporting table is linked to all the base tables of the four modules of the MOVER data schema and the damage scale table.

5.4.3. Intensity Measures (IM) table

The Intensity Measure (IM) table lists all the intensity measures from the most commonly adapted fragility and vulnerability functions for the hazard investigated within their descriptions. The IM Table is called upon by the Fragility Function and Vulnerability Function modules.

5.4.4. Damage Scales table

The Damage Scales table lists the most commonly found damage scales in the fragility function literature for the hazards investigated. The Damage Scale Table is called upon by the Fragility Function module.

5.4.5. Loss parameters table

The Loss parameter table lists the most commonly found loss parameters in the vulnerability function literature. The Loss parameter table is called upon by the Vulnerability Function module.

5.4.6. Engineering Demand Parameter (EDP) table

The Engineering Demand Parameter (EDP) table lists the most commonly found EDPs in the analytical fragility function literature for the hazards investigated. The EDP table is called upon by the Fragility Function module.

5.4.7. Reference table

The reference table provides the users all the information in a frame of bibliography regarding of the reference studies occulted during the data entry process on the project.

5.4.8. Data table

The Data table assists as a source table similar to the Reference table. It is created due to two purposes: The one is to identify the data sources based on which functions, indicators and indices have been scored against. The second one is to recollect the possibility to check on the resources that are available for the population the database. It shall be emphasized that the date of the acquisition of the date is a significant parameter to be considered in the assessment of the indictors and the indices.

5.4.9. Scoring tables

The scoring table may role as an attribute of the functions, indicators and indices to demonstrate the data quality. There is a scoring table for each base table of the 4 modules meanwhile the design of the schema treats these tables as separated entities.

5.4.10. Categories and Characteristics tables

The Categories and Characteristics tables offer the users definitions of the physical and social vulnerability categories and characteristics within the field that they cover to provide better understanding especially for the social indicators which may not indicate as self-explanatory as physical indicators.

The templates for the vulnerability and fragility functions are created based on the attributes on the MOVER modules and the meaning of the each attribute on the tables is explained below.

Template for vulnerability functions

ID=HZ-AS-BT-Author-Year	
Hazard	
Asset	
Taxonomy	
Typology of structure	
Countries ISO	
Approach	
Reference	
Figures	
Variables	
Vulnerability Function Mathematical Model	
Loss Parameter Name	
Intensity Measure Name	
Uncertainty	
Comments	

- ID: unique identifier of the vulnerability function in a form of “HZ-AS-BT-Author-Year”. BT refers the base table which can be fragility function (FF), vulnerability function (VF) or damage-to-loss function (DtL)
- Hazard (HZ): potential source, a condition or circumstances for harm; i.e. earthquake (EQ), flood (FL), volcano (VL), landslide (LS)
- Asset (AS): the considered element at risk by the vulnerability function; i.e. building (BL), infrastructures (IS), crop (CR) etc.
- Taxonomy: GEM taxonomy string for the asset
- Typology of structure: the original description provided by the reference
- Countries ISO: 3 character ISO 3166-1 code of the countries in which the functions may be applicable
- Approach: the possible forms of vulnerability function; i.e. empirical, analytical, hybrid etc.
- Reference: the reference study of the vulnerability function
- Figures: the plots, the necessary pictures or the drawings provided by the reference
- Variables: the description of the parameters used to plot the function

- Vulnerability Function Mathematical Model: the mathematical model of the function; i.e. cumulative lognormal, cumulative normal, bespoke etc.
- Loss Parameter Name: the parameter calculated for the function under the given hazard level i.e. relative loss, total fatalities, total economic loss etc.
- Intensity Measure Name: the reference parameter plotted against to the probability of exceedance of a given loss parameter; i.e. ash fall, flood height, spectral displacement etc.
- Uncertainty: description of the source of uncertainty that has been taken into account for the function
- Comments: additional notes/comments specified by the reference.

Template for Fragility Functions

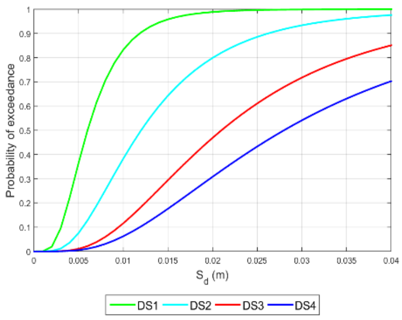
ID=HZ-AS-BT-Author-Year	
Hazard	
Asset	
Taxonomy	
Typology of structure	
Countries ISO	
Approach	
Reference	
Figures	
Variables	
Fragility Function Mathematical Model	
Damage State Names	
Intensity Measure Name	
Uncertainty	
Comments	

- ID: unique identifier of the fracility function in a form of “HZ-AS-BT-Author-Year”. BT refers the base table which can be fragility function (FF), vulnerability function (VF) or damage-to-loss function (DtL)
- Hazard (HZ): potential source, a condition or circumstances for harm; i.e. earthquake (EQ), flood (FL), volcano (VL), landslide (LS)

- Asset (AS): the considered element at risk by the vulnerability function; i.e. building (BL), infrastructures (IS), crop (CR)
- Taxonomy: GEM taxonomy string for the asset
- Typology of structure: the original description provided by the reference
- Countries ISO: ISO code of the countries in which the functions may be applicable
- Approach: the possible forms of fragility function; i.e. empirical, analytical, hybrid etc.
- Reference: the reference study of the vulnerability function
- Figures: the plots, the necessary pictures or the drawings provided by the reference
- Variables: the description of the parameters used to plot the function
- Fragility Function Mathematical Model: the mathematical model of the function; i.e. cumulative lognormal, cumulative normal, bespoke etc.
- Damage State Names: the calculated damage levels associated with the given hazard; i.e. slight, moderate, collapse etc.
- Intensity Measure Name: the reference parameter plotted against to the probability of exceedance of a given limit state; i.e. ash fall, flood height, spectral displacement etc.
- Uncertainty: description of the source of uncertainty that has been taken into account for the function
- Comments: additional notes/comments specified by the reference

Following the previously described vulnerability taxonomy, an existing fragility function (applicable to both countries) has been used to exemplify the various fields:

ID=EQ-BL-FF-AboElEzz-2013	
Hazard	Earthquake
Asset	Building
GEM Taxonomy string	MUR/LWAL/HEX:2
Typology of the structure	URM bearing wall structures—Low rise—2 storey
Countries ISO	NPL, TNZ
Approach	Analytical-Nonlinear static
Reference	Abo-El-Ezz, A., Nollet, M. J., & Nastev, M. (2013). "Seismic fragility assessment of low-rise stone masonry buildings." Earthquake Engineering and Engineering Vibration, 12(1), 87-97.

<table>
<tr><td>Figures</td><td>
</td></tr>
<tr><td>Variables</td><td>

IM=S_d (m)		
Damage States	**θ**	**β**
DS1 (Slight)	0.006	0.53
DS2 (Moderate)	0.012	0.61
DS3 (Extensive)	0.021	0.62
DS4 (Complete)	0.028	0.67

</td></tr>
<tr><td>Fragility Function Mathematical Model</td><td>Lognormal cumulative distribution</td></tr>
<tr><td>Damage State Names</td><td>Four damage states are considered
• DS1: Slight
• DS2: Moderate
• DS3: Extensive
• DS4: Complete</td></tr>
<tr><td>Intensity Measure Name</td><td>Spectral displacement (m)</td></tr>
<tr><td>Uncertainty</td><td>The uncertainties associated with the capacity, the displacement-based damage model, the inventory of existing buildings and the seismic demand are taken into consideration.</td></tr>
<tr><td>Comments</td><td>The stone walls were built of limestone blocks bonded with lime mortar.
Out-of-plain failure is omitted and the walls are assumed being properly anchored to floors.</td></tr>
</table>

6. Final remarks

This component of the METEOR project established the classification system (taxonomy) that will be used to define all of the elements related with the likelihood of damage and loss of the building stock. This taxonomy covers fragility curves, vulnerability functions and damage-to-loss models.

In order to understand the requirements for this taxonomy, an extensive literature review of past natural disasters in the two countries of interest (Nepal and Tanzania) was performed. This review allowed us to understand the most common natural hazards in the country, to determine how existing studies define the demand for hazard information (which has to be compatible with the vulnerability counterpart), and to identify which attributes are used to characterize the vulnerability of the elements exposed to the hazards (which have to be incorporated in the vulnerability models).

The proposed vulnerability taxonomy is strongly based on the GEM and MOVER (UCL) classification systems. The final list of attributes allows us to store critical information about the fragility, vulnerability and damage-to-loss models, including development methodology, list of damage states, parametric model, uncertainty in the probability of loss ratio, hazard intensity, and asset taxonomy. These attributes will be fundamental in upcoming METEOR activities to properly propagate the aleatory and epistemic uncertainty in all of the components of the loss assessment. Furthermore, these attributes are compatible with the data currently being used to store, manage and display fragility and vulnerability models in the OpenQuake-platform, as illustrated below.

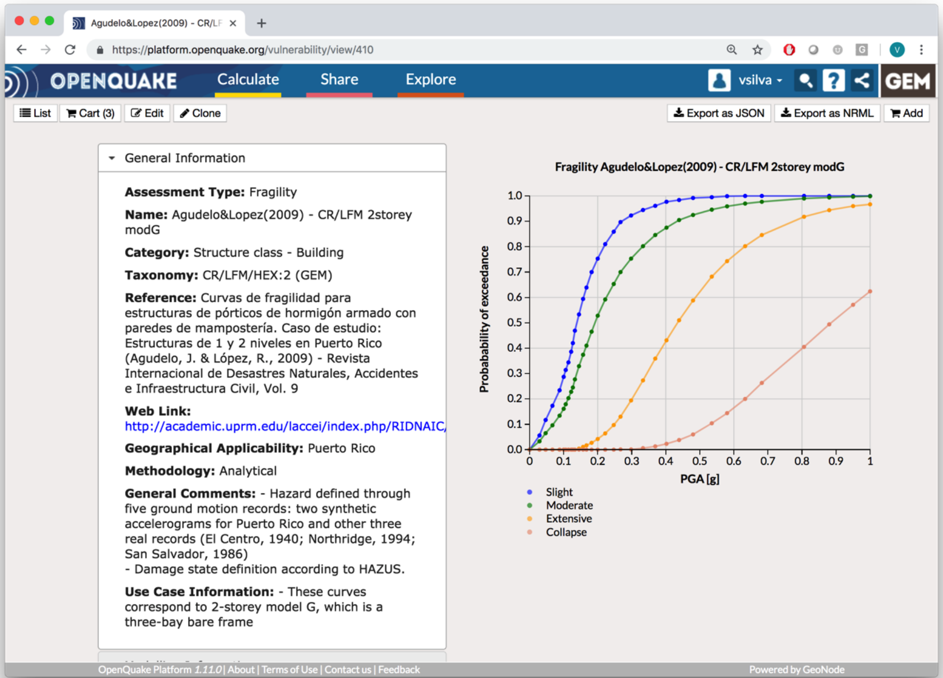


Figure 13: Graphical user interface of the OpenQuake-platform - vulnerability module

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