Risk of earthquakes in Sri Lanka

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ABSTRACT

Generally, earthquakes are experienced near geo-plate boundaries but there is a possibility of earthquakes occurring away from plate boundaries. Sri Lanka is situated in Indo-Australian plate and away from its boundaries. Although Earthquakes are not a norm in Sri Lanka, it should be considered in terms of geo hazards. Although Sri Lanka is located well away from the tectonic plate boundaries and has been considered an aseismic country in the past, intraplate activities may lead Sri Lanka as an earthquake prone area. This study focuses on reviewing previous research findings to gain a broad understanding of the possibility of earthquakes and this can be considered as desk research to find the risk of earthquakes in Sri Lanka. Geological, Geophysical and Oceanographic researchers have revealed very interesting information regarding the Indo Australian tectonic plate which leads to the new plate tectonic scenario of Sri Lanka. Geological weak zones also make Sri Lanka more vulnerable to earthquakes. Not only earthquakes but also Tsunami should be considered because the seismic activity in Indian Ocean may lead to a tsunami and it would be a huge disaster in Sri Lanka as we had experienced in 2004. The geological phenomena occurring in the Indian Ocean and the weak geological structure of Sri Lanka provide a challenge to the geoscientists and further researches are needed to understand the vulnerability of Sri Lanka to future hazards.

Keyword : - *Earthquakes, Intraplate Activities, Risk, Vulnerability, Plate boundaries*

1. INTRODUCTION

Earthquakes are one of the geologic hazards and the main reason to trigger earthquakes are plate tectonic activities. The countries near plate boundaries experience earthquakes more than the other countries. However, there is a possibility of earthquakes occurring away from plate boundaries because plate tectonic is not the only reason to trigger an earthquake. Earthquake due to the San Andreas Fault is one of the examples.

When considering Sri Lanka, earthquake activities are not a norm. Sri Lanka, the pearl of the Indian Ocean is located precisely between the northern latitudes 050-100 and the eastern longitude 790-820, which is relatively near the southern boundary of the Indian subcontinent. Sri Lanka is situated in Indo-Australian plate and away from its boundaries. In terms of natural disaster preparedness the consideration of earthquakes are required. Therefore, the location of Sri Lanka on geo-plates, the performance of nearby geo-plates and structural combination of Sri Lanka should be considered.

This study focuses on reviewing previous research findings to gain a broad understanding of the possibility of earthquakes and this can be considered as desk research to find the risk of earthquakes in Sri Lanka. Geological, Geophysical and Oceanographic researchers have revealed very interesting information regarding the Indo Australian tectonic plate which leads to the new plate tectonic scenario of Sri Lanka.

2. THEORETICAL BACKGROUND

Introduction The earthquake which is included in the geo hazard category is the most powerful disaster and is one of the disasters that cannot be predicted early. Given below are few definitions on what an earthquake is.

“Earthquakes are any sudden shaking of the ground caused by the passage of seismic waves through earth’s rocks” (https://www.britannica.com).

Seismic waves are produced when some of the energy stored in earth's crust is suddenly released, usually when masses of rock straining against one another suddenly fracture and slip. According to the Britannica website this incident caused an earthquake.

"An earthquake is an intense shaking of Earth's surface. The shaking is caused by movements in Earth's outermost layer" (https://spaceplace.nasa.gov).

NASA also has defined earthquakes as the shaking of the earth surface but they have mentioned the reason as the movement of the outermost layer.

"An earthquake is caused by a sudden slip on a fault. The tectonic plates are always slowly moving, but they get stuck at their edges due to friction. When the stress on the edge overcomes the friction, there is an earthquake that releases energy in waves that travel through the earth's crust and cause the shaking that we feel" (https://www.usgs.gov).

USGS has mentioned that an earthquake is what happens when two blocks of earth suddenly slip past one another. Generally, the earthquake is the shaking of the earth surface following a release of energy by seismic waves from the Earth's lithosphere and collapsing of ocean plate and continental plate because of convergent plate boundaries which are associated with the most powerful earthquake. The hard rock layer on the mantle beneath the earth's surface can be defined as a geo plate, which motions by the heat convection currents.

When considering the above definitions, it's clear that earthquakes are shaking the earth's surface and there are natural reasons to trigger earthquakes. Therefore the reasons for earthquakes should be considered deeply.
The earth is made of four basic layers with a solid crust, a solid mantle, a liquid outer core and a solid inner core (figure 01)

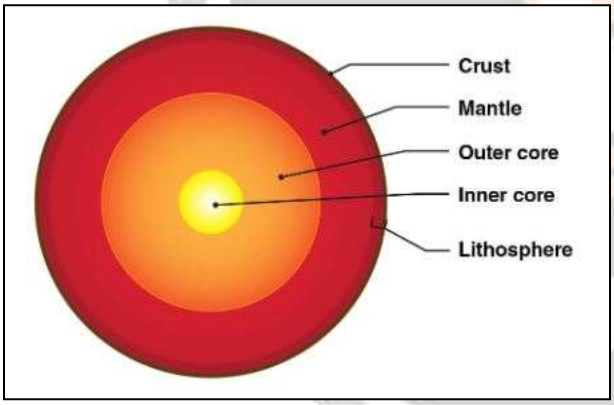

Fig -1: Earth's layer
Source: https://spaceplace.nasa.gov

The lithosphere has been made up with the solid crust and top layer of the mantle. The lithosphere is made up of pieces called tectonic plates and the edges of the plates are called plate boundaries. Tectonic plates are constantly shifting this non-stop movement causing stress on earth's crust. When the stress gets too large, it leads to cracks called faults and the plate boundaries are also made up of many faults. When tectonic plates move, it also causes movements at the faults. An earthquake is the sudden movement of Earth's crust at a fault line. Finally, when the plate has moved far enough, the edges unstick on one of the faults and there is an earthquake.

While the edges of faults are stuck together, and the rest of the block is moving, the energy that would normally cause the blocks to slide past one another is being stored up. When the force of the moving blocks finally overcomes the friction of the jagged edges of the fault and it unsticks, all that stored up energy is released. The energy radiates outward from the fault in all directions in the form of seismic waves like ripples on a pond.

There are 7 major plates and 12 sub plates, known as the oceanic and continental plates. In this way, earthquakes occur when the plates collide. Earthquakes, in particular, are caused by the convergence of continental and oceanic plates.

The starting point of an earthquake below the earth's surface is called a "hypocenter" and the location directly above the hypocenter on the earth's surface is called "epicenter" (figure 2). The seismic wave first affects this location (epicenter) on the surface. Seismic waves in the vicinity of the focal plane pass through the rocky ridges. Similarly, when the seismic waves are moving upward, they are extended from the center of the focus. Earthquakes occur most commonly in the deep zone of 500 to 720 km (Deniyawatta P., 2013)

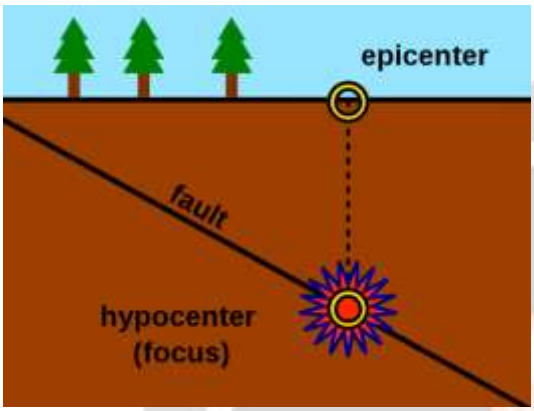

Fig -2: hypocenter and epicenter
Source: https://commons.wikimedia.org

Sometimes an earthquake has foreshocks. However, foreshocks cannot be identified till the larger earthquake happens. The largest main earthquake is called main-shock and always has aftershocks that follow.

3. THE RESEARCH PROBLEM AND THE METHODOLOGY

Sri Lanka is facing various natural hazards but still questionable "are we ready for any kind of disaster". The Tsunami incident in 2004 always reminds us that we were not ready for geo-hazard because it was a result of an earthquake which happened near Sumatra Island. Floods, landslides, strong wind and drought are common in terms of disasters in Sri Lanka but earthquakes are still an intrusive disaster. Therefore, identifying the risk of earthquakes would be helpful in getting ready to face the disaster.

To identify the risk of earthquakes in Sri Lanka, possibilities to trigger earthquakes have been considered. Secondary data collection method has been used in this study and published research on reasons for earthquakes have been considered to identify the possibilities of earthquake risk in Sri Lanka. Recent research articles and a few decades back research articles also have been referred to.

4. THE HISTORICAL EVIDENCE OF EARTHQUAKES IN SRI LANKA

Earthquakes are not common in Sri Lanka, but there have been documented incidents from the past. The first recorded earthquake occurred in central Colombo on 14th April, 1615. About 2,000 people were killed and 200 houses were damaged. It is also said that there was a deep opening on the earth (http://www.lankalibrary.com).

On 9th February 1823, an earthquake struck central Colombo and in January 1882 an earthquake was reported in the Trincomalee area. On 10th September 1938, an earthquake measuring 5.8 on the Richter scale struck the Gulf of Mannar. An earthquake in the eastern part of Sri Lanka was recorded with a Richter scale of 5.9 on 30th September, 1973. A 5.2 magnitude earthquake in the Gulf of Mannar occurred again on 6th December 1993 (https://www.researchgate.net).

The earthquake at Kirinda in May of 2011 was related to the over extraction of groundwater (W.N. Wilson, 2018). The magnitude 9.3 earthquake that struck Sumatra on 4th December 2004 has affected many coastal areas of Sri Lanka.

On the 12th of February 2020, a 5.4 magnitude earthquake which was recorded at depth 10 km in the North Indian Ocean hit the south - east coast of Sri Lanka around 2.34 am (figure 3), but there was no tsunami threat or other impact on Sri Lanka (https: // www.sundayobserver)

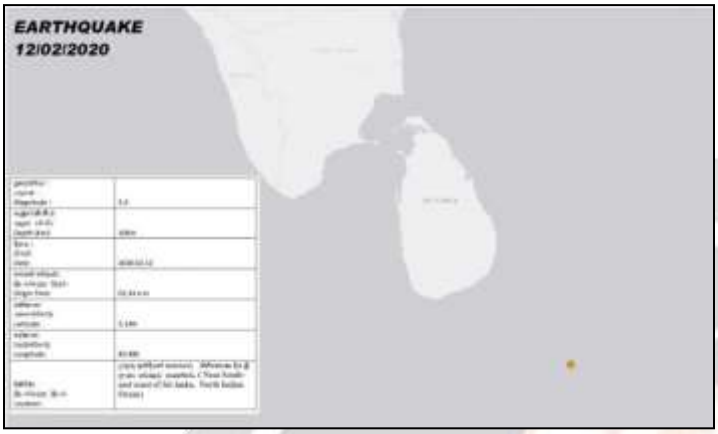

Fig -3: Earthquake recorded in the North Indian Ocean
Source: https://www.newsfirst.lk

These incidents mentioned above clearly show that Sri Lanka has been exposed to earthquakes and geological evidence should be considered for future earthquake incidents.

5. DISCUSSION

When considering the earthquake probability in Sri Lanka, its location and the nature of the location are very important. Sri Lanka is located the center of the Indo-Australian plate and far away from the plate boundaries (Figure 4). However, the area around Sri Lanka is experiencing earthquakes.

The Indian plate and the Eurasian plate collide with each other, and the region around the Himalayas in India is hit by severe earthquakes. There is also an earthquake zone in the west of India, but it is a plate divergence zone.

Fig -4: Plate boundaries
Source: https://pubs.usgs.gov

Sri Lanka is located in the middle of the plate, therefore; it does not seem that Sri Lanka has a threat from earthquakes. Even though most of the world's earthquakes occur at or near plate boundaries, there are other locations where earthquakes occur within plates (intraplate) which are significantly far from the conventional plate boundaries. The causes of intraplate earthquakes are not fully understood. The series of earthquakes which took place in New Madrid, Missouri, in 1811-12 and the 2001 Gujarat, North West India earthquake are examples of

intraplate earthquakes which caused significant destruction (https://www.geolsoc.org.uk). To study the risk of earthquakes in Sri Lanka, earthquakes that occur within the Indo - Australian plate and its intraplate activities should be considered.

In 1980, Weissel J. K. et al refers that intraplate seismicity, deformed oceanic crust & sediments and local areas of abnormally high heat flow characterize significant internal deformation of the Indo-Australian plate in the northeastern Indian Ocean. In this study the direction of principal stress axes for intraplate earthquake within the Indo – Australian plate has been identified (figure 5).

In figure 5 inward pointing arrows denote the axis of maximum compression. There can be identified the maximum compression near Sri Lanka. According to Weissel J. K. et al, intraplate compression's magnitude has been sufficient to deform oceanic into broad undulations and produce brittle failure in the oceanic crust over a large area in the northern Indian Ocean.

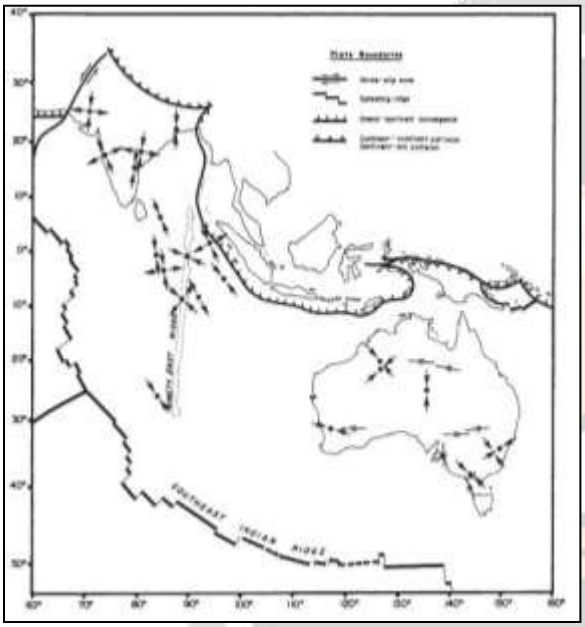

Figure 5: Directions of principal stress axes for intraplate earthquakes
Source: Weissel et al, 1980

With the intraplate stress of Indo – Australian plate, intraplate earthquakes have been experienced (figure 6).

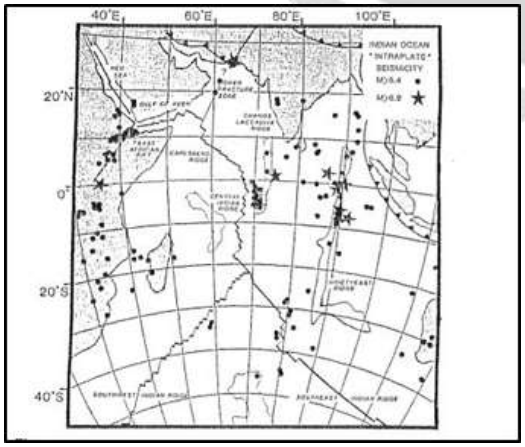

Figure 6: Intraplate earthquakes in Indian Ocean region
Source: Wiens et al, 1980

Wiens who studied the historical seismicity near Chagos in 1980 at the Indian Ocean reveals that Chagos seismicity is part of a deformation zone observed in the central Indian Ocean between the Chagos Laccadive ridge and the Nintyeast ridge which include unusual faulting and folding and high heat flow.

In 1988 Stein and Okal studied the largest historical earthquakes in the Ninetyeast Ridge area and mentioned that the ridge is presently a complex zone of deformation within the Indian plate. The Northern portion (30N - 100S) of the ridge has been identified as the active seismic zone. Therefore, the risk of Earthquakes in Sri Lanka is high with this active seismic zone. Sri Lanka is situated between Chagos ridge and Nintyeast ridge. Therefore, Sri Lanka can be considered under the intense risk of earthquake due to intraplate seismicity.

Chen J. and Zhang J. in 2007 made a detailed tectonic analysis based on the data of bathymetry, gravity and magnetics. Bathymetry and gravity maps show morphological features of many folds, which are related to the intraplate deformation of the Indo-Australian plate due to the collision between the Indian and Asian plates. They revealed that an additional plate boundary of transform fault type is developing based on the magnetic anomalies suggestions.

According to Okal in 1978 the Ninetyeast Ridge is the most prominent known example of intraplate deformation and Chen J. and Zhang J. in 2007 has determined the intraplate deformation in the Indo Australian plate near the Ninetyeast Ridge using gravity data.

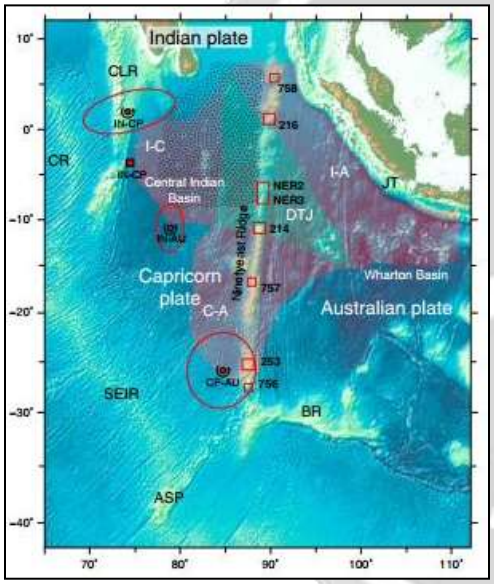

Figure 7: Ninetyeast Ridge environs and tectonic setting
Source: Sager W.W et al., 2013

The vast Indo-Australian plate in the central Indian Ocean is breaking into three smaller pieces separated by diffuse boundaries (Royer and Gordon, 1997). Shaded areas around the Ninetyeast Ridge in the figure 7 represent diffuse plate boundaries (I-C = India-Capricorn, C-A = Capricorn-Australia, I-A = India-Australia; DTJ = diffuse triple junction). Stippled zone northwest of the Ninetyeast Ridge indicates the area of lithospheric compression resulting from India-Capricorn convergence (Krishna et al., 2001, 2009).

Activities of Ninetyeast Ridge are triggering earthquakes (figure 8) and Sri Lanka also may be prone to the effects of earthquakes. Figure 8 shows epicenters from 1970 to 2012 with symbols scaled by body wave magnitude.

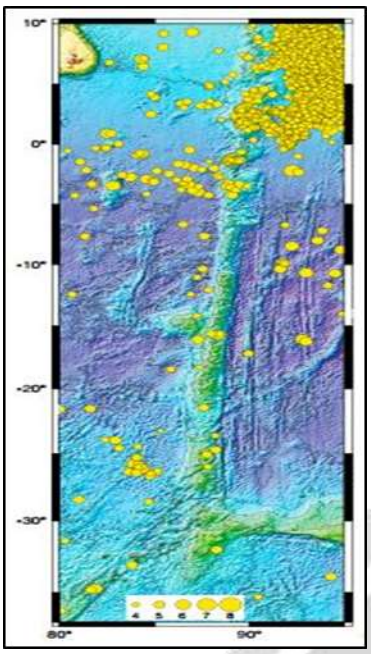

Figure 8: Earthquakes in the Ninetyeast Ridge vicinity
Source: Sager W.W et al., 2013

Bay of Bengal is one of the largest and deepest sedimentary fans of the world. Radhakrishna et al. in 2010 revealed that the sediments of the Bay of Bengal are underlain by early Cretaceous oceanic basement and two linear trending ridges, the 85° E ridge and the Ninetyeast ridges. The sediment thickness decreases progressively towards the south and also over the 85° E and Ninetyeast. In the central parts of Bay of Bengal, sediment thickness is about 8 km except for the areas over 85° E and Ninetyeast ridges (Radhakrishna et al., 2010). These two ridges divide the Bay of Bengal into three sub-basins in which thick pre-Bengal Fan sediments overlie the basement in the deeper part.

Figure 9 shows the sediment layers of the crustal section along and across the Bay of Bengal. The number three crustal sections represent the sediment layer at over 85° E and Ninetyeast ridges and Sri Lanka. When comparing the other crustal sections number three crustal sections indicate that the sediment layer is very low. Thick sediment layer may control the seismic waves and the area around 85° E and Ninetyeast ridges does not gain much help to control the seismic waves through the sediment layer and it may be a risk for the south-east coastal part of Sri Lanka in terms of earthquakes.

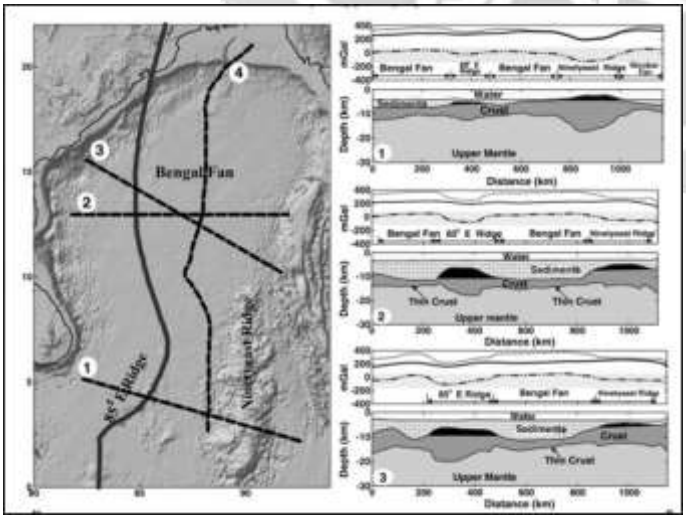

Figure 9: Sediment layers of the crustal section along and across the Bay of Bengal
Source: Radhakrishna et al, 2010

Considering all the above factors found by various studies it seems that Sri Lanka is in the risk of earthquakes due to intraplate activities.

Sri Lanka has been considered as a block within the larger crustal unit of India by Katz M. in 2000 using the tectonic models of these Precambrian events which was presented by spreading, collision, subduction, shearing or in situ jostling. According to Vithanage in 1972, separation of Sri Lanka was followed by vertical movement in Miocene which involved Lower Miocene uplift in the Central area followed by Pliocene - Recent uplift of the whole island. Katz mentioned that in 1995 westward movement of the Pacific plate and eastward propagation of rifting in the African plate lead to deformation of the Indo - Australian plate which may be reflected in the vertical uplifts in Sri Lanka and India. Sri Lanka is considered to be a part of the Southern Indian charnockitic mobile belt structurally dominated by North and Northeast trends (Katz M., 2000).

The nature of Sri Lanka inland seismicity also should be considered. Seismic activity reported within the country indicates a close correlation with the local geotectonic setup (P. Gamage & S. Venkatesan 2019). P. Gamage & S. Venkatesan in 2019 have also mentioned that a large area of diffuse seismicity located south-southeast of Sri Lanka enclosing the northern part of the Ninetyeast Ridge, could be a dominant source of strong shallow intraplate earthquakes, and could render direct threats of striking large-magnitude events in close proximity to the country.

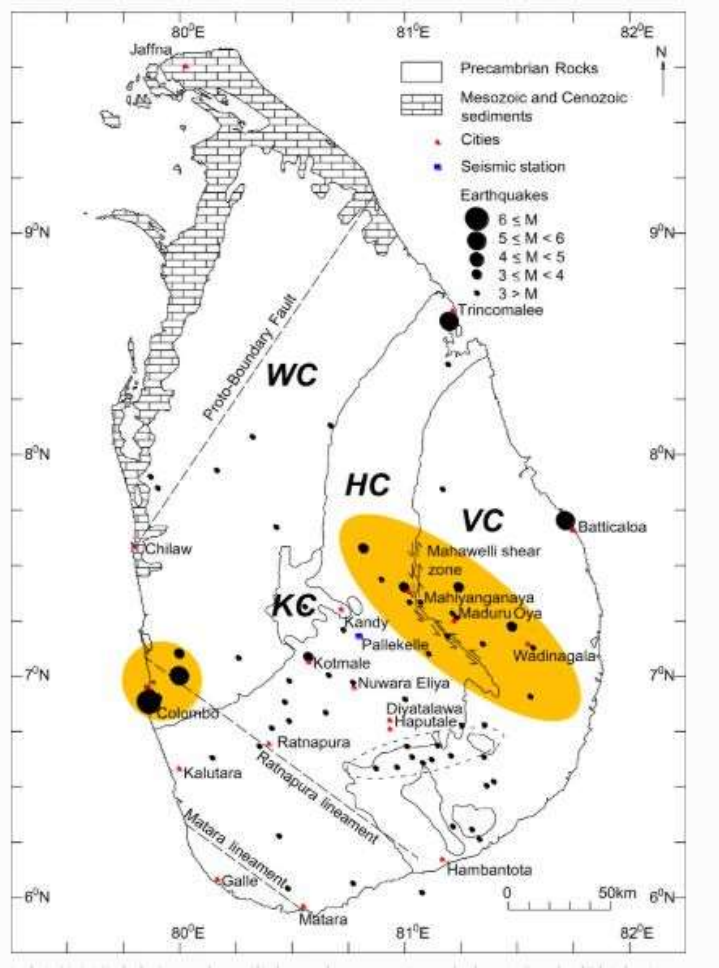

Figure 10: Local seismicity in Sri Lanka showing reported events within the country from 1500 to 2012
Source: https://link.springer.com

The highlands of Sri Lanka are abounding with faults, liniments and other geological weak zones (C.B. Dissanayake, 2005). Seismicity surrounding Sri Lanka may have an impact on these weak zones.

W.N. Wilson in 2018 has identified three reasons for earthquakes in Sri Lanka. Release of pressure on existing thrusts and folds can be considered as the first reason. This reason mainly highlighted that the stretching of rocks could have reactivated already existing weak joints. It is theoretically possible that this nature of slippage is still active along slip planes of the Highland range rocks (North- East to South-West) especially where the slope angle is high.

The second reason is dissolution of underlying limestone beds (calcite, dolomite and dolomitic marble). Limestone caves created by dissolution by water are common in the highlands and regions with invisible underground limestone caves are referred to as Karst topography regions. It reveals that the weight of a newly built construction such as a highway with heavy traffic or a building could cause the roof of an underlying cave to collapse. All these collapses could trigger small seismic activity. Some of the unexplained earthquakes in Highlands (National Atlas, 2007) could be explained as caused by these kinds of collapses.

Excessive use of groundwater causing the water table to drop below critical level has been taken as the third reason. It shows that minor earthquakes reported in the Hambantota and Ampara Districts are very likely to have been caused by the excessive pumping of groundwater through tube-wells and the earthquake at Kirinda in May of 2011 was definitely related to the over extraction of groundwater.n related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work Introduction related your research work.

4. CONCLUSIONS

Although Sri Lanka is located well away from the tectonic plate boundaries and has been considered an aseismic country in the past, intraplate activities may lead Sri Lanka as an earthquake prone area. Geological weak zones also make Sri Lanka more vulnerable to earthquakes. Not only earthquakes but also Tsunami should be considered because the seismic activity in Indian Ocean may lead to a tsunami and it would be a huge disaster in Sri Lanka as we had experienced in 2004.

The geological phenomena occurring in the Indian ocean and the weak geological structure of Sri Lanka provide a challenge to the geoscientists and further researches are needed to understand the vulnerability of Sri Lanka to future hazards.

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