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# Increasing seismic vulnerabilities for Bengal basin & the northeast India: Environmental impact of ground water depletion

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## Abstract

Earthquake is caused from tectonic activity deep inside the earth. The effect is the shaking of ground and everything on the ground resulting in large-scale devastation. The main geological feature is the fault-rupture in any direction away from the epicenter and soil stratification. Seismic hazards, the outcome of earthquake, result in slope instability, ground collapse or subsidence, liquefaction of soil base, structural destruction, tsunami etc. in the near-field, as well as, far-fields along line of faults. Seismic vulnerability analysis defines the damage prognosis in the light of potentiality of an earthquake in seismically active locations. While an earthquake at any region cannot be avoided being a natural phenomenon, the anthropogenic environmental impacts can advance the clock and increase the possibility of far major devastations from the quake. This present study, based on secondary data, tries to find the potential vulnerabilities of unrestricted groundwater extraction and the resultant increase in vulnerabilities of soil liquefaction and ground collapse from any major earthquakes passing through the traversing fault-lines, from the Northeast to the Bengal Basin or vice versa.

The convergence of Indian and Eurasian plates has developed a mountainous topography and led to occurrences of earthquakes in the region. According to widely accepted model of earthquake occurrences at this collision-plate boundary, this convergence is accommodated on the Main Himalayan Thrust Front. The detachment is the surface between the underthrusting Indian shield rocks and the overlying Himalayan rocks. Bureau of Indian Standards marked the Indian landmass into three tectonic provinces, viz. Himalayan region, Indo-Gangetic basin and Peninsular India. Four seismic zones are designated as II, III, IV and V. The peak horizontal acceleration (PHA) and spectral accelerations for periods 0.1s and 1s have shown high seismic hazard in most parts of the Northeast and the Bengal Basin. While the region close to the Bay of Bengal is placed under Zone III, the most parts of the northeast of Indian region has been placed in zone VI and a few pockets in V, the highest level of seismic hazard potential in Seismic Zonation Map of India. There have been two great earthquakes in 1897 (Shillong) and 1950 (Assam) in the region. Global Seismic Hazard Assessment Programme (GSHAP) also classified this zone under high seismic risk with peak ground acceleration values 0.35 – 0.4g. According to subsequent studies, the last major quake of $M_w$ 7.8 in April, 2015 near Kathmandu (Nepal) did not generate high-frequency waves and unzipped only a small part of the locked energy from the lower edge of the Main Himalayan Thrust Front. The Western Nepal, as well as the areas under north and northeast of India thus remained under potentially increased risk of any major quakes in future.

While the sub-Himalayan region extending from the Northeast of the country to the Bay of Bengal is seismically active, the potential vulnerabilities from earthquake for this geographical region can be anticipated from any of these two directions -

(a) Through fault-lines emanating tectonic impulse from Himalayan Thrust Front and its translation through Eocene Hinge Zone, and
(b) The quakes extending from Sumatran Subduction Trench, stretching along Lesser Sunda Islands off southern coast of Sumatra to Andaman Islands.

Geological and geophysical studies indicate evidence of seismic activity for these divergent margins where the seismic zones orient in NE-SW direction. Study of seismicity and fault planes of the past earthquakes in the Bay of Bengal region also focuses attention on deformations of the northern Indian plate. It provides evidence that the intra-plate region of the entire Bay of Bengal and peninsular India over the Indian plate is seismically active. In particularly, the Gangetic delta show higher seismicity in comparison to eastern plate boundary close to the seismically active arc of the eastern Himalayas. While the entire region is formed by sedimentary and saturated alluvial deposits of Barak–Brahmaputra–Ganga river systems, the soil deposits are soft, erratic and geomorphologically divided into fluvial plain, tidal flat, natural levee and fed by numerous channels. The soil stratum covers alternate layers of clay, silt and sand horizons.

The recent studies on the last major earthquake of Kathmandu (Nepal, 2015) showed a major contribution of groundwater extraction to trigger enhancement of the devastations. Enormous extraction of ground water, far exceeding the recharge potential, is creating formation of void space below overburden soil-stratum has resulted in the entire area of the Northeast and the Bengal Basin. Confined groundwater is increasingly under pressure due to weight of the overburden and is further pressed by piling of deep columns for high-rise concrete structures for developmental activities. The overburden pressure has been increasing below that region. Due to over-extraction, water-level of underlying aquifers vis-à-vis pore–water pressure is depressing year after year, while due to changing rainfall pattern and reducing tree-cover, the possibility of normal recharge is being restricted. These anthropogenic environmental impacts are likely to enhance the scale of devastations in the event of an earthquake episode, which would act as catalysts for large-scale soil liquefaction and structural devastations.

**Keywords:** himalayan thrust front, eocene hinge zone, sumatran subduction trench, soil liquefaction

## Introduction

The Surface deep inside the earth is broken into a number of constantly moving tectonic plates. The upper portions of the plates constitute the continents and ocean floors. The plates collide with each other due to their differential movements. The impacts of such collision results strain built-up in Earth's crust which is given way at one stage and translated from the epicenter to different directions and to the surface through the inherent fault in the lithosphere. The tectonic activities cause shaking of ground and all earth-forms. The geological features include fault-rupture in any direction of propagation in the near or far-fields. The consequent effects include liquefaction of soil base, soil stratification, slope instability, ground collapse or subsidence, structural destruction, tsunami etc. Seismic vulnerability analysis defines the damage possibility and potential of an earthquake in seismically active locations. Studying of historical data and the changing geological conditions of the region are used as tools for analyzing the seismic vulnerabilities. Bureau of Indian Standards (BIS) marked the Indian landmass into three tectonic provinces - the Himalayan, Indo-Gangetic and the Peninsular India. While the Himalayan region remains the most seismically active zone, active tectonic trends are also marked for the Bengal Basin. It is in the vicinity of three active plate boundaries *viz*. the Eurasian plate, the Indian plate, the Indo-Burma plate and two advancing deformation fronts *viz*. the Himalaya and the Indo-Burmese orogenic belts which represent intense seismic activity in the region. Seismicity of the northeastern Himalayas region results from collision tectonics between the Indian plate and the Eurasian plate. Advancement of the Indian Plate towards the Eurasian Plate is the most significant phenomenon which emanates periodic quakes, and the impacts are translated through various faults to the far-fields.

Geologically, the evolution of the Bengal Basin took place in different phases through plate movements and it remained an asymmetric polycyclic tectonic basin on the eastern margin of the Indian shield. The Indian plate moved at a velocity of about 10 cm/yr initially in the N-NE direction and collided with the Eurasian plate and then started moving towards the N-NW direction at a velocity of about 4 cm/yr. But the Bengal Basin remained tectonically disturbed for its proximity of major faults viz. Main Himalayan Thrust Front (MHT), the Main Central Thrust (MCT) and the Main Frontal Thrust (MFT) in the north and forming the boundary of the Dauki Fault and elevated Shillong plateau. The collision of the Indian plate with the Eurasian plate resulted in the uplift and the erosion of the Himalaya since the Tertiary to the Quaternary and the transportation of the eroded materials by the confluent Ganga-Brahmaputra-Meghna River system causing a huge deposition of sediments. The process still continues. The region remained under active subduction zone of the northeastern Indian plate. The Indian plate crushes with the Eurasian plate from time to time. One plate moves below the other causing subduction-zone earthquakes [2, 10]. The entire Bengal Basin continues to pose the risk of ground shaking and soil liquefaction from any plate movement or fault rupture from its northern extremity. This episode takes place repeatedly along the active Himalayan belt and Indo-Burma range. The quakes are transferred through the various faults and lineaments terminating in the Bengal Basin region. Significantly, the seismically active tectonic trends follow NW-SE and N-S flow-path and terminate into the deltaic region, extending up to the Bay of Bengal.

The Bangal Basin, together with its off-shore continuation, shrunk over time from an eastward subduction of the Indian plate below Andaman-Burmese Arc. The collision of Indian and Eurasian plates resulted in the uplift and consequent erosion of the Himalayas, which is still continuing. The transportation of eroded materials from the foot of the Himalayas down the slope evolved the basin in the northeastern-eastern part of the Indian subcontinent. It constituted the largest fluvio-deltaic, shallow marine sedimentary basin, which comprised of numerous riverine channels, floodplains and deltaic formations. The thick sedimentary deposits from this Ganga-Brahmaputra-Barak river system have sediment thickness of more than 18 km in the deeper basin zone [13]. The sediments below the surface contribute to ground failure and amplify ground motion. This increases the hazard potential during an earthquake. The compaction of sediments and depth of water-table exemplify soil-liquefaction potential. While plate-tectonics is the prime driving force behind any earthquake and studies on seismology continue in that direction, the new trend of research now concentrated on the surface and sub-surface activities like ground water extraction, underground mining, and hydro-power projects as possible contributing factors for enhancing seismic activities. The research identifies that the crustal un-loading process of ground water exceeding the recharge capacity could influence strain accumulation and modulate seismic activity beneath the causative source and in its peripheral zone that can be transferred to far-fields through the inherent faults.

**Materials & Methods**

Earlier it was considered that small magnitude earthquakes are influenced by the seasonal loading and unloading of groundwater in summer and winter. National Centre for Seismology (NCS), New Delhi identifies that “major Himalayan earthquakes are influenced by the anthropogenic groundwater unloading process in the Indo-Gangetic region. This region is most intensely irrigated in Southeast Asia. The Department of Earth and Atmospheric Sciences, NIT Rourkela brings out that around 7% of this process of anthropogenic ground water depletion has contributed to the advancement of the timing of the earthquakes in the northeast and its translation to the Bengal Basin region. The saturation level for stress is attained early due to depletion of groundwater. Researchers from National Geophysical Research Institute in Hyderabad and the National Centre for Seismology (NCS) in New Delhi, under India's Ministry of Earth Sciences have also found the connection between various surface or subsurface processes - natural or man-made -like reservoir impoundment, underground mining, and groundwater extraction can also promote long-term fault slip and modulation of seismicity advancing the clock for an earthquake. The researchers carried out a simulation study using Gravity Recovery and Climate Experiment data and hydrological models and identified, groundwater extraction in the Ganga basin modulates the stress accumulation process on the Main Himalayan Thrust (MHT), beneath the Himalayan arc where earthquakes originate. Excessive Groundwater usage in Indo-Gangetic plains results in lack of replenishment of the aquifers, leading to substantial reduction in the crustal mass. This crustal unloading causes horizontal compression and adds to the secular inter-seismic compression on the MHT.

The Indo-Gangetic plains cover around 250 million hectares of fertile plains of most of the northeastern and eastern part of

India. The crustal unloading of about 22,000 gigatons of groundwater per year distributed over the 1000-km length of the basin far exceeds the recharge. Assuming that the current rate of groundwater loss is applicable since 1960, the advent of the green revolution in India, the research estimated this crustal unloading process contributed about 7% of the secular inter-seismic stress change. The research further corroborate, the resulting stress accumulation process in the Nepal Himalaya was significantly influenced by ground water unloading, a major contributing factor for the last major quake of 2015. Ganges - Brahmaputra river systems drain enormous sediments along NW and NE slopes of the Himalayas descending to the Bay of Bengal through the delta. The eastern segment is covered by a number of NE-SW trending faults controlling the uplifting and subsiding land sculptures vis-à-vis slopes following the flow-path of the two mighty rivers and their tributaries to the delta. That apart, from the other direction, seismic impacts may be translated through the Great Sumatran fault. Sumatra, an island under Indonesia is situated at the boundary between two tectonic plates, viz. the Indo-Australian Plate and the Eurasian plate [25]. The quakes translated to South Bengal may cause major devastations in the deltaic regions and urban settlements. The devastating earthquake of 1897 caused widespread damage in the city of Kolkata. The last Tsunami of 2004 travelling through Sumatra fault devastated coastal region of Tamil Nadu and some areas of Andhra, while Bengal was not greatly affected. But the vulnerability of a high magnitude earthquake or tsunami from this Great Sumatra Fault extending to the Bengal Basin continues to be rife. The faults have the potential to divert seismic excitation from the Pacific Ring of Fire through the Alpide belt [13] extending from Java and transferring the impacts to this region.

Two possibilities thus arise in attenuation of seismic excitation into the Bengal Basin -

(a) Either through the collision of India plate with the Eurasian plate and transfer of the relieved stress through the various faults the from Himalayan belt and propagating to the Bengal Basin region,
(b) Or through the faults extending from the Sunda Trench, stretching along the Lesser Sunda Islands, off the southern coast of Sumatra to Andaman & Nicobar and subsequently to the landmass of Bangladesh, West Bengal or the entire southern coast of India.

In the event of translation of seismic impulse from any of the above two directions to the Bengal Basin, major devastation could be witnessed from widespread soil liquefaction and destruction of built-up concrete structures.

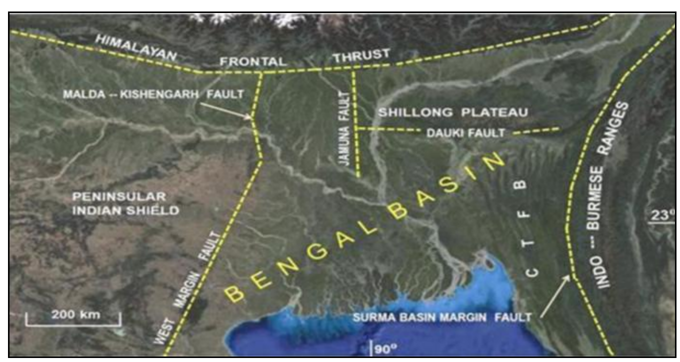
**The Bengal Basin is divided into 6 seismo-tectonic provinces**

(a) The Northeast Himalayan Collision Zone, (b) Indo-Burmese subduction Zone,
(b) Eastern Himalayan zone, (d) Shillong Plateau including Assam valley & Mikir Hills,
(c) The Bengal and Tripura Fold-belt and (f) The peninsular region.

The entire basin is under active seismo-tectonism and poses earthquake vulnerability for the whole region. It is pronounced that the most significant anthropogenic impetus for any episode of seismic excitation is the extraction of ground water, far exceeding the recharge potential in the entire region. The present study attempts to analyze the historical and lithological data to identify the potential seismic vulnerabilities of the Bengal Basin - extending from the northeastern foothills to the Bay of Bengal.

**Discussions & Results**

Geo-morphological history narrates that the Eastern Continental Margin of India (ECMI) was evolved following the Gondwanaland breakup during the late Cretaceous period (55 Ma). The northward drift of India was the result of breakup of Pangea continent and the Indian subcontinent at speed up to 20 cm $yr^{-1}$. The margin is circumscribed by rifted grabens and sags near to the shelf besides deep water basins in the offshore areas. Geological and geophysical studies indicate evidence of seismic activity for this divergent margin where the seismic zones orient in NE-SW direction. Study of seismicity and fault planes of the past earthquakes in the Bay of Bengal region focuses attention on deformations of the northern Indian plate. It provides evidence that the intra-plate region of the entire Bengal Basin and peninsular India over the Indian plate remained seismically active. In particularly, the Gangetic delta show higher seismicity than the eastern plate boundary close to seismically active arc of the eastern Himalayas. In the past, major earthquakes have taken place in many areas under the Basin. Most of these quakes were originated along the northern part. Some deep earthquakes within the Bengal fan have also had their origin from the faults from the Bay of Bengal and the Great Sumatra Fault. The quakes translated to the South Bengal and present country of Bangladesh or to the Shillong Plateau and had caused major devastations.



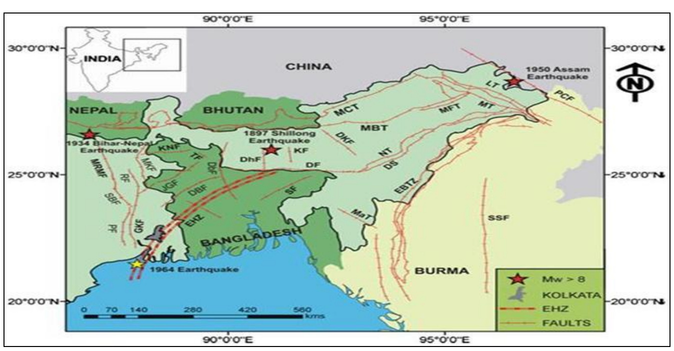

***Source***: Current Science, Vol. 109, No. 272. 2, 25 July 2015,

**Fig 1:** Satellite Image of the Bengal Basin

Several faults have been identified in the Bengal Basin region many of which show evidence of movements during this Holocene epoch. The Main Boundary Thrust runs along the southern flanks of the Sikkim Himalayas, while there are several active faults in the vicinity of Siliguri. In the north, the Bengal Basin extends up to the Himalayan Thrust Front (HTF), which is about 120km wide and pass along 2000km stretch from one end to the other of the Great Himalayas. It separates the Himalayan terrain from Indo-Gangetic Alluvial

Plains in the south. There are criss-crossing grabens and fault-lines, close to each other. The Malda–Kishengarh Fault runs north-south is the northwestern margin of the Bengal Basin, while the Garhmayna-Khandaghosh fault connects the Rajmahal Fault in the north [15, 16, 17]. The proximity of these fault lines to each other pose the danger that seismic impulses can be transferred from one fault to the other. However, proximity to faults does not necessarily pronounce translation into higher hazards as compared to the areas located further away. Damage from earthquakes depends on numerous other factors viz. soil chemistry, surface geology, the structures of the built-up installations and their engineering codes etc. [14]

Thrust movements from northeast to the southwest, that enabled the formation of Eastern Himalayas, are still in the active formative stages. The retained stress dissipates from time to time and gives vent to massive quakes in any direction along the fault lines passing through these areas. Since the massive quake of 1505 in Nepal-Himalayas, major stress continued to remain locked Himalayan Thrust Fault (HTF). Two major quakes took place thereafter, in areas close to the last quake site – in 1833 (magnitude 7.6) and 1934 (magnitude 8.2). But the locked energy was not released significantly. The next disastrous quake of April, 2015 at Gorkha region of Nepal also did not unzip the entire locked stress. The quake travelled to the north from its epicenter and could have been even more devastating, if it had travelled to the east/south-east or west/south-west directions. The ground shook back and forth once every four or five seconds, which affected tall structures - impacting much more than the massive quake of 1505. (Jean-Philippe Avouac, University of Cambridge, Aug, 2015). Vast areas in the western Nepal and north/north-east of India thus continued to remain under potential threat of more major quakes in future. That apart, another fault line, the Eocene Hinge Zone (EHZ) runs through the Bengal Basin from the northeast to southwest. In the north, it extends to Mymensing of Bangladesh and enters Myanmar. Significantly, this fault-line is not located on the edge of any tectonic plate and has not experienced any major quake in recent times. Studies however predict, this EHZ may become hyperactive at any time and trigger an earthquake of magnitude of 6 or higher.




*Source*: Map-Survey of India, Illustrations-Author

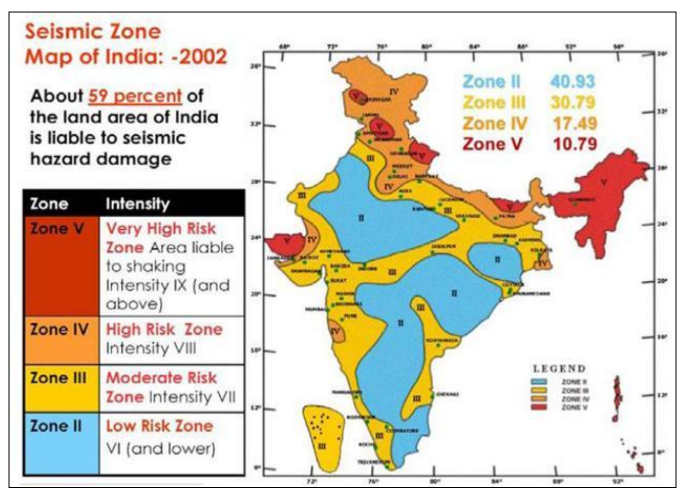
**Fig 2**

The other major fault systems of this region, viz. the Pingla Fault (PF), Jangipur - Gaibandha Fault (JGF) and Debagram - Bogra Fault (DBF), all extend along the margins of Bengal Basin. In the consequence, any seismic impulse emanating from the eastern Himalayas may channelize the impacts cascaded through these faults to the EHZ. Inversely, these faults may be excited in case of any seismic impulse to the EHZ from the Bay of Bengal region, which may extend up to the eastern Himalayas.

From the other direction also, seismic impulse may be translated through the Great Sumatran fault. Sumatra is at the boundary of two tectonic plates. The ocean floor southwest of Sumatra is part of the Indian/Australian plate, while Sumatra and the other islands of Indonesia form part of the Eurasian plate. The two plates meet on the ocean floor at the plate boundary, about 200 km off the western shore of Sumatra and about 5km below the ocean surface. This fault-line forms the boundary between Indo-Australian Plate and Eurasian plate and is called the Sumatran Subduction Trench. The oceanic Indian–Australian plate is slowly subducting under the continental Eurasian plate at a rate of about 4.5 cm $yr^{-1}$ [6, 10]. This subducting plate eventually sinks down into the earth's mantle, while at the mid-ocean ridge further west, new ocean floor is added to the plate. The vulnerability of high magnitude earthquake or tsunami remains rife from this Great Sumatra Fault extending to the north and stretching to the Bengal Basin. The fault has the potential to divert seismic vulnerabilities from the Pacific Ring of Fire into this region and inflict much more devastation than the last major quake of 2004 [10].

**Seismic vulnerabilities of the Bengal Basin region**

Magnitude of an earthquake is proportional to the energy released. It may attenuate or amplify as it travels and spread over larger region. **S**eismic vulnerability defines the loss as a function of seismic excitation. When an earthquake causes the ground to shake at a frequency that matches the pitch of shaking of the structures, it amplifies and results in collapse of the structures and other installations to the ground or the underground utility services.




*Source*: Seismic Zone Map of India as per I.S. 1893, Part-I, 2002

**Fig 3**

BIS marked (I.S. 1893, Part-I, 2002) [1] the Bengal Basin under Zone VI and zone III vulnerability status with a few pockets falling under zone V, the highest seismic vulnerability-prone areas. These areas are susceptible to suffer collateral damage from both far and near-source earthquakes. The degree of damage of the structures is influenced by the properties and type of rock, soil deposits, tectonic and geomorphologic features. The last major quake of 15-04-1964 of magnitude 6.4 in Richter scale was located over the Eocene Hinge Zone (Sagar Island, 120km off the city of Kolkata). The chemistry of soil layers up to a depth of 30m are very important in modifying the earthquake shaking and soil liquefaction potential. The geomorphologic setting of the Bengal Basin is over thick sedimentary and saturated soil deposits of the Ganga-Brahmaputra river system. The soil deposits are erratic and divided into fluvial plain, tidal flat, natural levee and numerous channels. There are mainly three zones in this sedimentary basin -

- the western shelf zone,
- the central hinge of shelf, called the Eocene Hinge Zone (EHZ) and
- The deep basin part in the east and southeast, opening in the Bay of Bengal.

Of these, the most prominent tectonic feature is the NE – SW trending EHZ. The basement of Bengal Basin plunges 4 to 10km, at some places even more, across the EHZ. Major areas of the human settlements and developments are located on the western part of the hinge zone. The thickness of sedimentary deposits varies significantly from shelf-area in the west to the deep-basin area in the east. The hinge-zone and the shelf-area are traversed by many faults. The EHZ is about 25km in width and occurs at a depth of about 450m below the surface, while the total sediment thickness below the urbanized-areas is about 7500m above the crystalline basement. At any stage, a number of anthropogenic impulses may accentuate the earthquake impacts, but major devastations for the Bengal Basin are expected from the following:

**Soil Liquefaction potential**

Earthquake ground motion alters as it propagates through the soil - from the bedrock to the surface. The parameters to estimate the ground response of the earthquake are their magnitude, local geology and surface topography, length of the propagation path between the source and site and properties of the soil through which the seismic wave travels. The magnitude of earthquake, degree of shaking, and destruction potential depends on numerous factors and is proportional to the energy released. It may attenuate or amplify in its travel-path or when it spreads over a larger province. The degree of shaking of the ground depends on the matching of the fundamental frequency of ground and the structures above the ground. The degree of damage of structures in turn is again influenced by the properties and the type of rock, soil deposits, tectonic and geomorphologic features etc. The phenomenon of pore pressure building-up followed by loss of soil strength - behaving like liquid material, is termed as soil-liquefaction. The susceptibility of subsoil to liquefaction, a complex behavior of soil due to the decrease in effective stress, is also regulated by the degree of shaking. The study of liquefaction susceptibility involves many superficial features like geological, hydrological and morphological characteristics of the area and the age of deposit, drainage quality etc.

The basin region is developed over the sedimentary deposits of water-bearing permeable rock, rock fractures or unconsolidated materials like sand and gravel or the aquifers and aquitard or the zone that restricts the flow of groundwater from one aquifer to another. The sedimentary deposits are fluvial in nature and dated back to Quaternary age (1.8Ma) [28] and have the potential risk of loosening of their natural strength and stiffness of saturated soil due to shaking or other rapid loading. The soil stratum starts behaving like liquefied mass. The soil tends to decrease in volume when subjected to shearing stress and its grains tend to consolidate into denser mass. The space between soils particles get filled with water preventing them to move closer to each other. In an earthquake episode, the shaking causes the pressure to increase. The bonding strength of the soil particles reduces. The particles move apart readily with respect to each other. The buildings and other structures have a natural pitch or frequency of shaking at which they resonate. The taller the structure, the longer the period to which they would resonate. When the bottom stratum is not consolidated, the structures cannot hold their position and start inclining from their axis and collapse [17, 18, 20]. The piling structures, dams, reservoirs and fly-over, Metro or other Railway- projects, high-rise construction projects passing through the sub-stratum thus pose increasing dangers [3, 4, 5]. Commensurate building codes for earthquake-resistant constructions are generally not adhered to in keeping with the extreme situations. Spurt in developmental activities driven by urbanization and economic development also enables compromising in designs and incompatibility to the seismic demands. In case of any major quake passing through the areas, these structures are likely to pose great danger and more so, induce danger for other small structures and installations in the areas near or far to these sites also.

**Peak Ground Acceleration (PGA)**

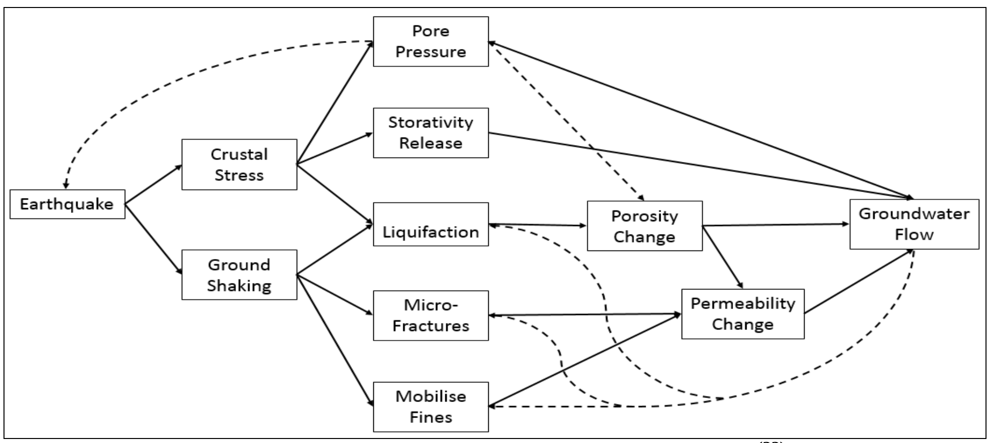
It is the measure of earthquake acceleration on the ground. PGA is important in assessing stability of buildings/ constructions and design parameters for their earthquake resistance potential. During an earthquake, the energy dissipated from the epicenter through undulating waves causes horizontally and vertically ground movement. PGA is the record of rate of change of motion (acceleration), while peak ground velocity is the maximum rate of movement/speed. The values are expressed in terms of g-force, denoting the acceleration due to the Earth’s gravity in $m/s^2$ (1g =9.81 $m/s^2$). The values depend on the length of fault, magnitude and depth of the earthquake. Deep boreholes are dug at the sites for assessment of PGA values. Simulation conditions of earthquake ground motion are created at the sites through engineering methods. The threshold capacity of earthquake acceleration is then measured at the sites for installations in the given geological set-up.[16] The PGA values for various seismic zones in the Global Seismic Hazard Assessment Program (GSHAP) Model study (1999) assessed design-PGA value for Kolkata metropolis and the suburbs as under:

| Seismic Zone | : | PGA Value |
|---|---|---|
| III | : | 0.20 - 0.30g |
| IV | : | 0.30 - 0.40g |

GSHAP also classified the Assam and adjoining region under zone of high seismic risk with PGA rising to the tune of 0.35 - 0.4g in the last 50 years. There have been incidents of two great earthquakes in the region - 1897 Shillong earthquake, and 1950 Assam earthquake. The Seismic Hazard Map of the Northeast found the PGA value of the region ranges from 0.05g to 0.6g for 10% exceedance while it ranges from 0.01g to 0.4g for the 20% exceedance in the last 50 years. These results provide alarm signals for all fast-sprawling high-rise constructions dotting the various regions and states, from the Himalayan foot-hills to the areas close to the Bay of Bengal. In the present empirical study, we would concentrate on the impacts of groundwater extraction and the concomitant effects on the Bengal Basin.

**Groundwater extraction**

The Bengal Basin area is formed primarily by fluvo-marine sediments from the Barak-Brahmaputra-Ganga river systems discharging their alluvial load down the slope from the eastern Himalayas. The deltaic plains cover alternate layers of clay, silt and sand horizons. The surface lithology exhibits quaternary sediments. While the top 30m of the sub-surface indicates softer clayey soil, the higher stratum shows more volume compressibility and relatively harder soil. The overburden pressure increases below that region. The productive aquifers occur at depths spanning of 50 - 160m, from where the groundwater is tapped indiscriminately. Simulation study using Gravity Recovery and Climate Experiment data and hydrological models (GRACE) identified groundwater extraction in the Ganga basin modulates the stress accumulation process on the Main Himalayan Thrust (MHT), beneath the Himalayan arc where earthquakes originate. Crustal unloading cause horizontal compression and adds to the secular inter-seismic compression on the MHT. The research estimates that the crustal unloading process contributed about 7% of the secular inter-seismic stress change. The study corroborates, the 2015 Nepal earthquake, as also all the other quakes occurring on the MHT are influenced by groundwater extraction in the Indo-Gangetic plains.




(Adapted from: http://seismo.berkeley.edu/~manga/eps200-2006.html)[32]

**Fig 4:** Relationships between earthquakes and groundwater processes

As noted by Central Ground Water Board (CGWB), groundwater extraction exceeds replenishment of the aquifer, all along the northern part of the country, leading to substantial lowering of water table. It reported the anthropogenic groundwater depletion rate for the Ganga basin (India-Nepal) is the highest ($\sim 22.56 \pm 3.8\ km^3\ yr^{-1}$), which is about 42% of the total loss in the entire region. This change is equivalent to a rate of mass loss of $22.56\ (\pm 3.8) \times 10^3 yr^{-1}$ gigatons, and the rate of unloading of $22.1 (\pm 3.7) \times 10^{13} yr^{-1}$ is distributed over the 1000 (±50) km length of the Ganga basin [31]. When the extraction of water is more than the rate of recharge, there forms a gap, which encourages land-subsidence. The balance between the hydraulic pressure and inter-granular pressure regulates the mechanism of soil subsidence. The depression of pressure affects the support for the clay and increases stress on the soil strata that increase the potential of land subsidence. Instances of subsidence have been noted in the past, where a seismic fault is locked and subsequently excited in any future quakes [12, 21, 22].

**Conclusion**

The geologic causes of this event can be traced back over 120 million years ago, when the southern supercontinent of Gondwanaland broke up. The subcontinent of India separated from Antarctica and started its steady motion northward. 50 million years ago it collided with Asia, raising the Himalayas and forming the Tibetan plateau. The plate collision continues even today as the Indian plate moves northward. Part of the plate boundary extends along the trench on the west coast of Sumatra. The Bengal Basin, especially the region close to the Bay of Bengal (BoB), is exposed to vulnerabilities from both directions through seismic events translated from north via EHZ or from the south through fault-lines extending from Great Sumatran fault via Andaman–Sumatra subduction zone. Geophysical signatures suggest, the BoB is located at a very complex tectonic location – Shillong Plateau in the north, the Indo-Burmese arc in the NE, Andaman–Sumatra subduction zone in the southeast and the Eastern Ghats Mobile Belt (EGMB) in the west. However, historically, episodes of major quakes from the sea-front into the Bengal Basin are very few. During last major quake of 26 Dec. 2004, the strains built-up over hundreds of years by slow movement of tectonic plates were released beneath Sumatra [26]. The line of propagation of the recent major quake of 21 May 2014 in the BoB was not directed towards the Indian landmass and the Bengal Basin was not greatly affected. However, the city of Kolkata and its surroundings districts experienced about 30 strongly felt shaking during the last 350 years. Many of these events are translated from distant sources. Of the recent episodes, an earthquake of $M_w$ 7.1 was experienced in 1934 at a focal depth of 80km, while another quake of $M_w$ 5.4 in 1964 was recorded at a focal depth of 36km on the EHZ. In both cases, the city of Kolkata suffered a lot, while the major devastations took place at South 24 Parganas district of the state. In the past, the city was affected by the 1897 Shillong earthquake and subsequent earthquakes of 1906 with epicenters close to Kolkata. There is a fault zone 4.5 km below the floor of Kolkata, which lie within potential vulnerability zone.

While an earthquake cannot be averted at any point of time, the possible devastations from anthropogenic impetus can be minimized to a great extent. Researchers from National Centre for Seismology (NCS), Ministry of Earth Sciences, CSIR-National Geophysical Research Institute (NGRI), Hyderabad and NIT Rourkela have gathered evidence of the consequences of human actions “advancing the clock” through groundwater depletion. Earlier it was considered that earthquakes of small magnitude are influenced by the seasonal extraction of groundwater in the Indo-Gangetic plains. NCS brings out that groundwater depletion can influence temblors in the Main Himalayan Thrust (MHT) to a great extent. Geophysicists from USA reported in 2014, depletion of groundwater in the San Joaquin Valley modulated the stress levels on San Andreas Fault and heightened the risk for earthquakes. The extraction of groundwater in the Indo-Gangetic basin is at least six times more than the San Joaquin Valley and is the most intensely irrigated region in Southeast Asia. The devastations from an earthquake and excitation of soil liquefaction could be enormous due to the dense population of the entire Bengal Basin region. It has been contended in a report published by Geological Society, London (2015) [29], while it is unlikely that an $M_w$~9 earthquake could occur in the eastern Himalayas, from the hazard point of view a great earthquake of $M_w$~8 anywhere along the Himalayan arc could kill about one million people in the northeast and the adjoining Indo-Ganga plains.

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