Earthquake Hazard Preparedness Index (EHPI) Mapping a Solution to Tackle Earthquake Disasters

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Billions of people inhabit Asian countries, and millions live on active faults. Most earthquake hazards are related to megathrust faults, which have caused some of the most devastating earthquake disasters in human history. No one would like a repetition of the devastation caused by the 2004 Indian-Ocean earthquake and tsunami and similar other events. The vulnerability of life to earthquakes and associated hazards will continue, and prediction remains impossible with the current scientific wisdom on the science of faulting, which has been accumulated after more than two centuries of hard work. Therefore, the challenge that hovers on our responsibilities is the possibility of large earthquakes on megathrust faults, which could prove devastating. And this challenge has not been fully explored in the past; here, we try to rekindle this critical conversation by showing the vulnerability of megathrust faults in Asia and how future earthquakes can significantly damage the highly populated and urbanized sections including the UNESCO Heritage sites. We propose the introduction of country-specific Earthquake Hazard Preparedness Index (EHPI) maps, which will rank a country's preparedness to handle earthquakes and associated hazards. The EHPI mapping will be combined with the existing earthquake hazards maps to rate the overall efficiency of dealing with earthquake hazards. The need arises from the fact that although we have spent more than two centuries understanding the science of earthquakes, we faced enormous defeat in the Sumatra-Andaman Earthquake of 2004, the Kashmir Earthquake of 2005, and other similar earthquakes events elsewhere. The devastating was not unexpected, but we had no mechanism to check the preparedness of a particular nation for such hazards. That changed the entire outlook on dealing with earthquake hazards and how to stop them from turning into monsters.

Keywords: *Earthquake Hazard Preparedness Index (EHPI), UNESCO, Earthquake,*

1. Introduction

Megathrust faults are the most dangerous fault systems on Earth, and the risks are primarily related to earthquake hazards[1,2,3,4)], which cascade when accompanied by tsunamis, landslides, floods, etc[5,6,7,8)]. These plate boundary faults occupy regions where two or more lithospheric plates interact and routinely cause large earthquakes that have remained the most destructive ones. Most megathrust faults are underwater in areas where plates subduct; therefore, such places are also prone to tsunami hazards. However, continental megathrusts also exist; one of the prominent examples in South Asia is the Himalayan megathrust fault that traverses the Himalayan foothills and has a clear topographic expression that distinguishes it from the Indo-

Gangetic plain in the south[7,8]. The earthquake events on these faults suggest many destructive earthquakes have ruptured various portions of the fault system and caused considerable damage to life and property[9,10,11,12]. Forecasting and quantifying the impending risks associated with the earthquake hazards on the megathrust faults is an ongoing mission, contributing more refined data with time. The earthquake hazards associated with megathrust faults in Asia pose an enormous risk to millions of people living on and around the faults. Although the science of earthquakes has dramatically progressed over time, involving investing more than two decades in understanding what drives earthquakes on faults, we cannot warn and save people from earthquake-related disasters because prediction is a long way to go.

Therefore, the challenge is the possibility of large earthquakes on megathrust faults, which could prove highly devastating in heavily urban regions. The critical quest about the cascading nature of earthquake disasters and that prediction will remain out of reach for coming years means our strategy must change to deal with earthquake hazards. In the past, we have exclusively used our scientific wisdom to map and understand the earthquake hazards; however, that has not changed much on the ground as most of the world is not prepared to handle large magnitude earthquakes. The challenge is not simply because the science has not reached people; it is more about what a particular nation has done to safeguard people. However, no systematic approach is currently available to map, evaluate, and grade the preparation of countries, their strategies to deal with hazards, and how well they have coped with past events. Therefore, the work presented here is a brief article that rekindles the critical conversation by highlighting the hazards associated with megathrust faults in Asia and how future earthquakes can significantly damage the highly populated and urbanized sections. We underline the earthquake risk associated with megathrust faults in Asia, where the United Nations Educational, Scientific and Cultural Organization (UNESCO) Heritage sites are located. And we take that as an opportunity to propose introducing a country-specific ranking system based on the Earthquake Hazard Preparedness Index (EHPI). The EHPI will be the first evaluation tool to rank countries on their progress toward earthquake hazards and how to live with them. The full version of our proposed ranking system will be published elsewhere because of space limitations.

2. Methodology

The earthquake events are plotted as coloured circles and superimposed on the tectonic map of south and southeast Asia. The geological structures are after Zahirovic et al.[12] with an additional fault, the New Guinea frontal megathrust fault. The megathrust faults are named (this study) to make it easy for the readers to understand the contest of the hazards posed by these faults to the regions in Asia[13] and UNESCO Heritage sites, which appear as green circles on the map. The seismological events are extracted from USGS. It was classified according to depth (km) and magnitude to represent seismic activities across this region. The heritage sites are freely available on the UNESCO website[14], and satellite maps are derived from multiple sources (shown in the bottom right of the figure). The population density layer and earthquake events are overlain on Asia's tectonic map to highlight people's vulnerability to active megathrust faults. Population density data were downloaded from SEDAC[15], and an interpolation map was generated using the point density tool and further differentiated using the symbology tool. The maps were created in ArcGIS 10.3.

We have introduced the concept of Earthquake Hazard Preparedness Index (EHPI) mapping. The goal of the EHPI is to evaluate the preparedness of countries to tackle earthquake hazards. The objectives are to map the earthquake hazards, risk, and preparedness of a nation. The mapping involves the evaluation of the percentage of the population that is prone to earthquake-related risk and what are the measures available to safeguard them. For example, the earthquake risk assessment of buildings will map the level of seismic shaking and secondary effects (such as liquefaction, landslides etc.). Ranking of the overall preparedness will use the EHPI system, and the countries with the higher index mean highly prepared, and the lowest index means not ready.

3. Results and Interpretations

The earthquake events plotted on the satellite image show the dominance of large magnitude earthquakes on megathrust faults (Fig. 1). The vulnerability of the UNESCO Heritage sites to the earthquake risk is highlighted by superimposing the sites on the megathrust faults and the earthquake events (Fig. 1). The hazard associated with the megathrust fault is evident from the data. The Himalayan megathrust fault is one of the most dangerous faults that border the frontal ranges from the nearby foreland basin (Fig. 1). The uplifted portions are north of the fault, suggesting severe shaking and earthquake-related cascading devastation can be expected in the hanging wall portions and regions near the fault. The Himalayan foreland basin, known as the Indo-Gangetic Plain, is located immediately south of the megathrust fault and could have additional hazards related to earthquake-induced liquefaction and seismic wave amplification.

Similarly, a few heritage sites occupy the hanging wall portions of the Sunda megathrust fault (Fig. 1), indicating their vulnerability to earthquake risk. Many heritage sites are located in SE Asia and relatively far off the active plate boundaries (Fig. 1), meaning less exposure to earthquake hazards. However, those sites are prone to risks associated with the other major faults, such as the Sagaing fault, the Sumatran fault, etc.[12)]

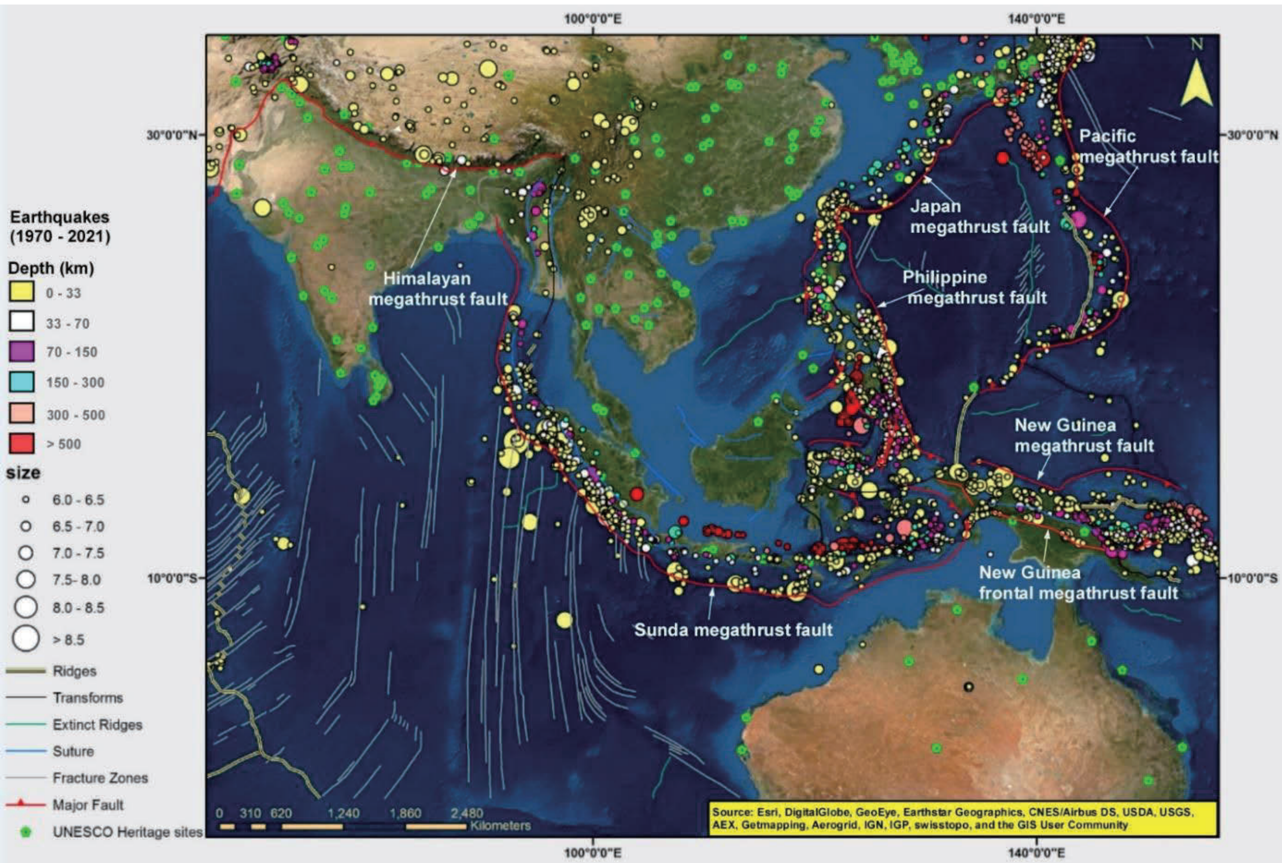

Fig. 1 The earthquake events are plotted as coloured circles and superimposed on the tectonic map of south and southeast Asia. The geological structures are after [9)] The megathrust faults are named (this study) to make it easy for the readers to understand the contest of the hazards posed by these faults to the regions in Asia and UNESCO Heritage sites, which appear as green circles on the map. The seismological events are extracted from USGS. It was classified according to depth (km) and magnitude size to represent seismic activities across this region. The heritage sites are freely available on the UNESCO website[11),] and satellite maps are derived from multiple sources (bottom right of the figure).

The New Guinea frontal megathrust fault is the plate boundary fault system that demarcates Australia from New Guinea; it is a thrust fault that verges south and poses a severe threat to the area. A few heritage sites are located in the region and are vulnerable to significant earthquake risk. New Guinea megathrust fault is the subduction zone thrust where the Pacific plates obliquely subduct south under the New Guinea region (Fig. 1). Therefore, the megathrust is south-dipping and verging North. It is the cause of earthquake hazards and poses a threat to life and property.

The Philippine megathrust fault is the primary source of high magnitude earthquakes in the region, and it traces the location where the Philippines Sea Plate subducts under the Eurasia plate. A few heritage sites are visible in the area, which are prone to earthquake hazards associated with the megathrust faults and the other faults within the upper plate. The Japan megathrust fault is the primary source of earthquakes north of the Philippine megathrust fault (Fig. 1). It dips towards the west to the northwest and poses a severe threat. Several heritage sites are located on the megathrust fault's upper plate, indicating vulnerability to medium to large earthquakes. West of the fault lies the Pacific megathrust fault, where two oceanic plates converge (Fig. 1). The fault is the source of large earthquakes in the region, and only two heritage sites are located in the area, which is prone to earthquake hazards.

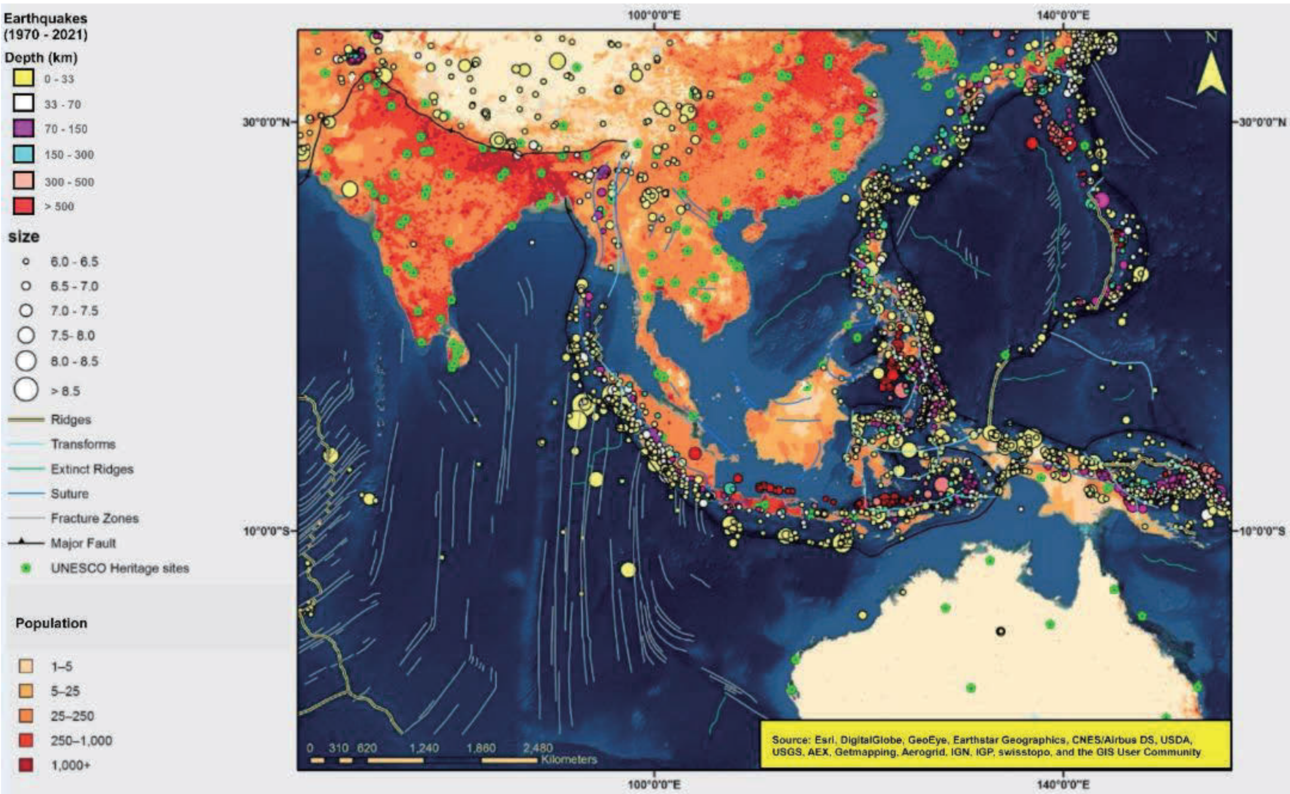

Fig. 2 The population density data are plotted on the tectonic map of south and southeast Asia, and the geological structures are after [13,15]. The earthquake events are shown as coloured circles. The UNESCO Heritage sites appear in green circles. The densely populated regions near the megathrust faults pose a severe threat to millions.

The mapping of the population density prone to the earthquake-related risk associated with megathrust faults in Asia (Fig. 2) suggests that many densely populated regions are prone to high levels of risk, for example, India, Bangladesh, Nepal, East China, and Indonesia. The megathrust fault-related hazards are enormous and could prove devastating, as suggested by overlapping the population density map on the faults. The map also shows the earthquakes in the region over the last few centuries; some caused considerable damage to human life and property and impacted other life forms, including coral reefs, etc. The earthquake distribution also highlights some significant earthquakes in regions that were not expected to rupture. The existing scientific wisdom on active faulting was insufficient to understand the cause of faulting away from the megathrust faults, and within the plate interiors, including the footwall of the Sunga megathrust region in the Indian Oceanic area (Fig. 2) that hosted >Mw 7 strike-slip faulting related earthquakes. Therefore, the existing seismic hazard maps are questionable and demand a remapping of the regions where mapping of the earthquake hazards needs review.

4. Discussion

The earthquake hazards associated with megathrust faults are of immense concern to our societies because the scale of devastation linked to these faults is enormous. The additional problems arise when earthquakes are associated with cascading events such as tsunamis, floods, landslides, and disruptions to communication and transport systems etc.[15,16,17,18,19,20,21]. Many studies suggest the possibility of large magnitude (Mw>7.0) earthquakes on megathrust faults[2,3,4,10,11]. Although the exact timing of earthquakes remains out of reach because of the complexity associated with the faulting processes, the expected scale of devastation can be visualized. The destruction associated with the 2004 M 9.1 Sumatra– Andaman and 2011 M9.1 Tohoku earthquakes reflect what such potential earthquake devastations would look like on the ground. The worst scenario could be expected because of the growing scale of unplanned urbanization and the population living in the vicinity of fault zones (Fig. 2). What is more concerning is the lack of resources, proper planning, education and outreach programs in Asia, which may prove detrimental to our progress towards winning the battle against earthquake hazards[8].

Megathrust faults are Asia's primary source of earthquake hazards (Fig. 1). The risk associated with these faults is enormous, which impacts life and infrastructure (Fig. 2). The megathrust faults traverse through the densely populated regions in Asia, which is particularly significant in countries where the Himalayan megathrust fault pierces through the highly urbanized areas with millions of people living in the vicinity of the fault zone (Fig. 2). The network of tectonic plate boundaries borders the Asian countries. These are places where plates interact and cause earthquakes and sometimes tsunamis, primarily on the megathrust fault zones (Fig. 2). The Himalayan megathrust fault zone is one of the most dangerous active fault systems in South Asia, which traverses through many countries such as India, Pakistan, Nepal, and Bangladesh. These countries have witnessed some of the most devastating earthquakes, and such risks will continue in the future. We highlight the earthquake risk to the UNESCO Heritage sites and densely populated regions in Asia and draw attention to the vulnerability to earthquake hazards that are mainly sourced on the megathrust faults (Figs. 1 and 2). The motivation is to use the mapping as an opportunity to emphasize the need for site-specific investigations to produce high-quality vulnerability maps for entire Asia and beyond.

We demonstrate that earthquake risk is not just associated with megathrust faults but also with other seismogenic sources, which are mainly within the plates. All are not shown in Fig. 1 because of the scale limitations. Therefore, the earthquake risk in Asia is substantial, most of which is associated with megathrust faults (Figs. 1 and 2). The previous works have shown that megathrust faults can produce 'great earthquakes' of magnitude 8.0 and above. Two examples are cited to highlight the impact of such events on life and property, The Mw 9.1 Tohoku earthquake of Japan (2011) and the Mw 9.1 Sumatra-Andaman earthquake of Indonesia (2004). Together, these two caused an unfortunate loss of >250,000 people and a loss of >US$210 billion to the economy[16, 17, 18], and an unknown loss to other forms of life like corals etc.

The science of earthquake occurrence along the plate margins is well understood, and the risk of living in the vicinity of earthquake hazards has been communicated[19, 20, 21], but a lot of work is still needed to impact ground realities[20, 21]. Our time may be running out, but we can learn from the available scientific wisdom that suggests plates interact and cause strain to build up in the crust, which usually gets released during seismic events. The interseismic periods are the quiet periods when rocks are strained, which causes deformation at micro to megascopic scales. Therefore, the interseismic periods can be longer or shorter depending on the fault behaviour, how strain is distributed in the crust's brittle portions, etc. These periods should be used as an opportunity to make preparations for the expected earthquakes. Such initiatives have not started in many parts of Asia, which suggests an immediate need to relook at the earthquake hazards and map the level of preparedness rather than just mainly focusing on the earthquake and associated risks. Therefore, we suggest and emphasize that Earthquake Hazard Preparedness Index (EHPI) mapping should be made a compulsory exercise for regions located on and near the active fault zone, particularly for the areas in the vicinity of megathrust faults.

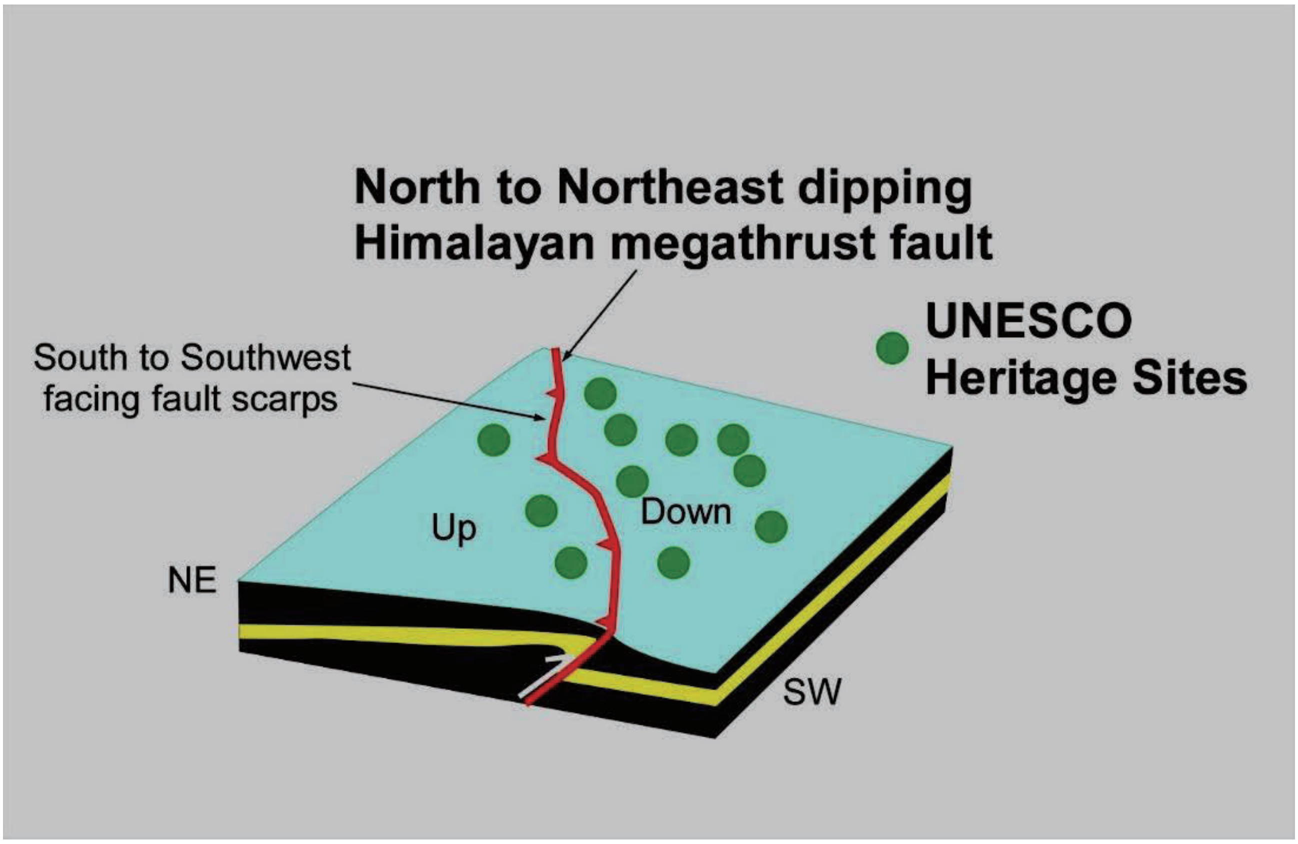

Fig. 3 The 3D cartoon illustrates the earthquake risk associated with the Himalayan megathrust fault to the UNESCO Heritage Sites. The fault block causes uplift in the hanging wall portions, which are more vulnerable to shaking because of the vergence of the fault. However, the earthquake-induced shaking can be felt near the fault zone, including the hanging wall and footwall portions

The rationale behind our suggestions is the lack of EHPI maps in any part of the world. Earthquake science is more than 200 years old, yet we lack a map that can quickly inform people of the level of preparedness in a particular region and the various risks. These maps can effectively reduce our ambiguities about hazards and focus our efforts on addressing the issues related to earthquake hazards and the cascading events that often involve complex problems associated with a significant seismic event. Therefore, we suggest introducing a country-specific ranking system based on the Earthquake Hazard Preparedness Index (EHPI). The EHPI ranking system will rank a country's preparedness to handle earthquakes and associated hazards. It will be an easy tool for people to know the risk of living in a region and the administration's steps to reduce the risk. It will create healthy competition globally as more countries would like to score higher on the index. The high index achievers should be awarded annually, which will plant the seedlings of competition for good, just like the university ranking system. The EHPI mapping could be combined with the existing earthquake hazards maps to rank the overall efficiency of dealing with earthquake hazards. We will outline the complete conceptual model in a full paper that we plan to finish in a year or two. Therefore, the present report is the first step towards that goal.

The need for the EHPI mapping is particularly significant for developing nations where hazards threaten people and ailing economies and turn an ordinary risk into a disaster. The mapping, evaluation, and ranking will highlight the measures taken up by a particular country to safeguard life and property from earthquake events. Therefore, even within a country, different parts of the state may compete to score better, which will become a tool for the safety and welfare of all states. We understand that such an exercise will need enormous work and cooperation between countries, which is only possible by working under one goal; safeguarding people from the earthquake and related hazards. The fact that megathrust faults cross-national and international political boundaries mean that international cooperation is critical to fulfilling the goals of the EHPI mapping exercise. Such collaboration will also enhance the flow of international scientists across the nations, which is another essential component of mapping and understanding hazards along the megathrust faults. The international teams could facilitate the cooperation to build earthquake-resistant infrastructure, which has remained an uphill task in most of the world, particularly in developing nations. Many countries in Asia, such as India, Pakistan, Bangladesh, Nepal, Indonesia, etc., still struggle to build a competent building infrastructure that can resist earthquake shaking and related hazards. Therefore, ranking countries is the best remedy to move forward and compete for good.

5. Conclusions

The work presented here is a brief outlook to highlight the dangers of living near megathrust faults. The earthquake risk is enormous in Asia, as megathrust faults can produce large earthquakes. The location of the UNESCO Heritage sites and the densely populated regions on the megathrust faults is worrying and suggests an immediate need to work on the ground and prepare for any kind of an eventuality expected manly on the megathrust faults. The need to have site-specific seismic hazard mapping is a must. There is a greater need to develop earthquake hazard preparedness maps and rank countries based on the earthquake hazards and the earthquake preparedness maps. Therefore, we have suggested a country-specific ranking system based on the Earthquake Hazard Preparedness Index (EHPI); the EHPI ranking system will rank a country's preparedness to handle earthquakes and associated hazards. It will use the existing steps taken by a government to address the earthquake and related risks and their position for the incoming challenges related to megathrust and other active faults. The EHPI mapping will prove a robust database to quickly access the country's progress towards safety and welfare from earthquakes. Therefore, it will be a handy tool to work on multiple fronts to map a nation's overall progress. It will also initiate health competition to perform better, positively impacting the overall safety from earthquake disasters.

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