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Mapping seismic risk awareness among construction stakeholders: The case of Iringa (Tanzania)

Giulia Jole Sechi [a,*], Fulvio Domenico Lopane [b], Eefje Hendriks [c]

[a] Universitat Internacional de Catalunya, Barcelona, Spain
[b] Centre for Advanced Spatial Analysis, University College London, United Kingdom
[c] Geo-Information Science and Earth Observation, University of Twente, Enschede, Netherlands

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ABSTRACT

To cope with earthquakes, resistant housing is crucial. Too often essential construction techniques are not applied in the most vulnerable contexts. Local construction stakeholders have a major responsibility in reducing vulnerability of the built environment. This exploratory study investigates current seismic risk awareness in the region of Iringa (Tanzania) and discusses its implications for disaster resilience policy and practice. This medium seismic hazard risk area presents an interesting case-study to map risk awareness of key construction stakeholders. Our analysis covers seismic risk maps, governmental policy documentation and stakeholder awareness data. Data collection across 17 villages includes a poll with 21 mason and 15 school principals, and 5 interviews with a district engineer, a contractor, an architect and two homeowners. This sample illustrates the severe lack of risk awareness in Iringa. Our evidence reveals limited risk awareness across all community-based stakeholders, including absent risk awareness of local masons. High risk awareness was found in national governmental policy documents. We conclude that local seismic risk awareness is influenced by: (i) absent structural building codes that consider seismic forces, (ii) lack of risk communication campaigns by the government or NGOs, (iii) and limited freedom of speech linked to natural hazards. Our findings advocate for enhancement of risk awareness by: (i) development of a Tanzanian structural building code with recommendations for seismic resistance, (ii) better risk communication strategies to bridge the knowledge gap between governmental departments and communities, and (iii) exclusion of natural hazards from the list of prohibited communication topics in legislation.

1. Introduction

Safe dwellings are key to reduce the mortality and financial losses caused by earthquakes [1]. Yet, despite the importance of safe designs, many communities at risk do not construct hazard resistant housing [2,3]. Especially citizens in low-income countries, living in poorly constructed dwellings, are disproportionally impacted by natural hazards [1], accounting for 93% of disaster related fatalities [4]. Among disasters, earthquakes account for approximately 56% of global disaster fatalities [5]. In the last 100 years, around 2.3 million people lost their life in a seismic event, and the majority of them were in low-income communities [6]. This illustrates that enhancing risk awareness of key-stakeholders in housing construction has been a major challenge in seismic areas around the world [1]. Furthermore, effective policies are crucial where uncontrolled urbanisation develops in hazard-prone areas and socially

* Corresponding author.
E-mail address: gj.sechi@uic.es (G.J. Sechi).

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vulnerable settings [7]. In this study, we aim to identify pathways to enhance housing safety in Tanzania by analysing governmental policies, and exploring seismic risk awareness from different stakeholders in the construction sector.

Risk awareness is fundamental, as it opens the door to discussing preparedness and working with techniques that improve housing resilience and prevent losses [8]. Governmental policies can play a pivotal role in strengthening risk awareness and construction knowledge [9–12]. However, studies have repeatedly found that both awareness and knowledge of local construction professionals and homeowners remain problematic for the safety of the built environment [13–16]. At the same time, the Sendai Framework is adamant in recognising the role of the local stakeholders in DRR (Disaster Risk Reduction) [1].

Studies have often described the gap between science and practice in DRR [2,17]. Recent literature calls to identify reasons for limited adoption of knowledge in practice [18]. Pure top-down communication has been identified as inadequate [19] and better knowledge exchange between science and practice has been recommended to enhance adoption of knowledge [2,20–22]. New decision-making spaces are currently being developed to overcome the current limitations and address an uncertain future with a multi-disciplinary and multi-hazard approach [23]. As a result, there remains a need for case study specific recommendations to enhance safety of the built environment. In this study, we explore current exchange of knowledge and seek for effective pathways to enhance knowledge adoption.

We have reasons to believe that risk awareness and hazard resistant construction knowledge might be problematic in Tanzania. While conducting humanitarian construction activities, we experienced first-hand a mismatch between scientific seismic risk knowledge and practice. Current scientific literature confirms significant seismic exposure in Tanzania (section 3.1). Similar seismic risks have led to strict building regulations in other countries. Yet, informal conversations with construction professionals revealed that seismic risk awareness was limited.

These observations motivated this systematic assessment of seismic risk awareness among key stakeholders to characterise the situation in Tanzania. The question we aim to answer is:

What is the **awareness** of key construction stakeholders of the **seismic risk** in the region of Iringa?

We then reflect upon the geophysical seismic hazard, the governmental policies and the risk awareness of the construction stakeholders, in order to understand the seismic vulnerability of the region of Iringa in Tanzania.

2. Methodology

2.1. Case study area

We first analysed the seismic activity across all the regions in Tanzania. We selected the region of Iringa because of its increased regular seismic activity in the last two decades [24], and because of the proximity of national and regional characteristics. Among the characteristics of Iringa that are close to the national average situation in Tanzania, in fact, there is the seismic risk, that is categorised as moderate [25–27]. Similarities were also found comparing the national and local data for population education level, the urban and rural split (34%/66% national; 36%/64% Iringa), education level (64% primary school completed, 17% secondary and 3% tertiary, national; 65% primary school completed, 14% secondary and 7% tertiary, Iringa) main income generating activity (41% farmers and fishermen, 20% casual labour, 14% business owners, 18% dependants, 4% formal sector salaried, national; 40% farmers and fishermen, 21% casual labour, 18% business owners, 12% dependants, 6% formal sector salaried, Iringa), wealth distribution (58% of the population in the two lowest quintiles, national; 65% of the population in the two lowest quintiles, Iringa) [28,29]. Therefore, studying risk awareness in Iringa can help to reflect upon the situation in the rest of Tanzania.

We chose to avoid areas with extreme seismic risks: in fact, in those areas, it is likely that seismic awareness is linked to frequent experiences of earthquakes. When seismic risks are moderate, the role of information and communication in decision-making is more important. The two earthquakes that occurred close to the city of Iringa (i.e. the capital of the Iringa region), for instance, happened in 2001 and 2009, with a magnitude of 4.6 and 4.5 respectively. Some respondents might have been too young to remember those events and as a result, the lack of a vivid memory or experience can enable us to reflect upon the effectiveness of information, education and communication around seismic risks.

Iringa is a rural area located in the inland of Tanzania. The north-west part of the Iringa region is primarily covered by the Ruaha National Park and the southern part has a low seismic risk. Therefore, we focussed on the populated central and northern part of the region. The region is subdivided in five districts and the selected communities are located in three of them: the municipality of Iringa, the district of Iringa and the district of Kilolo (see Fig. 4).

Communities were selected based on their accessibility by car during the pandemic, in the raining season. The housing in all communities was primarily informally constructed, which is also common to the Tanzanian construction sector. Most of the villages that we have visited are not officially or precisely mapped; even the National Bureau of Statistics [30] provides the GIS files for regions and districts and leaves empty the sections for wards, villages and enumeration areas. For instance, only 4 out of 17 communities have been part of a land tenure assessment funded by USAID and communities often do not agree on the position of the boundaries of the parcels or even the village [31]. Based on the documentation of our partners organisation IBO Italia and the information provided by the Tanzanian National Bureau of Statistics, communities are estimated to have a comparable size, ranging from 1 k to 5 k residents, and housing density, approximately 10–35 persons/km^2 [30]. In all communities the primary sources of income are derived from agriculture [29,32].

2.2. Data collection

2.2.1. Seismic risk analysis

To understand the level of awareness needed we first analysed the scientific seismic risks. To frame the East African geological context and to analyse the Tanzanian seismic risk, we collected data pertaining the location and magnitude of past seismic events, the location of faults and the values of the current estimated Peak Ground Acceleration (PGA). For replicability and methodology transferability purposes, and to demonstrate the accessibility of seismic hazard information, we made use of open-source data. Information about location, date and magnitude (M) of past seismic events has been collected from the United States Geological Survey (USGS) online repository [24]. In this paper we always refer to mb (short-period body wave magnitude) or M_L (local magnitude) when mb is not available, as they are both based on the seismogram amplitude and were designed to be consistent [33]. Fault lines data is also derived from USGS: using Finko & Liouty's shapefile [34] we collected USGS data pertaining major fault revealing the continents' geological structure. Finally, PGA data with a 10% probability of being exceeded in 50 years has been collected from the Global Earthquake Hazard Map, part of the Global Earthquake Model (GEM). PGA maps have been created by the GEM Foundation combining several maps with different data sources based on national and regional probabilistic seismic hazard models [35–37].

The PGA is one of the most common way to assess the seismicity of a region, but it's not the only one. Same PGA may also mean different earthquakes (e.g. shorter/longer in time, with/without liquefaction). Furthermore, unknown faults can be activated or unexpectedly generated, abruptly changing the risk profile of a region. The deadly 2010-11 Christchurch earthquakes, for instance, were unexpected by the local population [38] and caused by movements on unknown faults [39], which resulted in dramatic damage and losses. Seismic hazard maps and building codes are based on probabilistic methods that may fail, as they continuously adapt to a geology that is never fully predictable. For this reason, hazard maps, such as the ones based on the PGA or currently known fault lines provide a solid ground for discussions, but are a human rationalisation of natural events that may suddenly vary, uncontrolled.

2.2.2. Risk policy analysis

To understand the risk awareness and level of knowledge at a governmental level, we firstly analysed international disaster risk reduction policies. Official documents were consulted from international aid organisations and disaster risk reduction institutions, including GFDRR and UNDRR. Afterwards, we specified our search to Tanzania and East-Africa, analysing official governmental documents available on disaster risk reduction in general, seismic risk communication, and seismic guidelines in building codes.

More specifically, to assess the Tanzanian government view on the seismic hazard and the associated communication strategies we studied and examined the relevant official websites, documents and bills, including: (i) the Geological Survey of Tanzania (GST)'s website [27] which was established as a government executive agency in 2005, (ii) the latest Disaster Risk Reduction and Management Strategy 2012–2016 [40] produced by the Partner States of the East African Community to jointly address EARS, (iii) the Tanzanian 2015 Disaster Management Act [41], the (iv) 2018 and 2020 Electronic and Postal Communications Regulations [42,43], (v) the 2015 Cybercrimes Act [44], the 2015 Statistics Act [45] and the 2016 Media Services Act [46].

International and national governmental policies were collected through our humanitarian partners or provided online (or via email) by the agencies for disaster risk reduction (i.e. the Geological Survey of Tanzania [27], the East African Community [47], UNDRR [48] and PreventionWeb platform [49]), by the National Housing & Building Research Agency [50] and by the Tanzania Communications Regulation Authority [51]. The Italian [52], Indian [53] and New Zealand [54] building codes were purchased as necessary. The documentation sample focused on the documents that addressed seismic hazard, seismic construction standards, risk communication and awareness. The policy analysis was conducted identifying the phrases describing the East African Rift system, the seismic demand values, the seismic structural design, risk awareness and risk communication. We then used codes to identify the seismic Peak Ground Acceleration, the seismic zones classifications, the ductile structural details and the ductility factors used in the international building codes for a comparable seismic demand, the role and involvement of the local stakeholders, freedom of speech and the various strategies to raise or oppose the stakeholders' risk awareness. Coherencies and oppositions between codes were analysed to present the current state of the art.

2.2.3. Field research

Field data was collected using a mixed method approach between February and April 2021. This qualitative study features 5 interviews and a poll of 36 key-stakeholders.

The research team consisted of the lead researcher, an interpreter, and a member of the local NGO (IBO Italia). The latter was essential for the introduction to the relevant stakeholders. The research team was based in the city of Iringa, during the rainy season, thus the movements were restricted to a few hours driving in the directions with better roads. The visits in the 17 villages entailed several hours driving on tracks each day and a considerable effort from the research team to connect with the relevant stakeholders. Due to the Covid-19 pandemic, face-to-face interactions with the local stakeholders proved to be a challenge and the total number of participants have been limited.

The participants have been sampled by the local interpreter and the member of the local NGO; the selection was based on their

Table 1
Research questions posed during the interviews and the poll.

Data collection	Stakeholders	Research questions
Unstructured interview	1 district engineer 1 architect 1 contractor 2 homeowners	• Have you ever felt an earthquake? • Are there some seismic areas in the region of Iringa? • Is there a specific building code you use to make construction decisions (if applicable)?
Poll	21 local masons 15 school principals	• Is this a seismic area?

availability and willingness to take part, and on the reachability of their geographical location. The participants were also asked to nominate further potential contributors, as per the snowball sampling technique. Women, as expected, are very rare in the construction sector: only one mason identified as a woman and 6 school principals out of 15. The majority of respondents (36 out of 41) preferred interacting in Swahili, rather than English.

Ethical guidelines from the European code of conduct [55] have been followed, especially with regards to confidentiality, privacy of the data collected and collecting verbal consent. For example, detailed notes have always been taken by the interviewer. The questions (see also Table 1) were posed by the lead researcher and translated directly by the interpreter. In addition to the interviews, photos and videos were made to document our observations and illustrate our case study understanding. All interviews were transcribed and translated. The results have been analysed with the Constant Comparative Method [56]: labelling the significant passages of the interviews and analysing contrasts and similarities within the single interview and between the different interviews and the poll results.

2.3. Interviews

To acquire an initial deep understanding of the seismic risk perception of the decision makers in the housing construction sector, we interviewed: (i) a manager of a contractor company based in Dar es Salaam that works throughout the country, especially in the Iringa region, (ii) an architect owner of an architecture firm, based in Dar es Salaam and North Tanzania who works also in the Iringa region, (iii) an Iringa district engineer, and (iv) two homeowners with technical building knowledge, currently building a house in the district of Iringa. The interviewed stakeholders have a prominent role in decision making with regard to the safety of the buildings. The questions were aimed to investigate their seismic awareness "*Are there seismic areas in the region of Iringa?*", their past experiences "*Have you ever felt an earthquake?*" and their familiarity with policies "*Is there a specific building code you use to make construction decisions?*", when applicable.

2.4. Poll

To gain an understanding of the risk awareness on the field we travelled across the region of Iringa and we asked only one question, "*Is this a seismic area?*", to masons and primary school principals. The school principals are interesting stakeholders as they are responsible for the school's buildings safety and maintenance. In total, we reached 21 local masons of the wards of Kihesa and Nduli, in the outskirts of the city of Iringa, and 15 school principals of the villages of *Isimani, Kibaoni, Kibena, Ulete, Mgama, Msolwa, Lwato, Nyamihuu, Mfyome, Kipera, Kidamali, Tanangozi, Pomerini, Mfukulembe* and *Ibumila.* The details of the occupation of the school

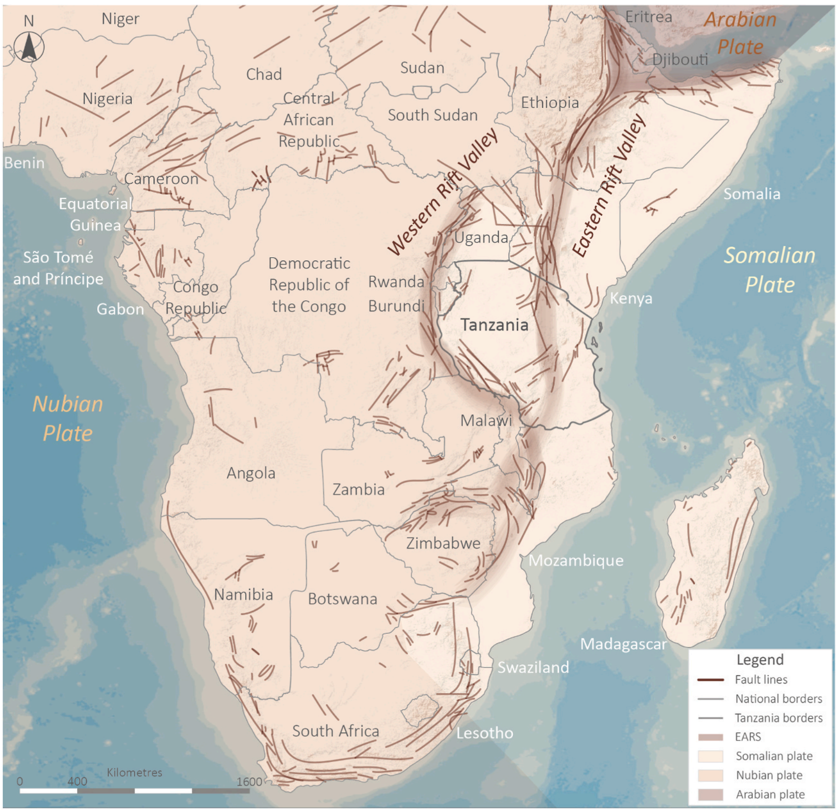

Fig. 1. Tanzania is an African country located in the east coast of the continent, in the Great Lakes region, and is surrounded by the western and eastern branches of the East African Rift System (EARS).

principals and the identity of all the participants are not made explicit to preserve their privacy. This is crucial for the respondents because of the 2020 Communication Act (see section 3.4) that limits the freedom of speech on natural calamities.

3. Seismic vulnerability

3.1. Seismic hazard in Tanzania and in the iringa region

Over the last 100 years, Tanzania has experienced more than 780 seismic events, of which around 85 have a magnitude of 5 and higher [24]. The most intense tremor ever recorded in Africa occurred in Tanzania: the M (magnitude) 7.4 Rukwa earthquake, in 1910 [24,27,57,58]. According to the USGS database [24], recently the Iringa region drastically increased its seismic activity: between 1980 and 2000, it experienced only 2 earthquakes with magnitude higher than 4 (M4 and M4.3), whereas between 2001 and 2021 an average of one M4.4 earthquake every 4 years hit the Iringa region, (with an average depth of 10 km, see Fig. 4).

These events are caused by seismically and volcanically active divergent plate boundaries in the East African Rift System (EARS) [59,60]. This is the most relevant seismic area in the African continent and is located between the Somalian and Nubian tectonic plates [61] (see Fig. 1). Tanzania is crossed by the eastern branch and surrounded by the western branch of EARS [61–65].

According to the Global Facility for Disaster Reduction and Recovery and the current literature [66,67], the seismic risk of the region of Iringa is of medium level. In fact, as reported in the website of the Geological Survey of Tanzania (GST) [27] and confirmed by extensive academic research [26,59–62,64,68], the EARS' eastern rift branch is 60 km wide and crosses the Iringa region (see Fig. 2).

Furthermore, according to the Global Earthquake Model hazard map [36], the district of Iringa falls mostly between the 0.08 g and 0.13 g Peak Ground Acceleration (PGA) area with a 10% probability of being exceeded in 50 years (see also Fig. 2). To provide a reference scale: according to the latest Italian building codes, under the same probabilistic conditions, regions with values between 0.05 g and 0.25 g are classified as medium seismic hazard areas [52]. When compared to India [53] and New Zealand [54], which are two well-known very active seismic areas, the majority of the Indian territory, and the Auckland and Northland regions in New Zealand, have equal or smaller PGAs than the Iringa region [36]. It is important to note that in those areas specific structural ductile design is compulsory according to the Italian, Indian and New Zealand law.

The local Tanzanian Government appears to be aware of the seismic risk and determined in applying a prevention strategy to mitigate it [27,40]. On GST's website, reporting their own words: "*It is important for the public to be aware of geological hazards and their impact to lives and property and importantly the possible mitigation measures affordable to a normal citizen in order to reduce risks. […]*

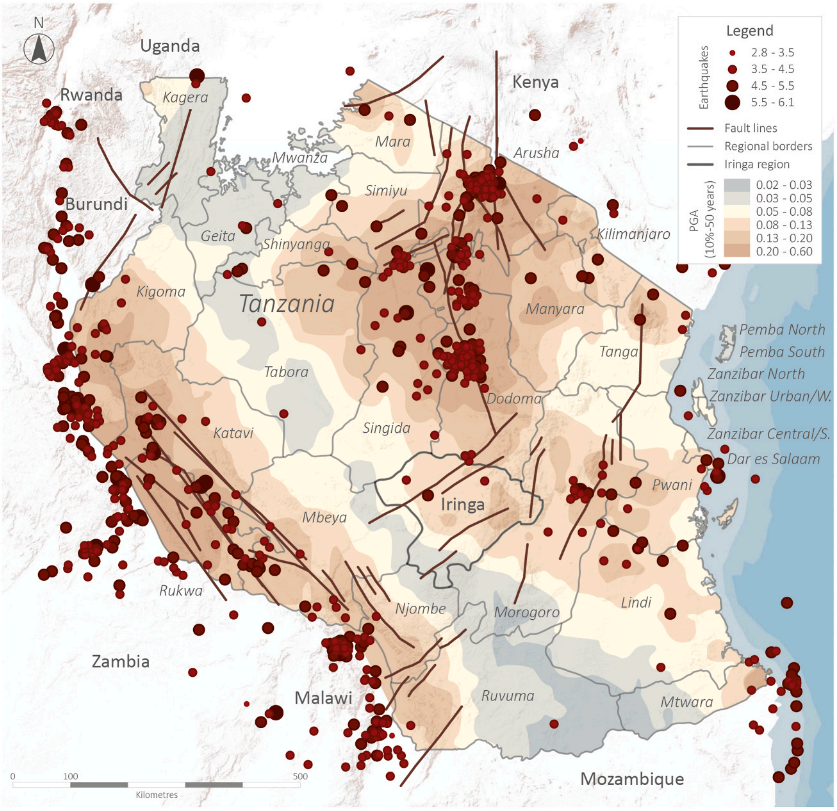

Fig. 2. - Map of the Peak Ground Acceleration (PGA) in Tanzania, with fault lines and recorded earthquakes since 1950 (data from [24]*). Tanzania is subdivided in 31 regions, which, in turn, are constituted by a variable number of districts. The Iringa region is situated in the southern highlands and comprehends the districts of Iringa, Kilolo and Mufindi, in addition to the municipalities of Iringa and Mafinga.*

Earthquakes cannot be prevented, but the damage they cause can be greatly reduced with communication strategies, proper structural design, emergency preparedness planning, education, and safer building standards." [27].

3.2. Informal settlements' vulnerability and scarce seismic performance

Despite the moderate seismic magnitude, various damaging earthquakes affected the Tanzanian population, due to the high vulnerability of the local informal settlements. For instance, the Rungwe earthquake sequence (2000/2001, maximum magnitude M4.6), damaged around 600 houses and affected more than 6000 people [65,69]. In 2002, several buildings, including the Parliament ones, have been heavily damaged in Dodoma and close to Lake Victoria by two M5.6 earthquakes [65,69]. In 2005, a M6.8 event caused several deaths in Democratic Republic of the Congo (DRC) and western Tanzania [37]. In 2016 the M5.7 Bukoba earthquake caused more than a dozen victims and 200 injuries [37,70]. Moreover, Tanzania proved to be capable of extreme seismic events, such as the largest ever recorded in Africa: the aforementioned M7.4 Rukwa earthquake [27,57,65]. Informal settlements are more vulnerable to natural hazards [71,72], because the buildings' location can be unsafe [73], the connection to services unstable [72,74] and the constructions' quality poor [72,75,76]. Tanzania is rich of informal settlements [75,77–81], where *informality* refers to scarce presence of regulations, building permits, contracts, trained masons, architects and engineers [82,83].

Informal construction has become the standard in Tanzania. Between 1990 and 2014, informal dwellers in the Sub-Saharan Africa increased of 56% [84,85] and this trend is observable in Tanzania as well. In 1995, 70% of the national population was living in informal settlements, and in 2010 more than 80% of the population of Dar es Salaam (the largest city in Tanzania and in the whole East Africa) was living in unserviced and unplanned settlements [79]. In the Iringa region, only 5% of the population has a title deed as proof of land ownership, while 31% has a letter from the village head [28]. Uncontrolled urban sprawl aggravates informal settlements' vulnerability [80] and Tanzanian urban population's growth rate is 5,2% per year [86]. Furthermore, even the formal construction sector is matter of debate for its average poor quality [78,87]: for instance, in 2006, only 8% of the registered Tanzanian contractors' employees had received formal training in vocational schools or similar [81].

Informal building typologies in Tanzania are not prepared to cope with earthquake vibrations. Different buildings' typologies have different structural elements that are particularly sensitive to seismic shakes [88,89]: such as connections for light timber frames structures or mortar quality in masonry buildings. Current typical construction techniques in the Tanzanian panorama include local versions of: adobe, rammed earth, *quincha*, burnt clay bricks masonry (see Fig. 3), sand bricks masonry and reinforced concrete [29,75,78,90]. Considering that 66% of the dwellings' walls in the Iringa region are made of unreinforced masonry [29] and, due to the absence of a local building code with ductile structural details [50,91], local buildings are characterised by low-ductility and high lateral stiffness. This aspect dramatically increases the vulnerability of the Tanzanian non-engineered constructions to lateral forces, as low-ductility attracts high seismic forces and lead to a fragile behaviour [37,92]. In Malawi's regions close to the Tanzanian borders, for instance, similar construction techniques are common and local informal settlements proved to be very seismically vulnerable [88].

Fig. 3. The local built environment: (a) typical unreinforced burnt bricks masonry dwelling; (b) building with rare RCC horizontal and vertical bands, which are an optimal seismic detail; (c) and (d) unreinforced burnt brick masonry building under construction. (Iringa, 2021).

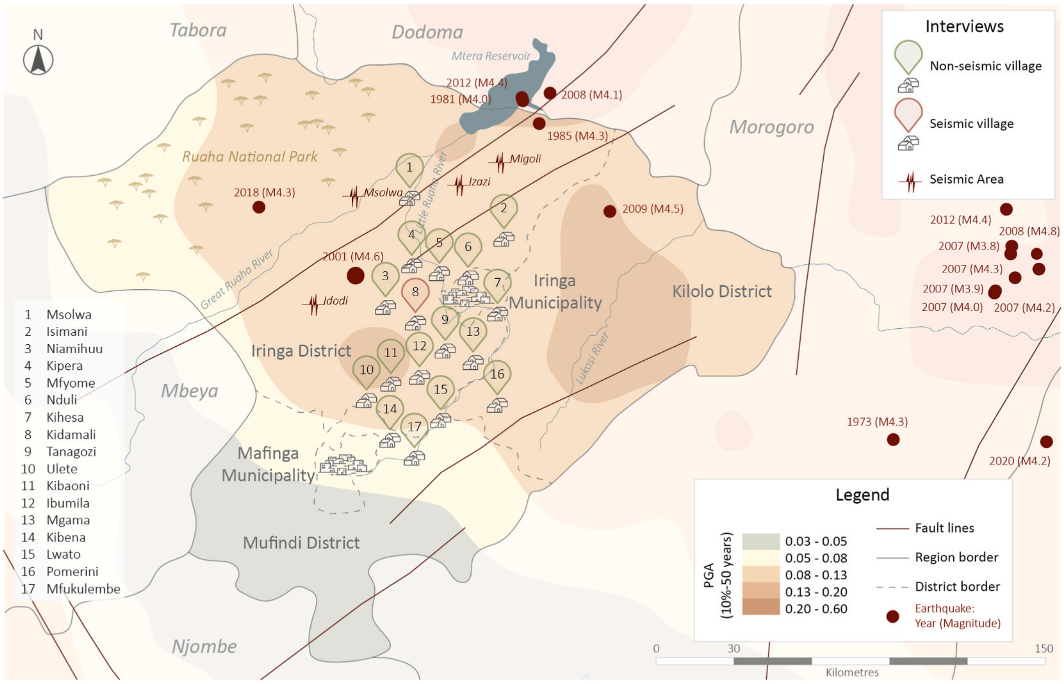

Fig. 4. Map of the findings of this research (i.e. seismic or not seismic areas, according to the results of the interviews and the poll), overlapped to the seismic hazard identified by scientists (i.e. PGA map, fault lines and past seismic events).

As a result, the dwellings and their inhabitants in the Iringa region are at risk of being severely impacted, despite the moderate profile of the seismic hazard.

A relatively low seismic local magnitude or hazard profile, in fact, should not be deceptive. Medium-sized earthquakes (between M4 and M6) in Tanzania proved to cause significant damage, mostly due to the constructions' typology and the informal settlements' quality. But even in Italy, the 2009 L'Aquila M_L5.8 earthquake [93] and the 2012 Emilia M_L5.9 earthquake [94] caused 336 victims and more than 95,000 displaced people. Despite the Italian seismic experience and the robust building code, two relatively moderate tremors exceeded the parameters set by the seismic maps and found a vulnerable setting. Seismology, in fact, is based on statistics and probabilities, and it's not predictable. Accordingly, in the region of Iringa a seismic event on the top range of the expected PGA, or higher, could strike in an inclement time and location, and find an unaware and unprepared population in non-engineered dwellings. The scientific information is available and consistent, but it is useless without proper communication and supporting policies.

3.3. Absence of seismic structural safety guidelines

The quality of the current building codes is arguable in most of East Africa. The World Bank, on a scale from 0 to 15, assigns a score of 2 to the quality of East African building regulations and of 3 to the quality control during construction in East Africa [95]. Recent research [91,96] analysed East African building codes provisions and found them overall insufficient and not consistent with the actual seismic ground acceleration. Even uniquely due to gravity loads, buildings' collapses have become dangerously common [96,97].

As claimed by the scientific literature [87,91,96,98] and confirmed by the interviews conducted in this study, a specific structural building code in Tanzania does not exist and it is common practice to build with no reference to any building standard whatsoever [91,99]. In some occasions designers may refer to foreign building codes [87,91,97], mostly the old British Standard, likely due to the fact that Tanzania was formerly a British territory.

On the National Housing & Building Research Agency website [50], some technical guidelines titled "*Loads for Structural Design*" used to be available, but at present the only accessible document is the preface. According to those guidelines, the Iringa region was in seismic zone 2, where the range is from 0 (not seismic) to 3 (extremely seismic). Zone 2 is characterised by "*Not violent, moderately frequent*" earthquakes, magnitude 5 to 6 on the Richter Scale. These guidelines appear to be retrieved as they are no longer available on the website; due to their scarce level of detail it is difficult to compare them to other standards, although the seismicity level assigned to the Iringa region appears consistent with the scientific research discussed in section 3.1.

An adequate structural building code, that is tailored on the local context and not borrowed from other countries with different architectural traditions and geological characteristics, is essential for the quality and safety of the built environment. In fact, practitioners need clear and technically solid references to design and retrofit any type of construction. The absence of a national structural building code contributes to the un-regulation of the informal settlements, prevent a controlled improvement of the structural safety of the constructions and, therefore, constitutes an aspect of vulnerability of the built environment.

3.4. Limited freedom to discuss seismic risks

Local regulations prevent the population from freely discussing natural disasters such as earthquakes, floods and droughts, on all digital channels. Freedom of speech on the digital channels in Tanzania has been subject to international and national debate for several years: despite a certain legitimate purpose, the current freedom of speech in Tanzania is deemed limited and not aligned with the principles that regulate democratic states [100–108]. Through the 2015 Cybercrimes Act [44], the 2015 Statistics Act [45], the 2016 Media Services Act [46] and the 2018 Electronic and Postal Communication Act [42] the government is able to monitor and censor social media, blogs, websites and even private messages on applications such as WhatsApp, especially with regards to events of national interest. In the last 10 years, dozens of persons have been arrested for publicly or privately expressing their negative opinion on the local government members [101]. The World Bank vehemently expressed its concern [105], as in 2018 persons were arrested to publish statistics that were presenting evidence opposed to the government official ones [102,109].

Recently, the Third Schedule of the 2020 Electronic and Postal Communications Act, under article no.8 "*Prohibited Content*", on par with bomb-making and drug production, includes [43]: "*(b) circulating or making available information with regards possible terrorist attacks, droughts, weather forecasts or occurrence of natural calamities without the approval of the respective authorities;*". This policy reveals a problematic situation for the organisations that aim to raise awareness around earthquake risks.

4. Stakeholders' seismic risk awareness

Among the 15 school principals surveyed across the region of Iringa only the one based in Kidamali mentioned earthquakes as a potential risk. All the others considered the area where they live as not seismic. The school principal based in Kidamali also mentioned having experienced a low intensity tremor in the last years and was concerned about the structural safety of the school's buildings. The tremor they mentioned most likely is the M4.6 event dated August 26, 2001, whose epicentre was only 30 km far from Kidamali (see Fig. 4).

None of the 21 surveyed local masons and of the 2 homeowners considered their working and living areas as prone to seismic hazard. Therefore, at the community level the seismic risk awareness is close to null.

During the unstructured interview, the architect advised that "*only the north part of the country is seismic, where the rift valley is*", mentioning "*Dodoma, Arusha, Kigoma, Kagera and Mwanza, the surroundings of Lake Victoria and Mount Kilimanjaro*" (see Fig. 2). Furthermore, according to them, the seismic demand should be considered in the structural design "*only for buildings that have three storeys or more*". "*The most used building codes are the British Standards, followed by the Kenyan and the Ugandan ones*".

Similarly, the contractor advised that "*Iringa is not a seismic area. So there are no special building codes. It's an earthquake free area, unlike Dodoma"* (which borders with Iringa on the northern side)*, "and north Tanzania*". In their experience, they have never been asked to implement any specific seismic details, in any Tanzanian region, even when they work in the north: "*it's not a common thing here*".

Conversely, the district engineer advised that in the district of Iringa the wards of "*Pawaga, Idodi, Izazi and Migoli are considered seismic, because they are within the great rift valley*" (see *Seismic Area* in Fig. 4). Although they did feel the 2001 M4.6 earthquake, when they were in secondary school in the municipality of Iringa, the latter was not listed in the seismic areas. The district engineer also shared that in that occasion a friend of theirs, scared by the tremor, jumped from the first-floor window and broke their legs. Furthermore, "*we normally use the British Standards* [110] *or for seismic design the Eurocode 8* [111]", the latter only in the northern part of the Iringa region.

Proceeding with the key actors' perception examination, the Government's position is straightforward in including the whole Iringa region among the areas crossed by the eastern branch of EARS: "*the East Rift System which is about* 60 km *wide extends from north-east through Mara, Arusha, Manyara, Singida, Dodoma and Iringa regions"* [27]. As outlined in section 3, the Government's documentation [27,40,41] clarifies that the region of Iringa requires adequate preparedness at the community level and structural design at the engineering level.

At the national policies level, the Disaster Management Act [41] establishes that the Tanzanian Disaster Management Agency is the entity responsible for the DRR management and coordination, including the formulation of policies and plans, and the knowledge promotion for risk public awareness. Its structure branches down to the villages' level, where a Village Disaster Committee shall include three religious representatives, two private sector representatives, one NGO representative, one Red Cross or similar representative and two prominent persons of the village. Their function is to raise awareness and implement DRR measures. Through the 2015 Disaster Management Act the Government of Tanzania clarified roles, responsibilities and internal structure of the entity accountable for the whole cycle of DRR management, including funding."

At the international level, the East African Community (EAC), which includes The Democratic Republic of the Congo, the Republics of Burundi, Kenya, Rwanda, South Sudan, Uganda, and the United Republic of Tanzania, in 2012 produced a framework [40] to jointly address the natural and human-induced disasters that affect their region. The starting point of this framework is an acknowledgment that the resources and capacities to prevent and respond to a disaster of the individual countries are insufficient, and that the general public risk awareness is low. This joint document presents the current hazards (including earthquakes) affecting the region and the associated strategic actions to be pursued: educational programs to raise awareness are repeatedly mentioned, as opposed to building codes whose role is neglected. There are clear references to the Hyogo framework [110] and it appears the level of awareness of the risks and of the potential coping strategies is present, although the quality and the level of detail of the framework is far from the Hyogo and Sendai ones.

As a result, as we analyse the official governmental position and we travel across the layers of the society down to the community level, the seismic awareness appears to gradually reduce. While the relevant national agency recognises the importance of seismic awareness in the disaster risk reduction cycle and calls for action, the construction actors (i.e. district engineers, architects, contractors and masons) are less and less aware of the seismic risk affecting the areas where they work and live. At the bottom of the ladder, we find the school principals and the homeowners, whose seismic awareness is close to null.

5. Discussion

5.1. Comparing scientific seismic risks and awareness

Even the most knowledgeable stakeholders have insufficient risk knowledge:

Our results reveal that the risk awareness of the district engineer is high, although not completely correct. The wards that they defined as seismic correspond quite well to the areas with a higher PGA and crossed by an active fault (i.e. the northern part of the Iringa region). Nevertheless, surrounding wards were not considered seismic by them, although from a geological point of view they are due to wave propagation. As a result, seismic provisions in the buildings design are not applied consistently in the Iringa region. We think that his academic engineering background has allowed him to gain access to risk maps and his connectivity to governmental departments has given him possibilities to better identify risks.

Despite highly vulnerable position, the seismic risk perception is low:

In Fig. 4 our findings are mapped against the active fault lines, the Peak Ground Acceleration map and past seismic events. Some villages, such as Kipera, Isimani and Pomerini are less than 10 km away from an active fault line, while Msolwa appears to be situated precisely on a fault line. Despite their critical location, the interviewed school principals had no perception of the seismic risk. Nonetheless, fault lines' exact location can be imprecise. Thus, we consider the comparison with past seismic events and the PGA map more meaningful.

Most of the area subject to our investigation has an estimated maximum PGA of 0.13 g or higher, which, according to international standards (see section 3.1), requires ductility in the structural design that is not currently provided. The epicentre of the 2001 M4.6 earthquake, which was only 10 km deep, was around 25 km away from the villages of Nyamihuu, Kidamali and Kipera. Nevertheless, Kidamali was the only village mentioned as potentially seismic by the school principal. Other villages with a similar distance to the earlier 2001 earthquake were not considered seismic, including Nyamihuu and Kipera. The same earthquake was personally felt by the district engineer in the city of Iringa. Based on our data, we have identified a problematic disconnection between the actual seismic risks and the awareness in communities. While the district engineer could play a potential role in enhancing the risk awareness within the district, we claim that the potential causes of the lack of awareness reside in the current policies.

5.2. Scarce seismic risk communication and policies

The government clearly constitutes a repository of sound scientific knowledge and includes Iringa in the regions that require special attention for moderate seismic risk [25,27], but it appears that the key intermediary stakeholders (e.g. architects, engineers, contractors and masons) have an incomplete understanding of the natural hazardous areas and, consequently, they can hardly be effective risk communicators.

The Sendai Framework [1] provides clear guidance that well applies to the case subject of this study: (i) each State has primary responsibility on DRR strategies and local stakeholders have a major role in reducing the risk, (ii) policies and practices are critical in the prevention phase, which is essential to not rely only on disaster response and recovery, (iii) DRR information should be publicly disseminated and regularly reviewed: communities at risk should be aware, (iv) risk communication campaigns to promote a culture of disaster prevention are strongly suggested. According to our results, the above indications are not followed by the current Tanzanian policies. Their adoption could greatly reduce the disaster risks.

5.3. The need to explore communication strategies

Overall, it is apparent that in Iringa there is a miscommunication issue and that relevant information has not permeated all the layers of the actors in the DRR field. This finding aligns with other studies that have identified knowledge gaps between science and practice [17,22,111,112]. This has an immediate and concrete impact on the quality of the buildings in the Iringa region, on the resilience of their communities and ultimately on numerous human lives. We therefore call for urgent and widespread seismic prevention and effective communication strategies to raise the awareness of the technical practitioners and of the local communities in the Iringa region. As the geological government agency suggests [27], TV and Radio programs can greatly help in reaching the local communities and spreading DRR concepts. Trained construction stakeholders could work to informally bridge the knowledge gap, transferring and applying sound information.

5.4. The need of a building code

Furthermore, the absence of a local building code [91,96] hampers the practitioners daily work and makes their acknowledgment of the seismic risk more difficult. Our study corroborated the findings outlined in section 3.3, and we hereby call for adequate Tanzanian building standards, that refer to the actual geographical areas and not the British or other countries' territory. The structural building code could guide practitioners in understanding which areas require attention and in designing buildings with adequate ductile capacity. The building code could follow the development of the EARS over the years, guaranteeing an up to date and reliable support. In fact, seismic building codes are often updated after major devastating seismic events. In this case, a proper regulation could be established and enforced before such an event occurs and it could limit the damage and losses.

5.5. Call to lift bans on risk communication

We have found that top-down communication of the seismic risk is limited to absent. At the same time, also bottom-up communication of risks seems to be limited, as it appears that the local communities do not express themselves much with regards to the past seismic events that they may have experienced. Our interpretation of the scarce seismic risk perception of the locals, despite the quite frequent local seismic activity, is that the strict regulations outlined in section 3.4 influence the communication within the communities on a deep level, into the fabric of the society. Prolonged restricted internal communications could have affected the local communities' perception or interpretation of the items that were "undiscussable" as not formally acknowledged and approved by the government. The local authorities' position, in fact, has always been that the population opinion should follow the official mainstream one. And this is the reason why various international organisations like Human Rights Watch [109], Amnesty International [106] and The World Bank [105] have questioned human rights in Tanzania. If the population is not officially allowed to talk about something, they can hardly acknowledge it. Especially now that natural hazards are explicitly included in the prohibited topics, this oppressive environment jeopardises DRR strategies that are based on the communication of natural hazards to raise awareness and preparedness.

In fact, considering that the geological national body (GST) is transparently and unquestionably calling for more seismic awareness and preparedness at the community level, also through TV and radio programs designed by the government [27], it appears that the heart of the matter are the national communication regulations. Therefore, we advocate for the deletion of weather forecasts, natural hazards and droughts from comma b, article 8 of the third schedule of the 2020 Electronic and Postal Communication Act [43], to ensure they can always be freely discussed and DRR strategies can use digital platforms to raise awareness and increase the resilience of the local communities, also when not formally approved by the government.

Furthermore, it is important to be aware that it is a privilege to be worried about seismic risks; low awareness at the communities level may be caused by the difficulty of the locals to be worried about an additional geological aspect, that only manifested in a moderate magnitude in their area. Prevention is key in disaster risk reduction, but it can be perceived as a luxury when compared to the daily struggles of secure livelihood. Nevertheless, we might not know exactly where or when, but it is certain that earthquakes in seismic areas will occur in the future. Adequate policies and prevention could save lives and reduce damage to the infrastructure. Therefore, our perspective as engineers could be far from what the local communities feel as priorities, but we see there is a responsibility for scientists and humanitarian practitioners to raise awareness and address shortcomings in policy-making.

5.6. Further research

This study is a pilot for a more extensive systematic investigation of risk awareness in Tanzania. We recommend to study other areas in Tanzania with different seismic risks, to enable a stronger representation of the situation in the country and to study the exact role of risk policies and communication.

In this study we analysed the role of key construction stakeholders. Maybe there are other, non-construction stakeholders that could also help to raise awareness. Humanitarian organisations could potentially interact with government actors during their construction projects. They could lead by example and apply earthquake resistant construction techniques in their designs (as IBO Italia did in Iringa and Save the Children did in Kigoma). On a higher level they could work on seismic risk prevention programs, always together with the local authorities that must be authors of their change. We have observed that communities are not fully able to address their own risk awareness without interference of more risk aware actors or knowledge sources. It is valuable to investigate what communities can do for themselves. We recommend further research into knowledge networks and knowledge resources that are currently used by community-based actors. These could indicate potential pathways to raise local awareness without waiting for governmental initiatives. In Tanzania, in fact, there appears to be potential in the use of social media to reach community actors.

6. Conclusions

The Iringa region's seismic hazard is scientifically unanimously recognized as of medium level. Despite the moderate seismic profile, in the last 20 years the local population experienced an average of one M4.4 earthquake every 4 years and in the history of Tanzania medium-magnitude quakes proved to cause considerable damage.

Nonetheless, the seismic perception across the layers of society is controversial. At the governmental level, DRR activities are encouraged, but professional practitioners are only partially aware of the seismic risk and have contradictory and incomplete knowledge. At the same time, the large majority of the members of the local communities are completely unaware of living in a medium earthquake prone area. Therefore, from the top-town perspective, it appears that the relevant scientific information is not correctly flowing towards the most vulnerable members of the society, creating potentially dangerous premises. Trained construction stakeholders (e.g. district engineers, architects, contractors) could have a key role in transferring knowledge.

The evidence of scarce seismic risk perception turned the spotlights on the current policies. The absence of adequate building standards aggravates the vulnerability of the built environment, where, in any case, informal settlements have a major role. We therefore make a case for a proper, geographically specific, building code, that could support designers and include seismic ductile construction details. In fact, the latter are compulsory in other seismic countries for areas with the same PGA, such as Italy, India and New Zealand. DRR activities focused on seismic awareness and prevention, as already recognized by the national geological agency, are also deemed essential to reach the local communities and reduce the settlements' vulnerability.

Furthermore, from the bottom-up perspective, internal communication regulations limit the freedom of expression, recently also expressly on natural hazards. This crucial policy aspect may impact local awareness and preparedness, jeopardising the communities' resilience from within. We therefore advocate for the deletion of weather forecasts, natural calamities and droughts from comma b, article 8 of the third schedule of the 2020 Electronic and Postal Communication Act, to ensure that the local population can always freely discuss them.

Considering the emphasis put on the local stakeholders' awareness and involvement by the Sendai Framework, we suggest that understanding the geographical risk and analysing the awareness of key stakeholders can help to identify potential communication problems. The current Tanzanian DRR policies recognise the importance of risk communication and established an internal governmental structure to implement DRR strategies down to the villages level, although the factual implementation appears to be scarce. The quality of the adopted EAC Disaster Management framework appears to be lower than the Sendai Framework and, according to our analysis, its impact is not adequately effective. Strategic policies, such as building codes at the level of other comparable seismic areas (e.g. certain areas of India, Italy, New Zealand) and the implementation of a detailed DRR framework such as the Sendai one, are lacking. The current exposure of the Tanzanian communities to seismic disasters appears considerable; however, the adoption and application of more advanced risk awareness policies and building codes could be the first step towards a safer country.

Declaration of competing interest

There are no conflicts of interest.

Data availability

Data will be made available on request.

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