Earthquake Occurrence as an Extreme Event as conceptualized from Genesis to Prognosis implicating Hazard, Vulnerability and Risk in the Indian and Japanese Peninsula

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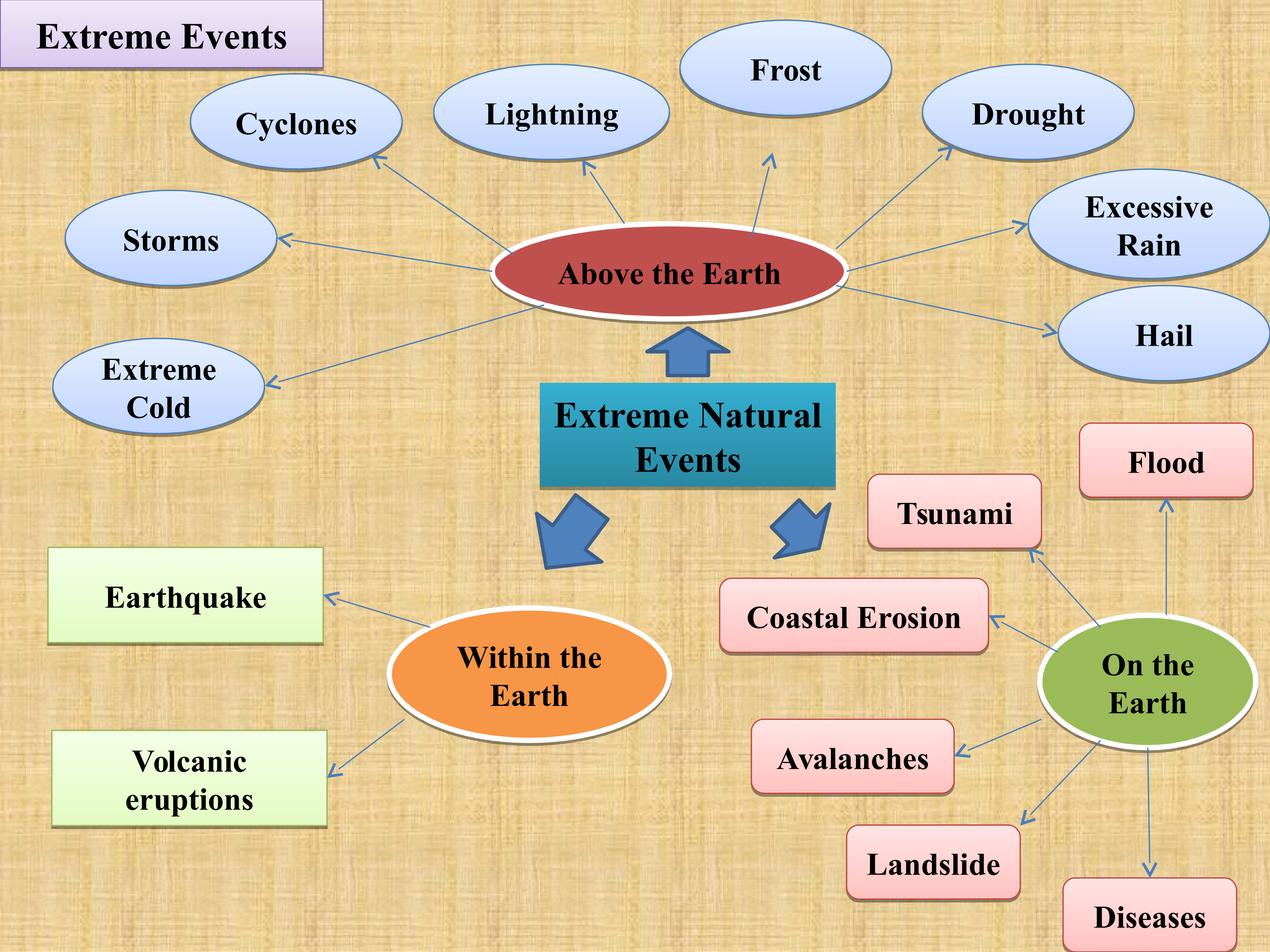
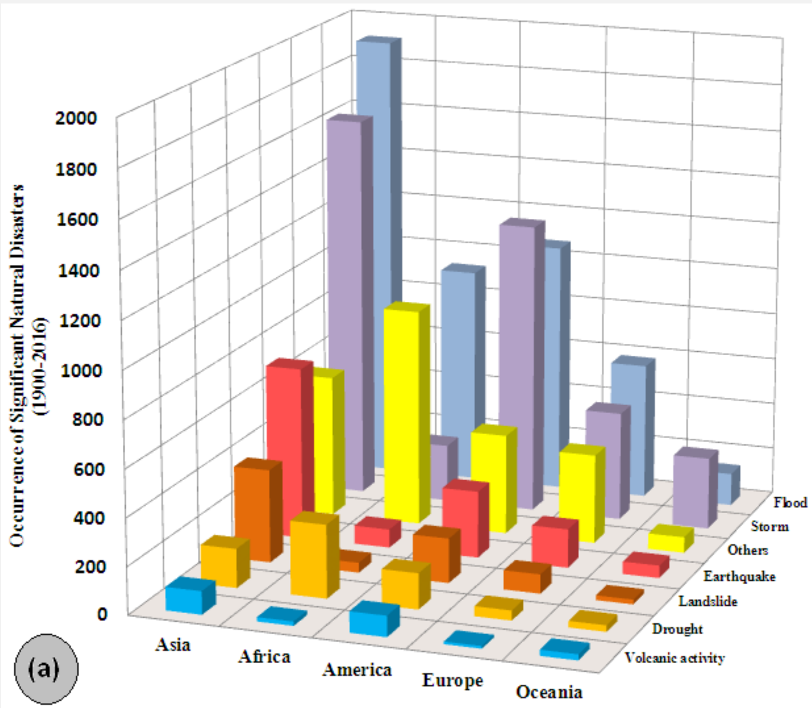
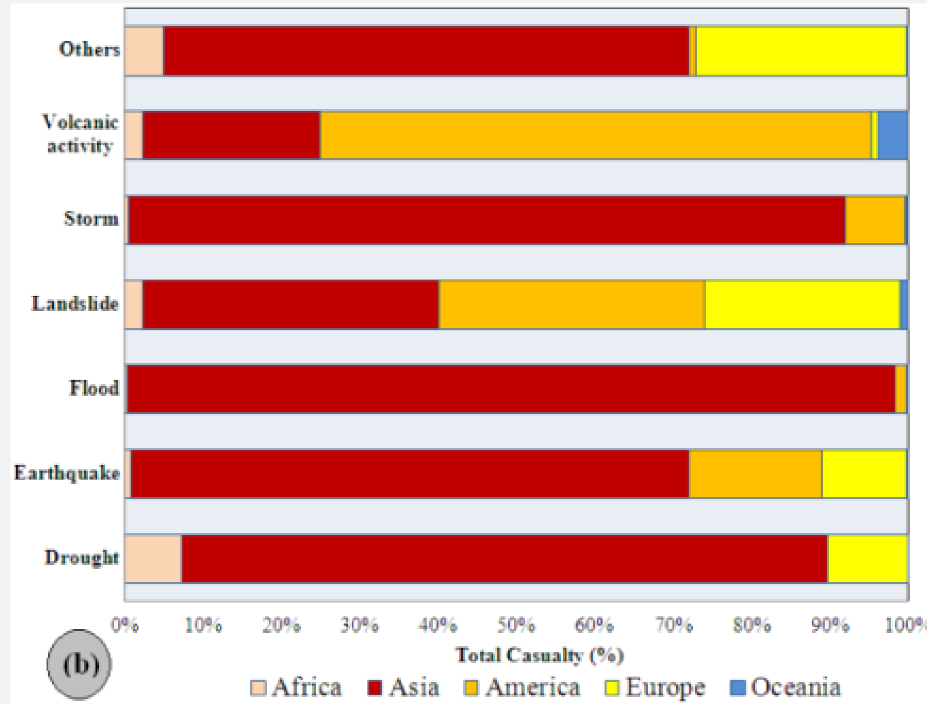

Extreme Events
Cyclones
Lightning
Frost
Drought
Storms
Excessive Rain
Above the Earth
Hail
Extreme Cold
Extreme Natural Events
Flood
Tsunami
Earthquake
Coastal Erosion
Within the Earth
On the Earth
Volcanic eruptions
Avalanches
Landslide
Diseases

Natural Disasters during 1950-2016: A Global Scenario





(a) Occurrence of significant number of Natural Disaster during 1900-2016 for different continental region in the World (b) Total casualty reportedly caused by natural disasters (source: CRED; EMDAT: http://www.emdat.be)

Limiting Behaviour of Sums or Averages

(See [Embrechts et al., 1997], Chapter 2.)

We are familiar with the central limit theorem.

Let $X_1, X_2, \ldots$ be iid with finite mean μ and finite variance σ^2. Let $S_n = X_1 + X_2 + \ldots + X_n$. Then

$$P\left((S_n - n\mu)/\sqrt{n\sigma^2} \leq x\right) \xrightarrow{n\to\infty} \Phi(x),$$

where Φ is the distribution function of the standard normal distribution

$$\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-u^2/2} du.$$

Note, more generally, the limiting distributions for appropriately normalized sample sums are the class of α–stable distributions; Gaussian distribution is a special case.

Limiting Behaviour of Sample Extrema

(See [Embrechts et al., 1997], Chapter 3.)

Let $X_1, X_2, \ldots$ be iid from F and let $M_n = \max(X_1, \ldots, X_n)$.

Suppose we can find sequences of real numbers $a_n > 0$ and b_n such that $(M_n - b_n)/a_n$, the sequence of normalized maxima, converges in distribution, i.e.

$$P\left((M_n - b_n)/a_n \le x\right) = F^n(a_n x + b_n) \stackrel{n\to\infty}{\longrightarrow} H(x),$$

for some non–degenerate df $H(x)$.

If this condition holds we say that F is in the *maximum domain of attraction* of H, abbreviated $F \in \mathrm{MDA}(H)$. Note that such an H is determined up to location and scale (by the convergence-to-types theorem), i.e. H specifies a unique *type* of distribution.

F2. Generalized Extreme Value Distribution

The general form of a df in the generalized extreme value (GEV) family is

$$H_\xi(x) = \begin{cases} \exp\left(-(1+\xi x)^{-1/\xi}\right) & \xi \neq 0\,, \\ \exp\left(-e^{-x}\right) & \xi = 0, \end{cases}$$

where $1 + \xi x > 0$ and ξ is the *shape* parameter. Note, this parametrization is continuous in ξ. For

$\xi > 0$ $\quad H_\xi$ is equal in type to classical Fréchet df

$\xi = 0$ $\quad H_\xi$ is equal in type to classical Gumbel df

$\xi < 0$ $\quad H_\xi$ is equal in type to classical Weibull df.

We introduce *location and scale* parameters μ and $\sigma > 0$ and work with $H_{\xi,\mu,\sigma}(x) := H_\xi((x-\mu)/\sigma)$. Clearly $H_{\xi,\mu,\sigma}$ is of type H_ξ.

Earthquakes and Tsunamis

- According to long-term records (since about 1900), we can expect about 18 major earthquakes (7.0 - 7.9 on the Richter scale) and one great earthquake (8.0 or above) in any given year
- The number of earthquakes and tsunamis resulting in fatalities has increased approximately in proportion to global populations
- The growth of giant urban cities near regions of known seismic hazard is a new experiment for life on the Earth
- Tsunamis are a threat to life and property for all coastal residents

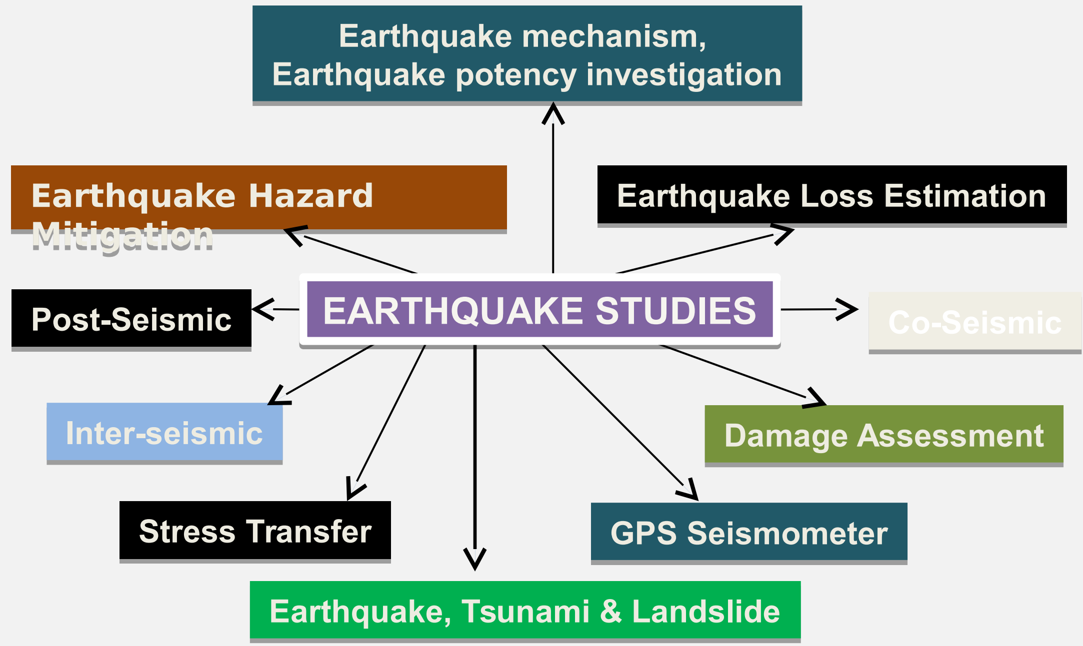
Sources: NEIC 2003; USGS 2004; UNEP 2005 (GEO 2004/2005)

❖ *The seismic vulnerability of the world is rapidly increasing due to fast urbanization, destabilization of environment and social framework.*

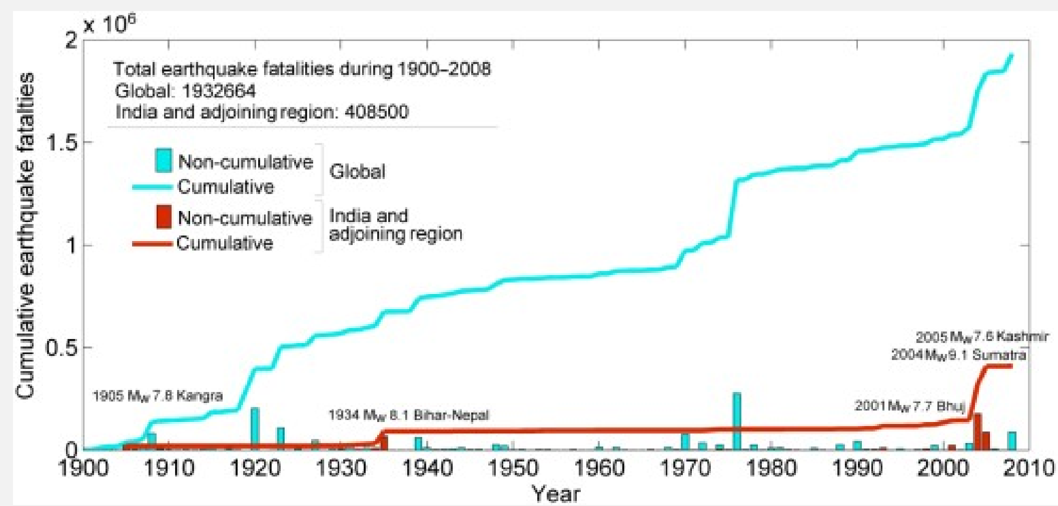
❖ *According to a conservative estimate, more than 15 million lives have been lost and damage worth hundred billion dollars has been inflicted in the recorded history due to earthquakes.*

India and adjoining regions is about 21% of the global total according to significant earthquake database of National Geophysical Data Center.

❑ **Unprecedented population growth have compounded the prevailing seismic risk.**

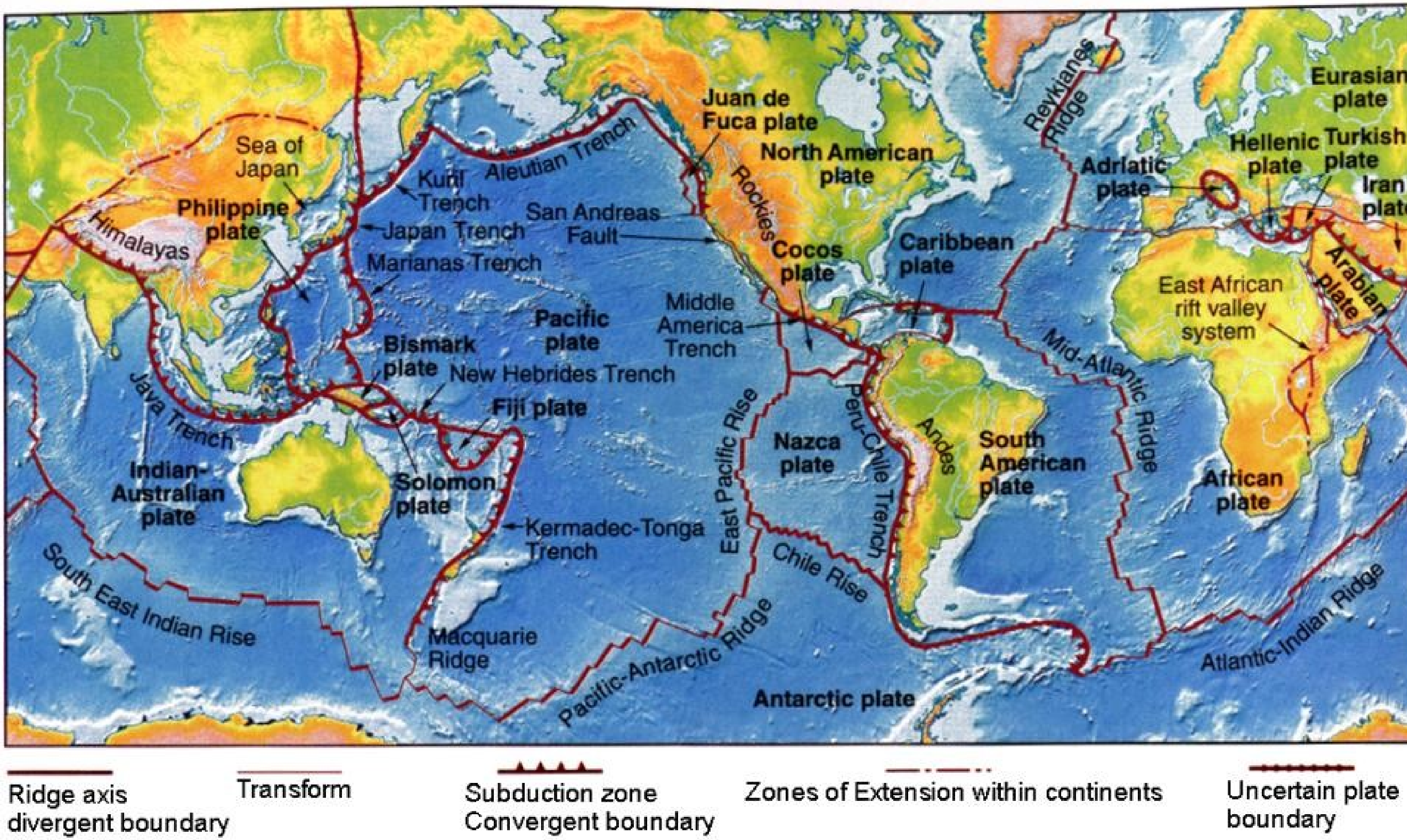


Earthquake related fatalities in India and adjoining regions with respect to the global observations



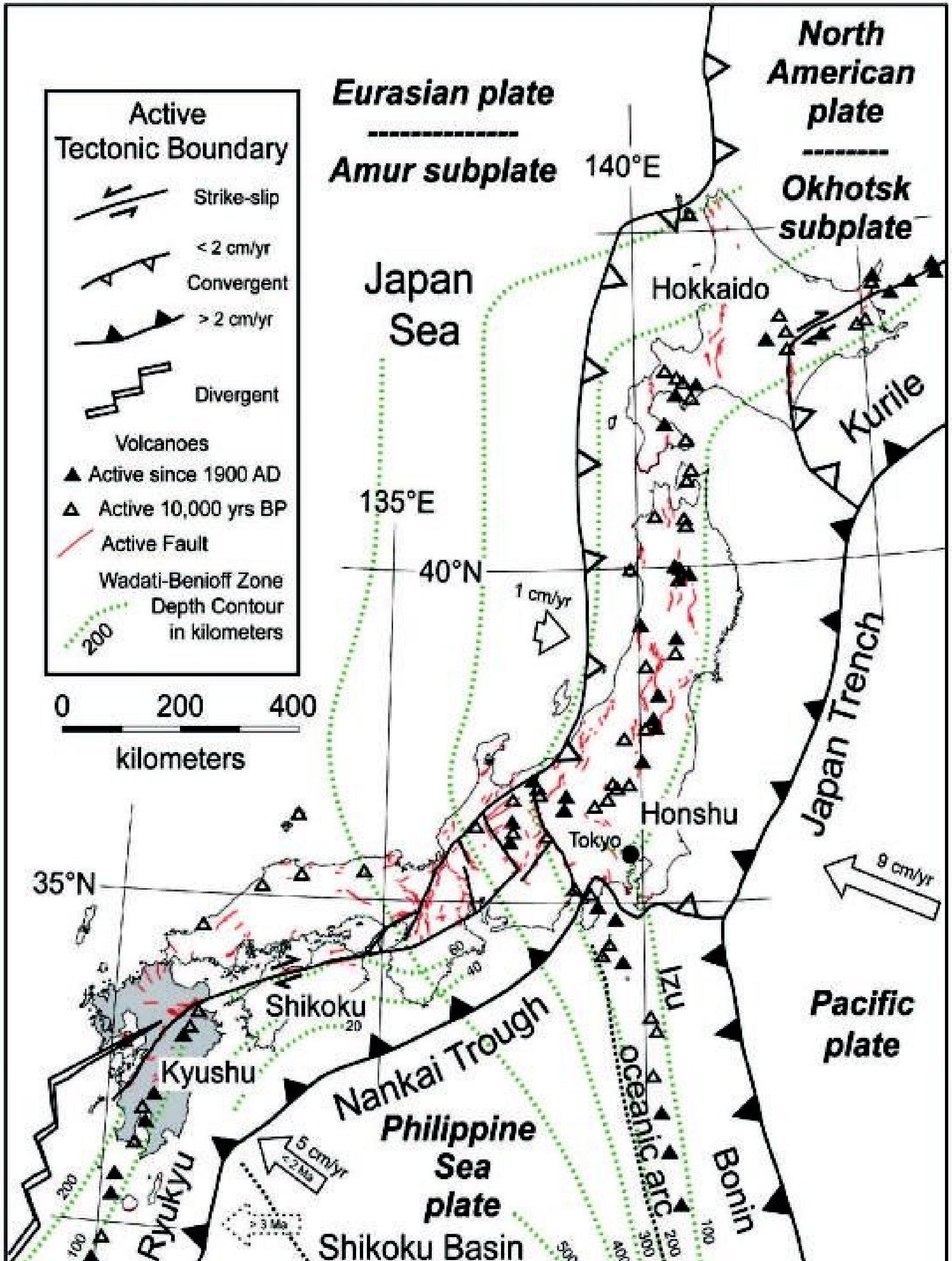
➢ *Urban Safety has gained importance in recent years with rapid increase in construction activities and growth in urban population all over the world.*

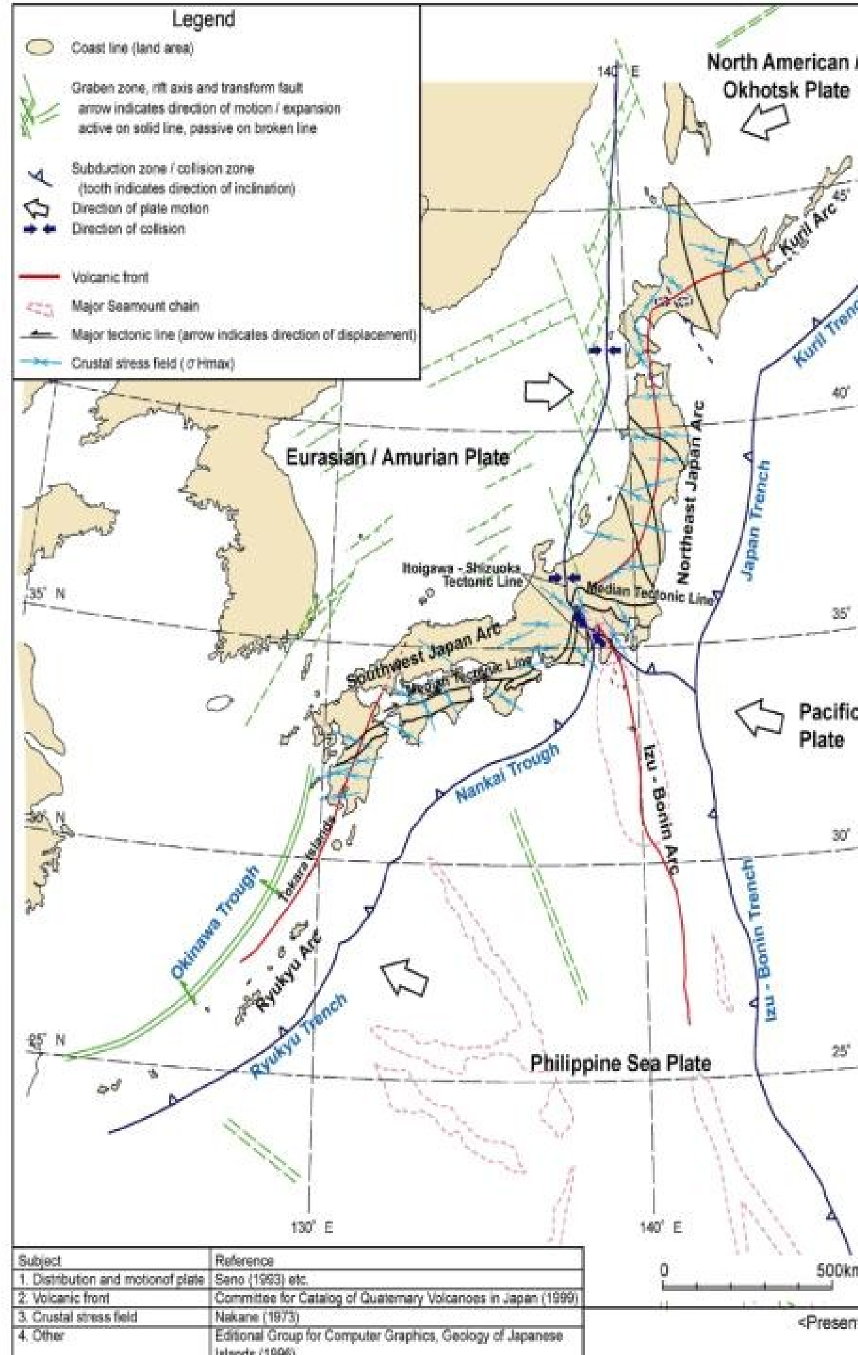
➢ *It poses a challenge to planners, administrators, engineers and architects alike due to its multi-dimensional nature, which cover areas from structural design,*


Eurasian plate
Juan de Fuca plate
North American plate
Reykjanes Ridge
Sea of Japan
Aleutian Trench
Kuril Trench
Philippine plate
Himalayas
Japan Trench
San Andreas Fault
Rockies
Adriatic plate
Hellenic plate
Turkish plate
Iran plate
Marianas Trench
Cocos plate
Caribbean plate
Arabian plate
East African rift valley system
Pacific plate
Middle America Trench
Bismark plate
New Hebrides Trench
Mid-Atlantic Ridge
Java Trench
Fiji plate
East Pacific Rise
Nazca plate
Peru-Chile Trench
Andes
South American plate
Indian-Australian plate
Solomon plate
African plate
Kermadec-Tonga Trench
Chile Rise
South East Indian Rise
Macquarie Ridge
Pacific-Antarctic Ridge
Atlantic-Indian Ridge
Antarctic plate
Ridge axis divergent boundary
Transform
Subduction zone Convergent boundary
Zones of Extension within continents
Uncertain plate boundary

Earth Plate

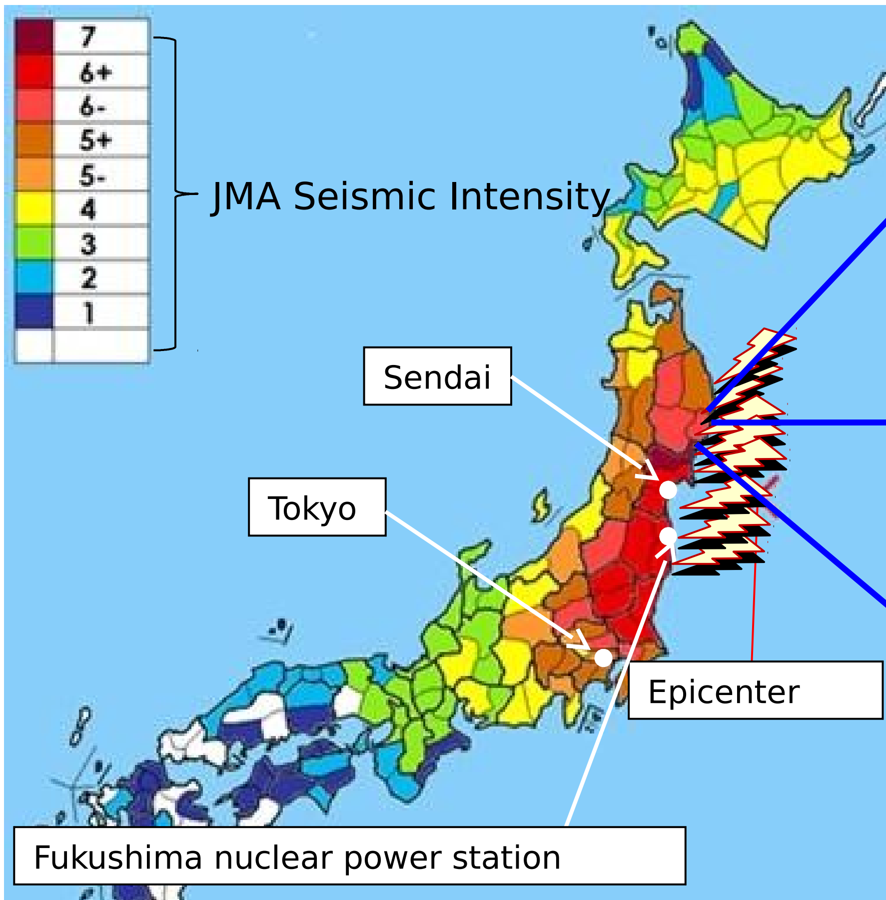
Tectonic and Plates around Japan with





The Great East Japan Earthquake & Tsunami

- Date and Time: 11 March 2011 (FRI) 14:46 JST (05:46 UTC)
- Magnitude: 9.0 (<u>the largest magnitude recorded in Japan's history</u>)
- Epicenter: N38.1, E142.9 (130km ESE off Oshika Peninsula) Depth 24km



(Japan Meteorological Agency)

Miyako (Iwate)
Run-up height:38m*

Otsuchi (Iwate)
Run-up height:17m*

Kesennuma (Miyagi)
Run-up height: 20m*

* The 2011 Tohoku Earthquake Tsunami Joint Survey Group
(http://www.coastal.jp/)

Some time Seismic Hazard maps fail because of

- bad physics (incorrect description of earthquake processes)
- bad assumptions (mapmakers' choice of poorly known parameters)
- bad data (lacking, incomplete, or underappreciated)
- bad luck (low probability events)

2011 Tohoku Earthquake
450 km long fault, M 9.1

Off Sanriku-oki North ~M8
0.2 to 10%

Off Sanriku-oki Central ~M7.7
80 to 90%

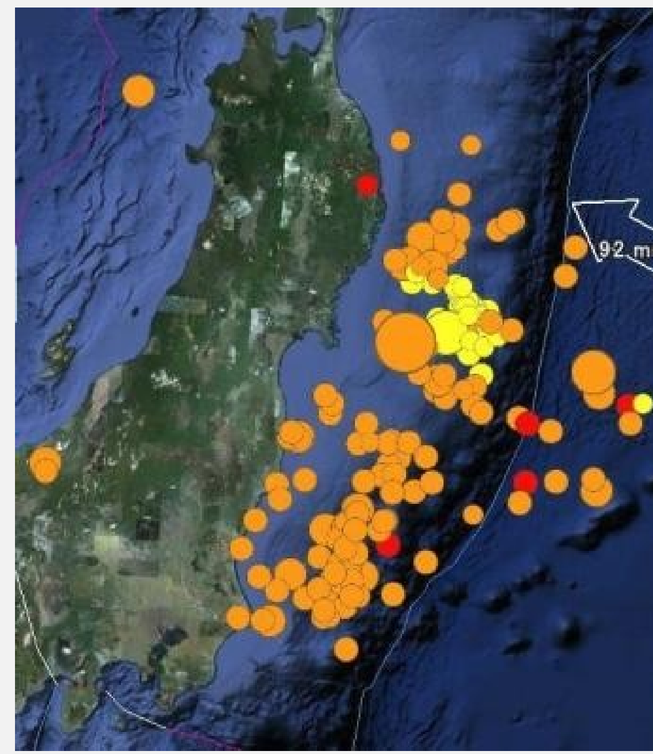
Off Miyagi ~M7.5 > 90%

Off Fukushima ~M7.4 7%

Off Ibaraki ~M6.7 – M7.2
90%

Assumption: No M > 8.2

Sanriku to Boso M8.2 (plate boundary) 20%
Sanriku to Boso M8.2 (Intraplate) 4-7%



Expected Earthquake Sources
50 to 150 km segments: M7.5 to 8.2
(Headquarters for Earthquake Research Promotion, Japan)

4th April 1905 Kangra Earthquake

- Magnitude: Mw=7.8
- Time : 6.19 a.m
- Death Toll: 20,000

Barjeshwari Devi temple Kangra

Earth Fissures, Kangra Bhawan

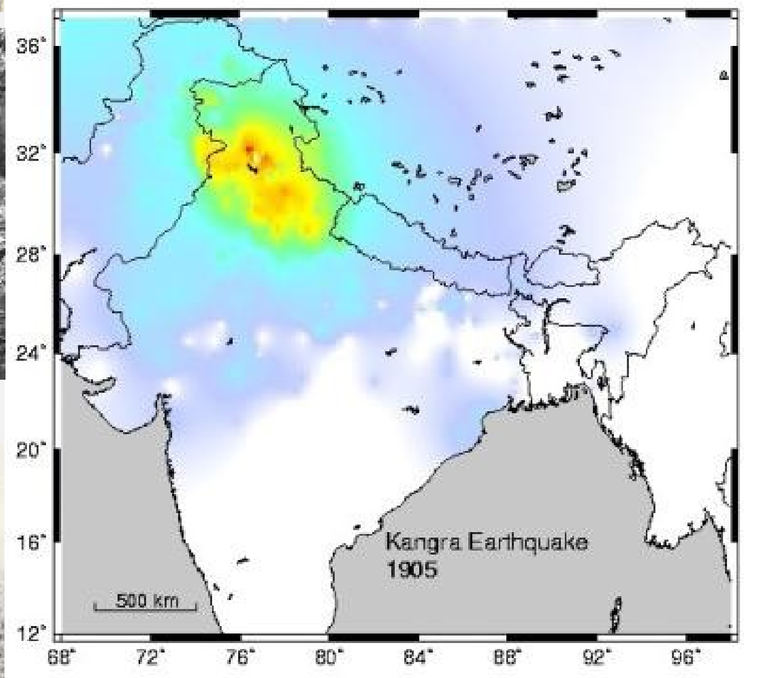
Chari village near Dharamsala

Area below Kangra Bhawan

Palampur market after earthquake

Palampur church after earthquake

Predicted shaking intensity from the 1905 Kangra earthquake (Hough et al., 2005)



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: http://123himachal.com/dharamsala/links/1905.htm

Where do earthquakes form?

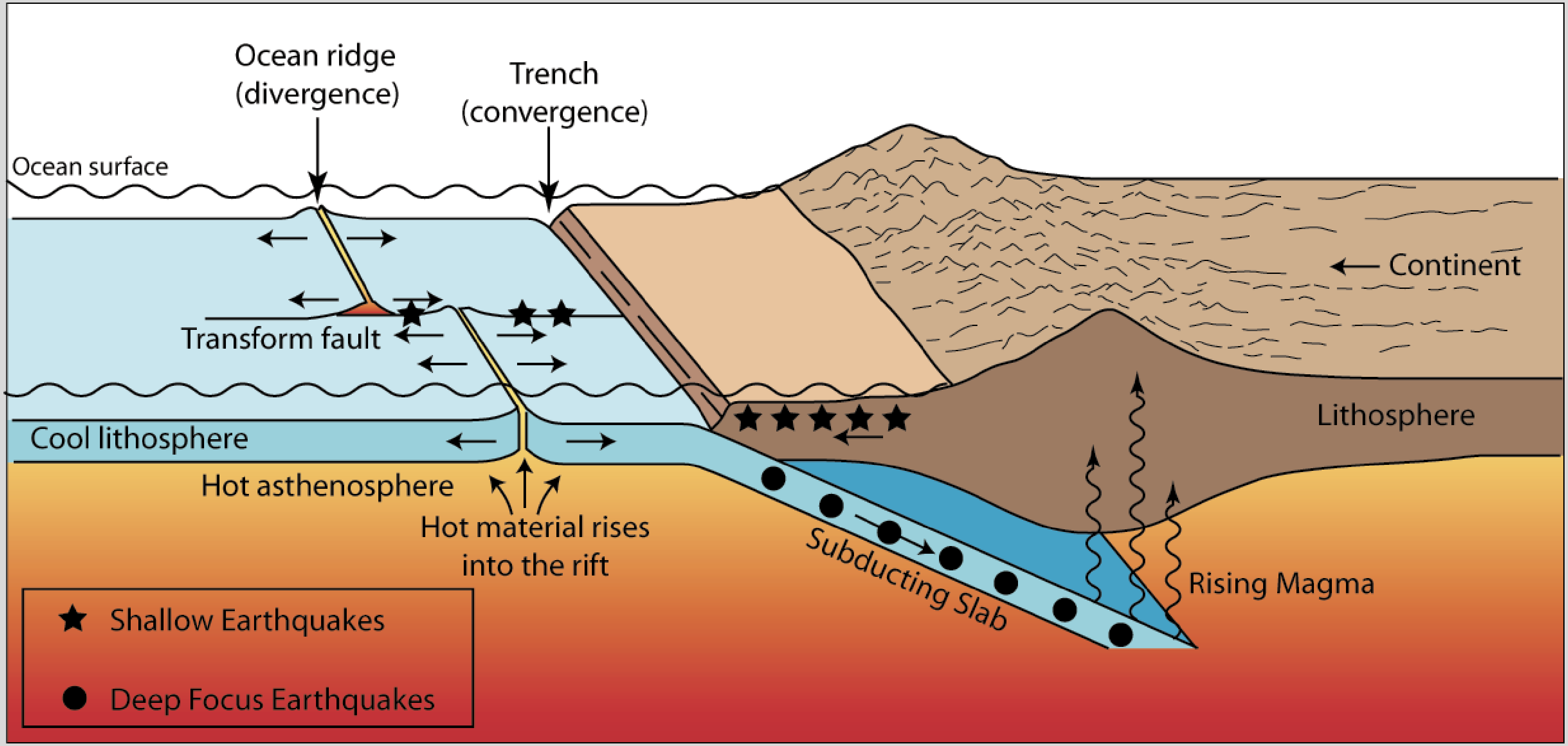
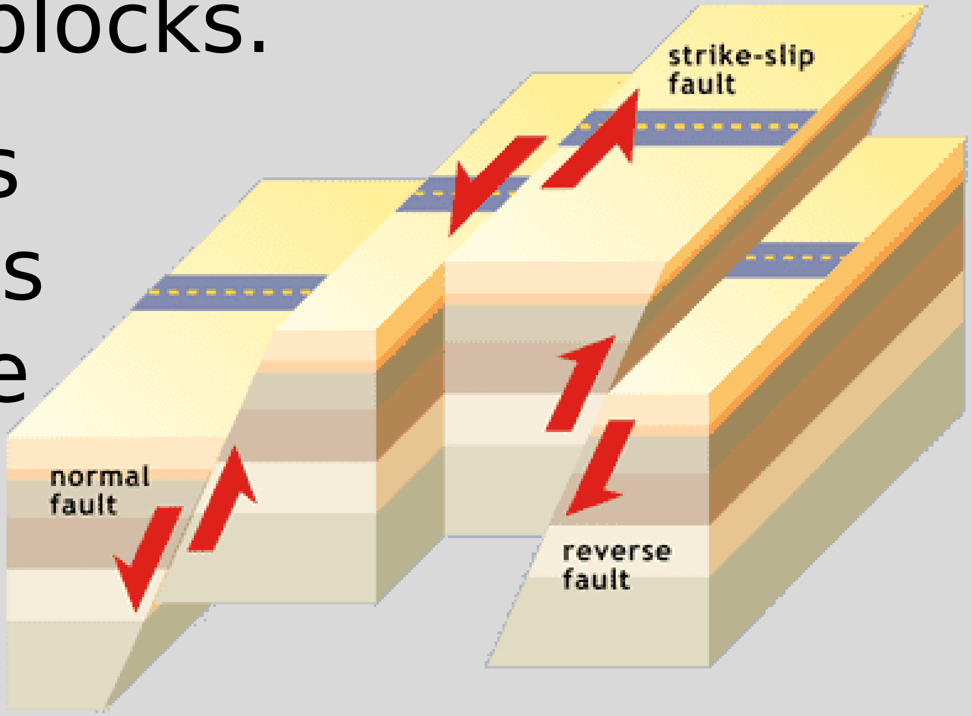


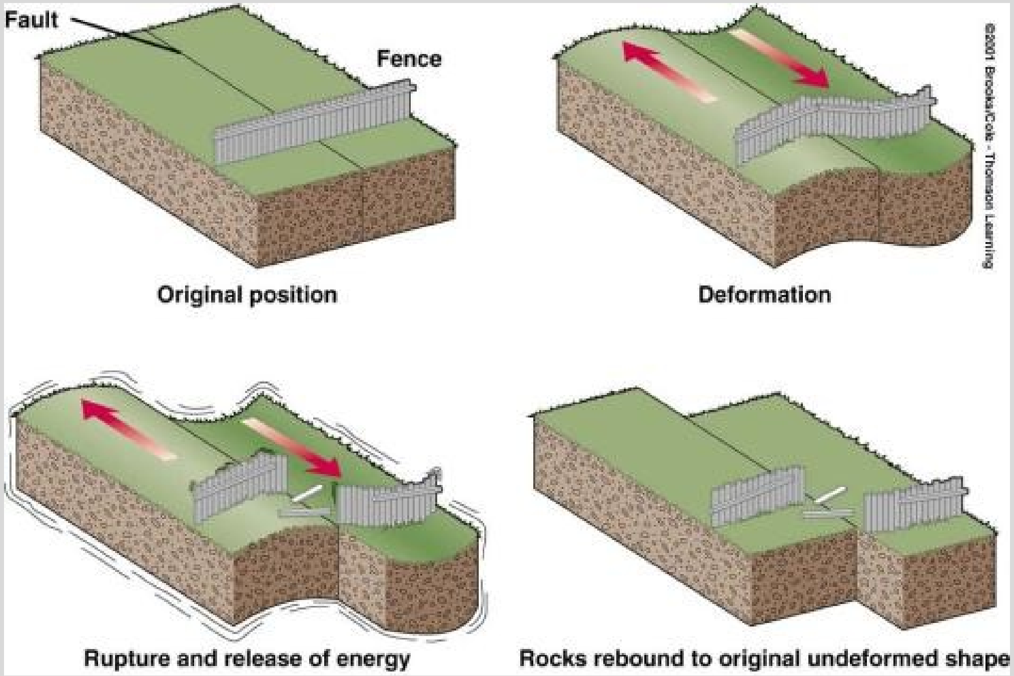
Figure showing the tectonic setting of earthquakes

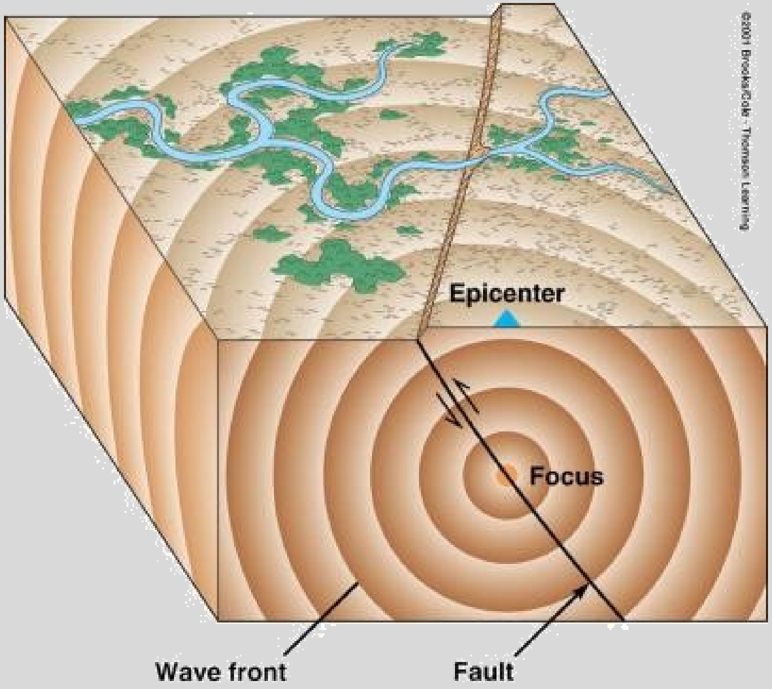
How earthquakes occur?

- Earthquakes occur at **FAULTS.**
- Fault is a weak zone separating two geological blocks.
- Tectonic forces cause the blocks to move relative one to another.



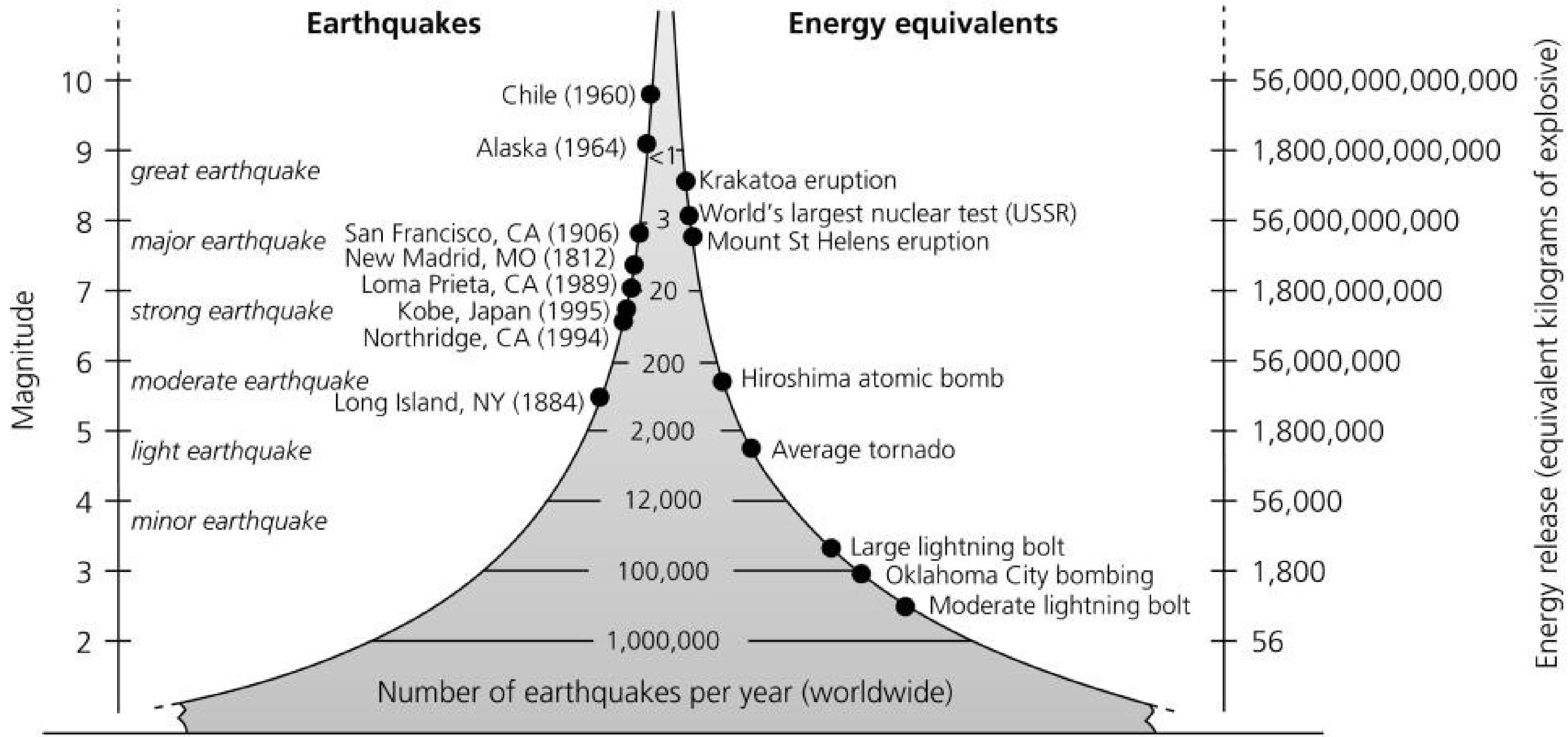
How earthquakes occur?
Elastic rebound theory





- **Because of friction, the blocks do not slide, but are deformed.**
- **When the stresses within rocks exceed friction, rupture occurs.**
- **Elastic energy, stored in the system, is released after**

Figure 1.2-2: Comparison of frequency, magnitude, and energy release.

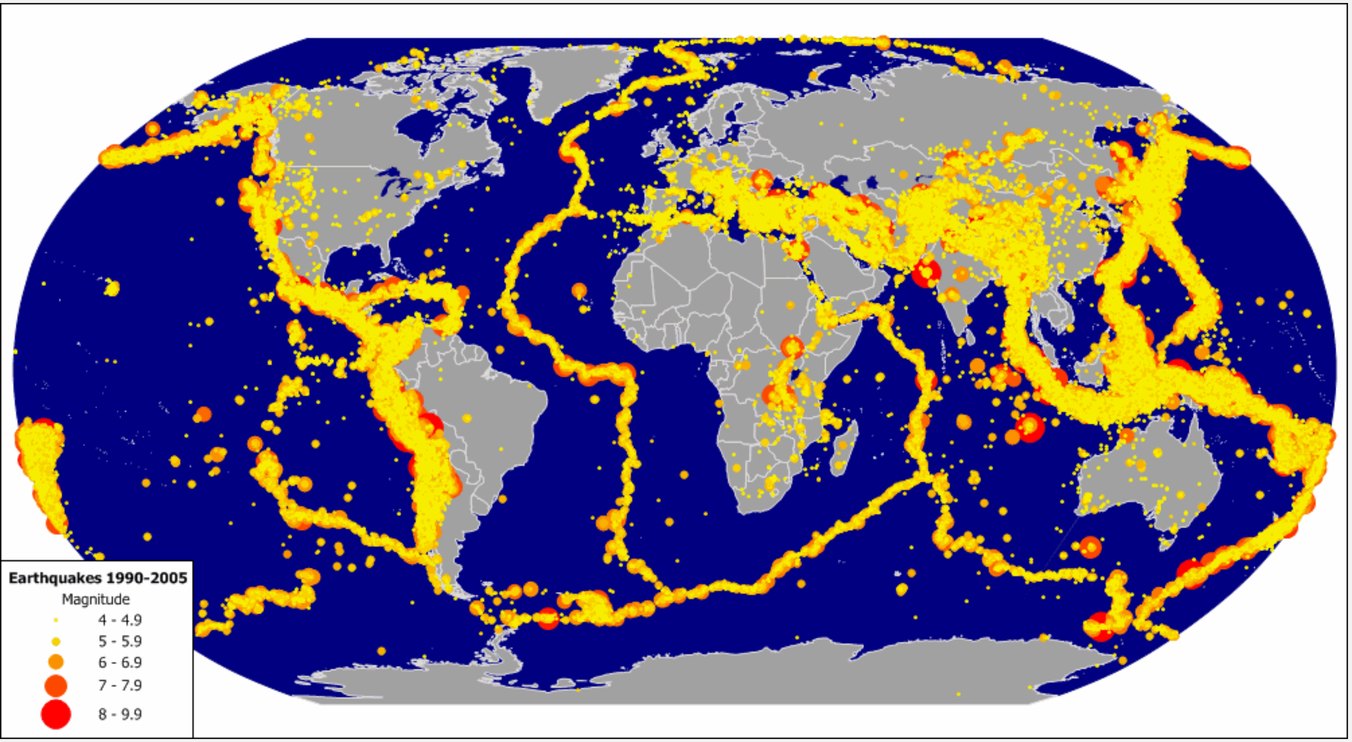


Earthquakes of a given magnitude are ~10 times less frequent than those one magnitude smaller. An M7 earthquake occurs approximately monthly, and an earthquake of M> 6 about every three days. Hence although earthquake predictor I. Browning claimed to have predicted the 1989 Loma Prieta earthquake, he said that near a date there would be an M6 earthquake somewhere, a prediction virtually guaranteed to be true.

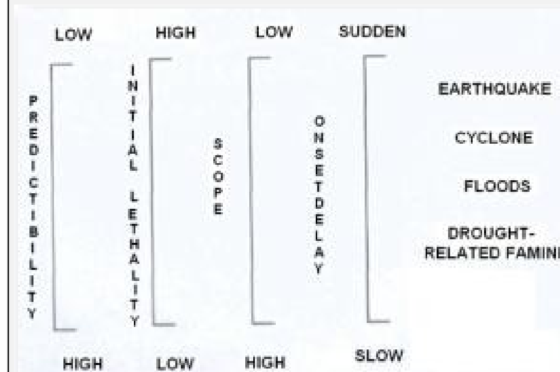
Magnitude is proportional to the logarithm of the energy released, so most energy released seismically is in the largest earthquakes. An M 8.5 event releases more energy than all other earthquakes in a year combined. Hence the hazard from earthquakes is due primarily to large (typically magnitude > 6.5) earthquakes.

Global Earthquake Scenario

World Seismicity



Ranking of principal Disaster on relative scales of predictability, Initial lethality, Scope and Onset delay



Source: http://www.usgs.gov/

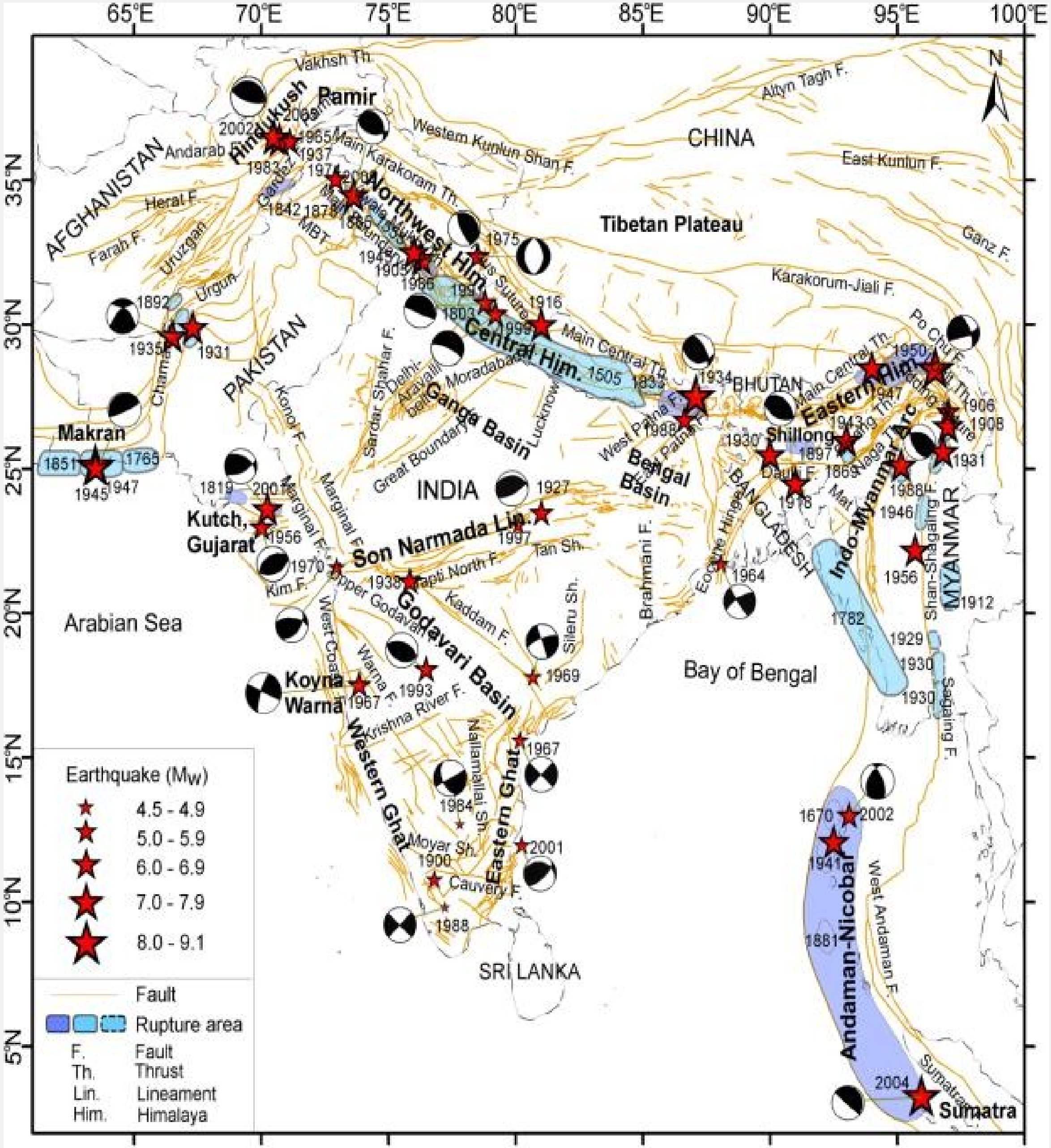
Loss of Life versus Population: 1947-1980

# of events	180-earthquake	7-tsunami	18-volcanic
N. America	77	60	96
Carr./C.A.	30,613		151
S. America	38,837		440
Europe	7,750		2,000
Asia	354,521	4,459	2,805

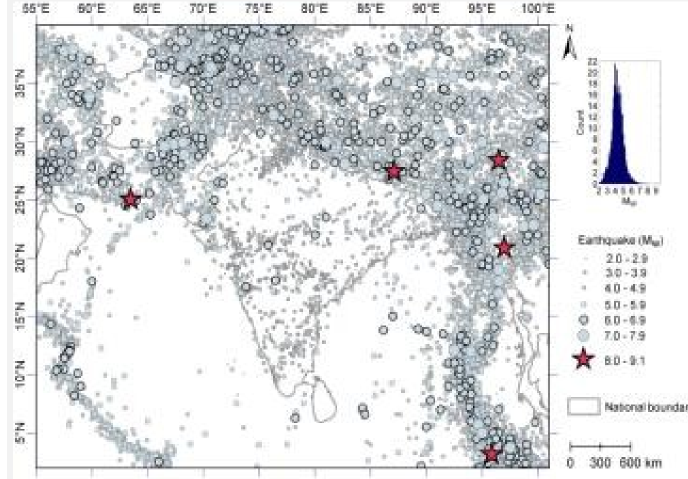
Since 1980- major events

# of events	Earthquakes	Tsunami	Volcanic
N. America	~120		?
Mex./Carr.	288,000		?
S. America	38,837		23,000
Europe	? 26-Italy		?

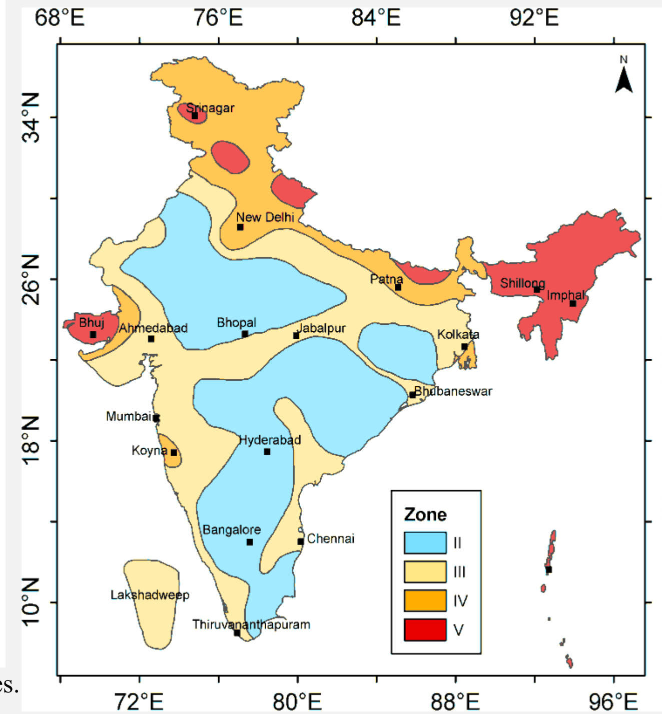
A seismotectonic map of India and the adjoining regions



Declustered seismicity of South Asia

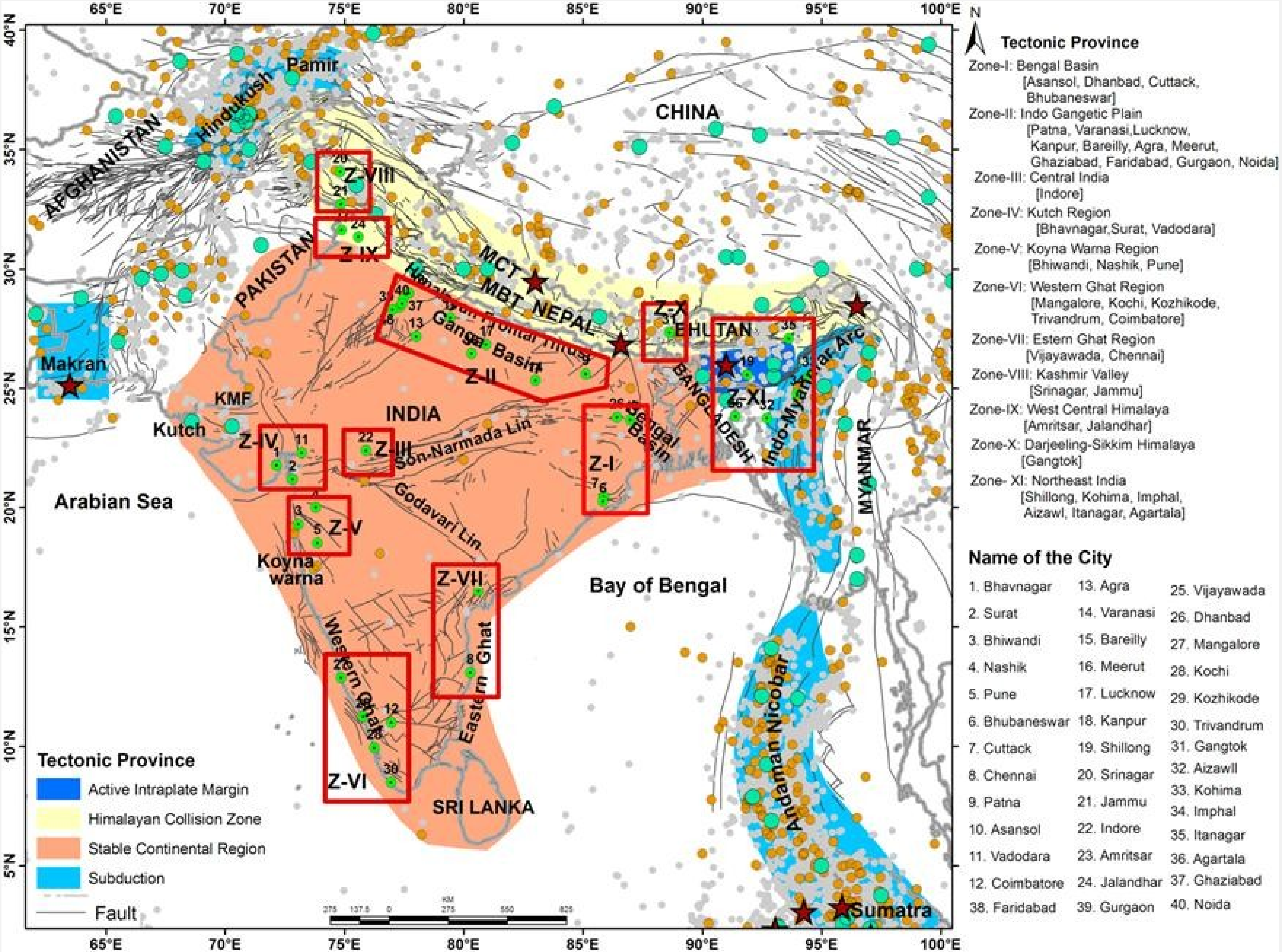


Seismic zonation map (BIS, 2002).



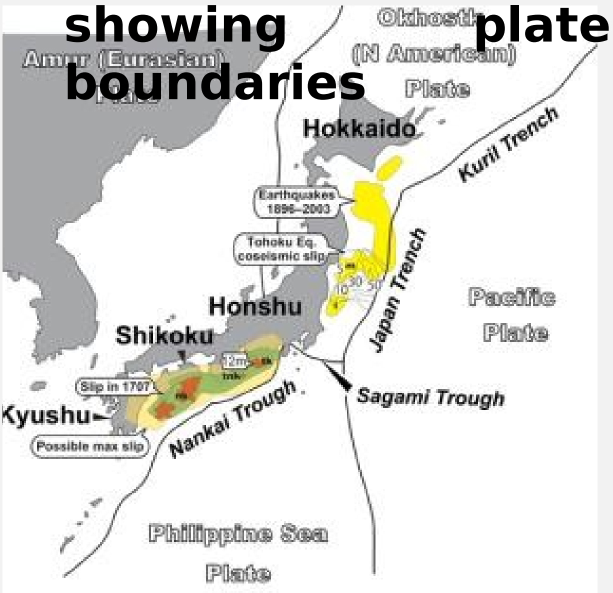
Citation: Nath, S. K. and Thingbaijam, K. K. S.: Probabilistic seismic hazard assessment of India, Seismol. Res. Lett., 83, 135–149, 2012.

Major tectonic Province along with 40 cities which considered for Probabilistic Seismic Hazard Assessment

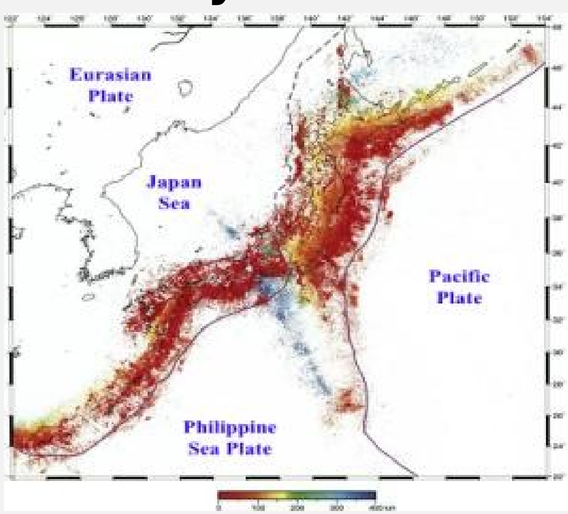


Distribution of earthquakes in and around the Japan Islands:

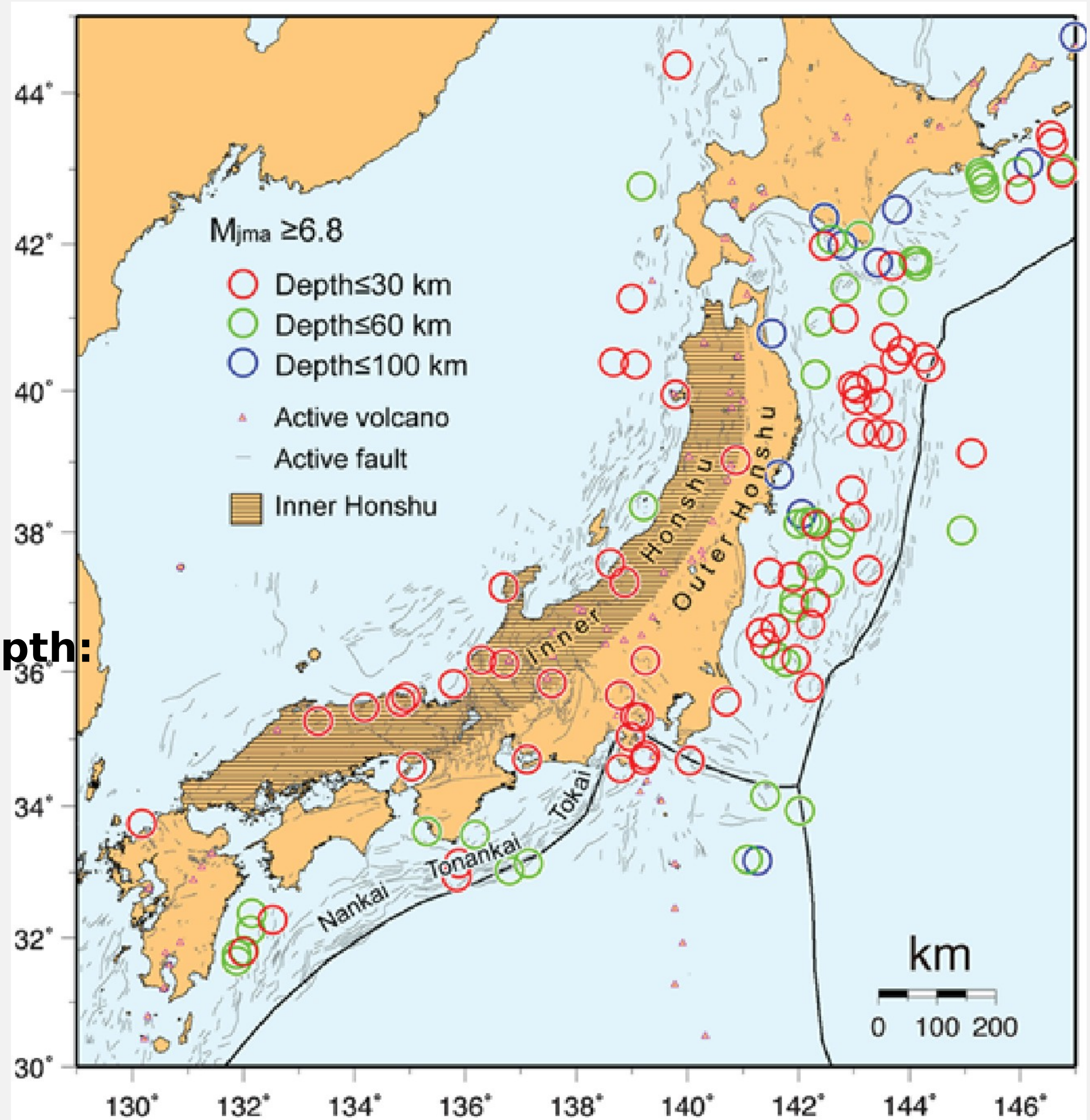
- **Outline map of Japan and surrounding areas showing plate boundaries**



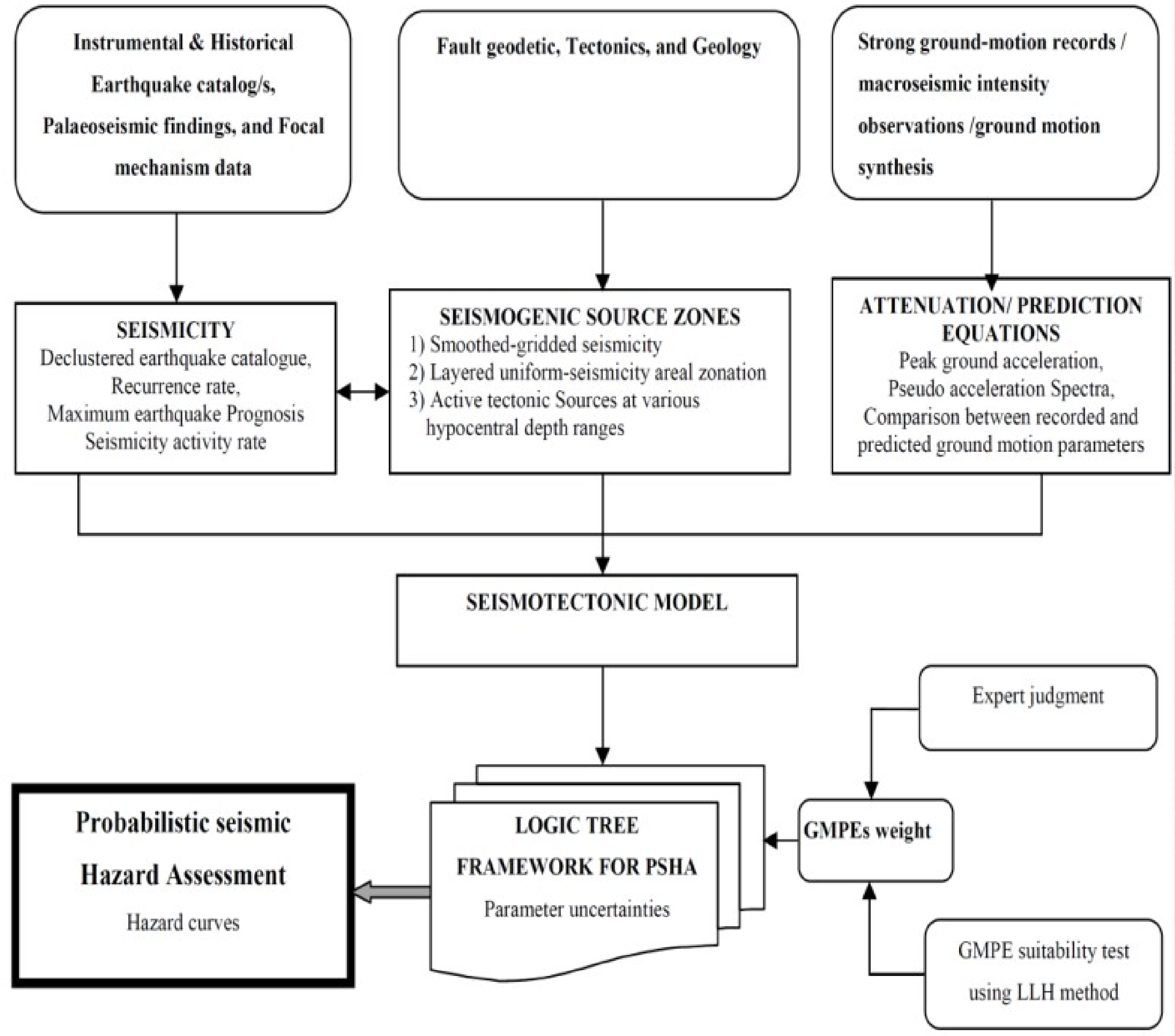
Seismicity with Focal Depth:



Source: Thomas et al., 2012

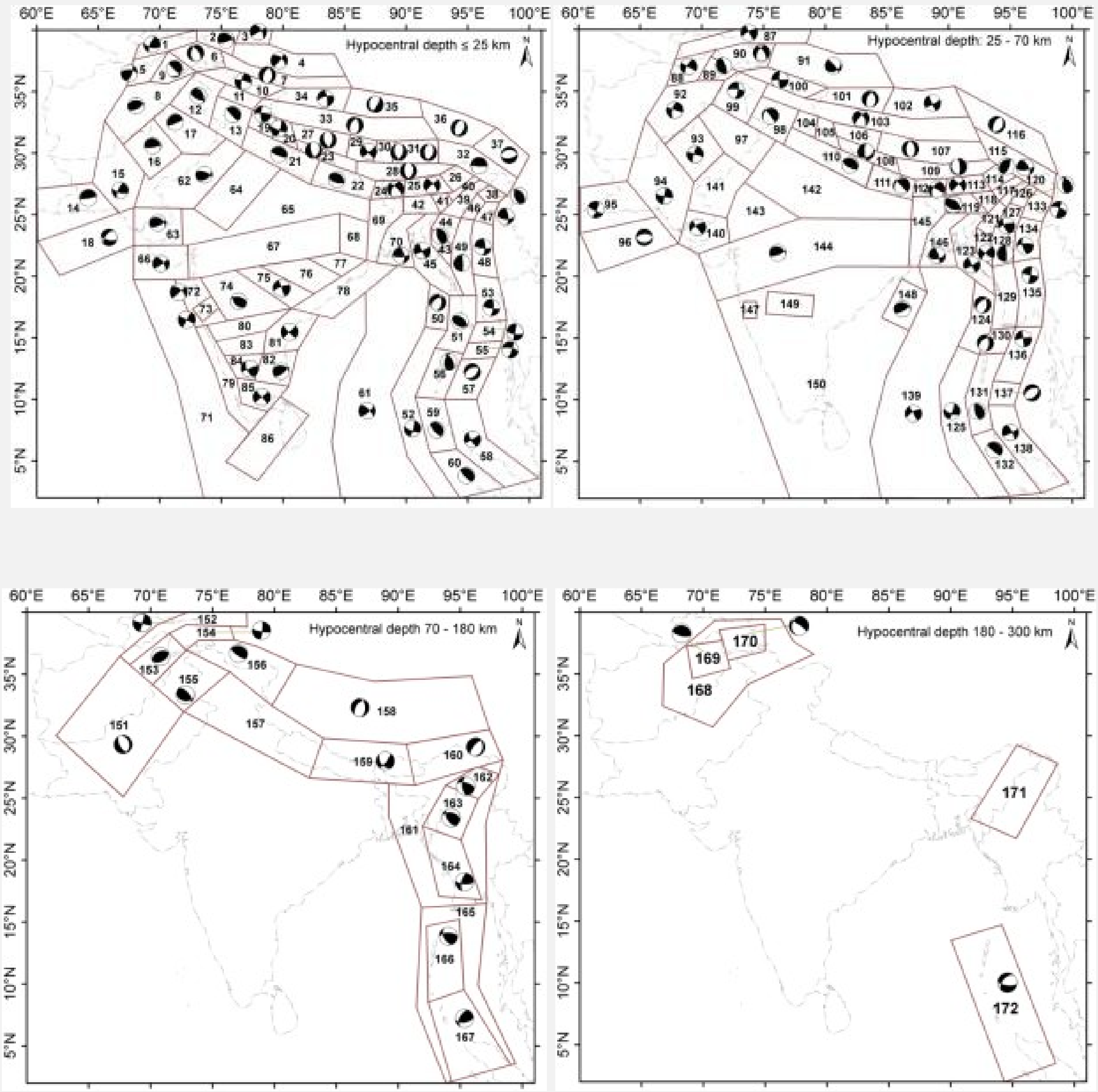


Probabilistic Seismic Hazard Analysis:



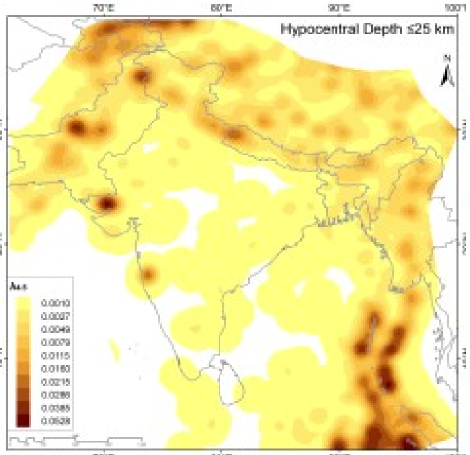
Layered Seismogenic Source Zones:

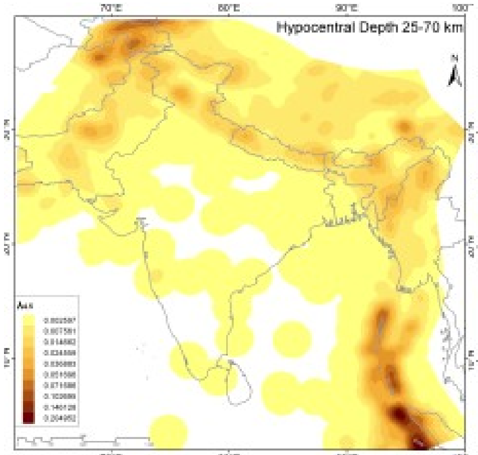
- Based on the hypocentral depth of occuring seismic events of various magnitudes four Layered seismogenic sources corresponding to hypocentral depth ranges: 0–25 *km*, 25–70 *km*, 70–180 *km*, and 180–300 *km* are considered.
- The source zonation is carried out on the basis of seismicity, fault patterns, and type of focal mechanisms demarcating 172 source zones.
- Representative focal mechanism evaluated for each zone by summation of moment tensor data

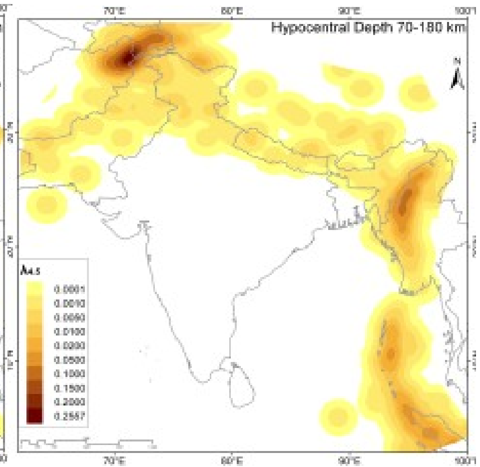


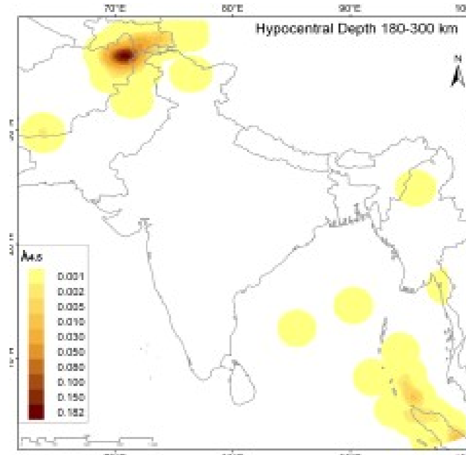
[Citation: Nath, S. K., and K. K. S. Thingbaijam (2012). Probabilistic seismic hazard assessment of India, *Seismological Research Letter* **83**, 135–149]

Smoothened seismicity models for threshold magnitudes Mw 4.5 at four hypocentral depth ranges of 0-25km, 25-70km, 70-180 km and 180-300km indicating the seismic activity distribution

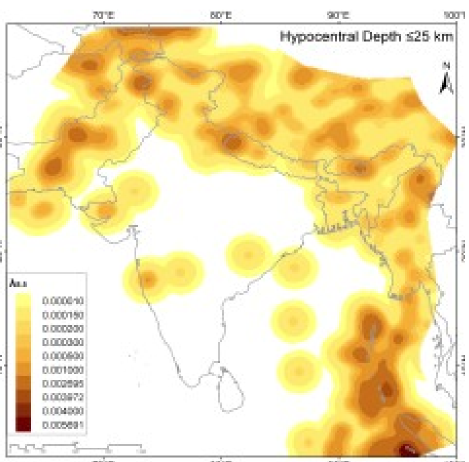


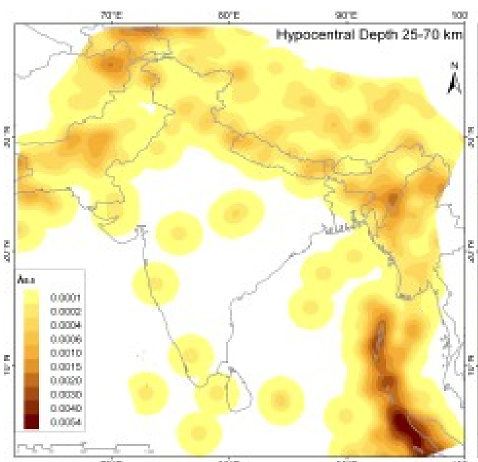


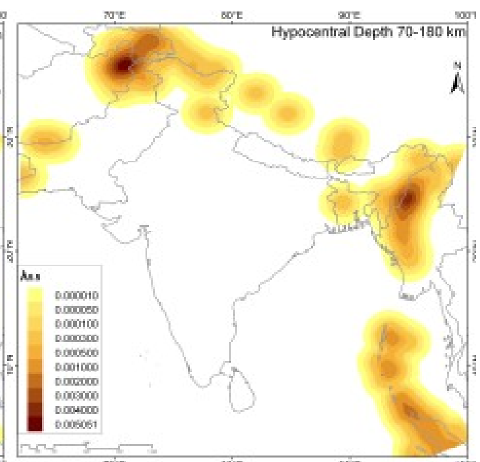


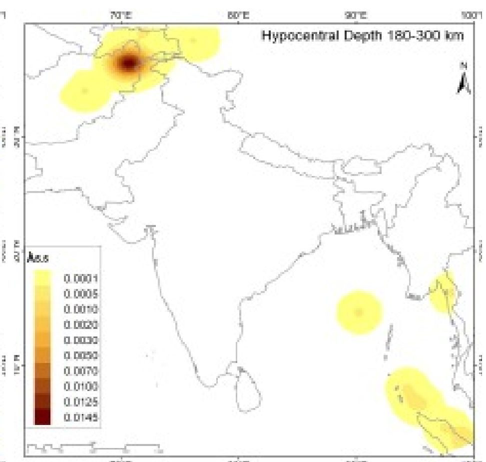


Smoothened seismicity models for threshold magnitudes Mw 5.5 at four hypocentral depth ranges of 0-25km, 25-70km, 70-180 km and 180-300km indicating the seismic activity distribution









Seismicity Parameters

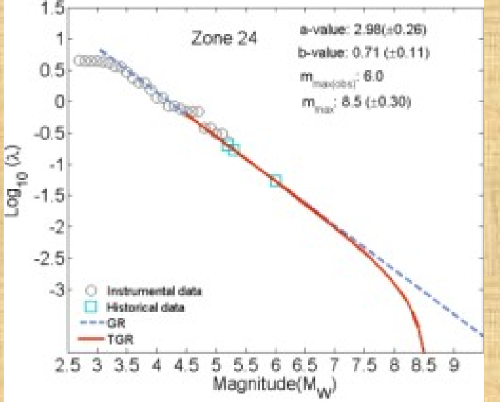
Gutenberg and Richter (GR) relationship (Gutenberg and Richter 1944)

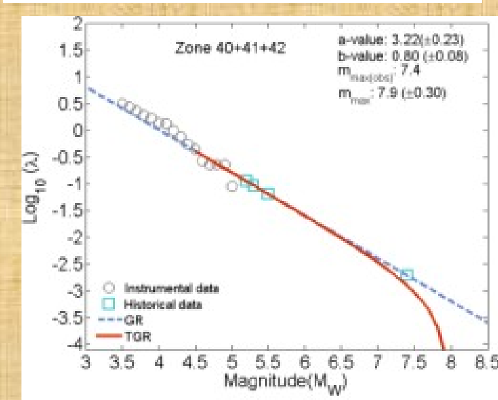
$$\log_{10} \lambda(m) = a - bm$$

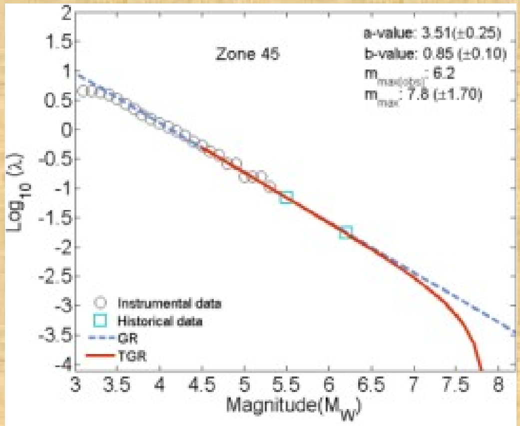
A modified version (Cornell and Vanmarcke 1969)

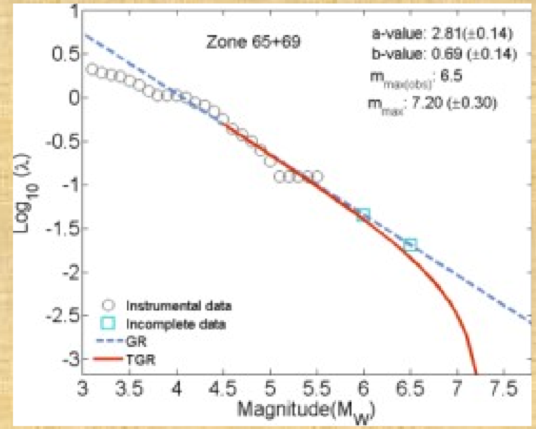
$$\lambda(m) = \lambda(m_{\min}) \frac{10^{-b(m-m_{\min})} - 10^{-b(m_{\max}-m_{\min})}}{1-10^{-b(m_{\max}-m_{\min})}}$$

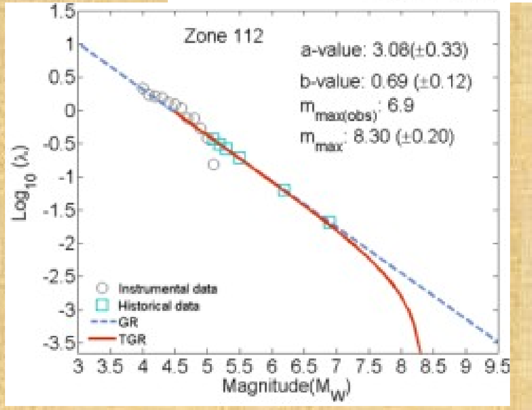
$\lambda(m)$ is the cumulative number of events with magnitude $\geq$ m , b-value is the slope parameter.











Representative frequency magnitude distribution plots at some typical polygonal seismogenic sources: The red line represents Truncated Gutenberg-Richter (TGR) relation, the blue line representing Gutenberg-Richter (GR) relation while the circles & squares represent the instrumental events (complete data coverage) and incomplete data (including the historical data as extreme data coverage) respectively.

Ground Motion Prediction Equation:

1. Atkinson and Boore , 2006. (BA06):

$$LogPSA = C_1 + C_2M + C_3M^2 + (C_4 + C_5M)f_1 + (C_6 + C_7M)f_2 + (C_8 + C_9M)f_0 + C_{10}R_{cd}$$

Where

$$f_0 = \max(\log(R_0 / R_{cd}), 0); f_1 = \min(\log R_{cd}, \log R_1);$$
$$f_2 = \max(\log(R_{cd} / R_2); R_0 = 10; R_1 = 70; R_2 = 140;$$

2. Campbell and Bozorgnia, 2003. (CB03):

$$\ln Y = c_1 + f_1(M_w) + c_4 \ln\sqrt{f_2(M_w, r_{seis}, S)} + f_3(F) + f_4(S)$$

Where

$$f_1(M_w) = c_2M_w + c_3(8.5 - M_w)^2,$$
$$f_2(M_w, r_{seis}, S) = r^2{}_{seis} + g(S)^2(\exp[c_8M_w + c_9(8.5 - M_w)^2])^2,$$
$$g(S) = c_5 + c_6(S_{VFS} + S_{SR}) + c_7S_{FR},$$
$$f_3(F) = c_{10}F_{RV} + c_{11}F_{TH},$$
$$f4(S) = c_{12}S_{VFS} + c_{13}S_{SR} + c_{14}S_{FR}$$

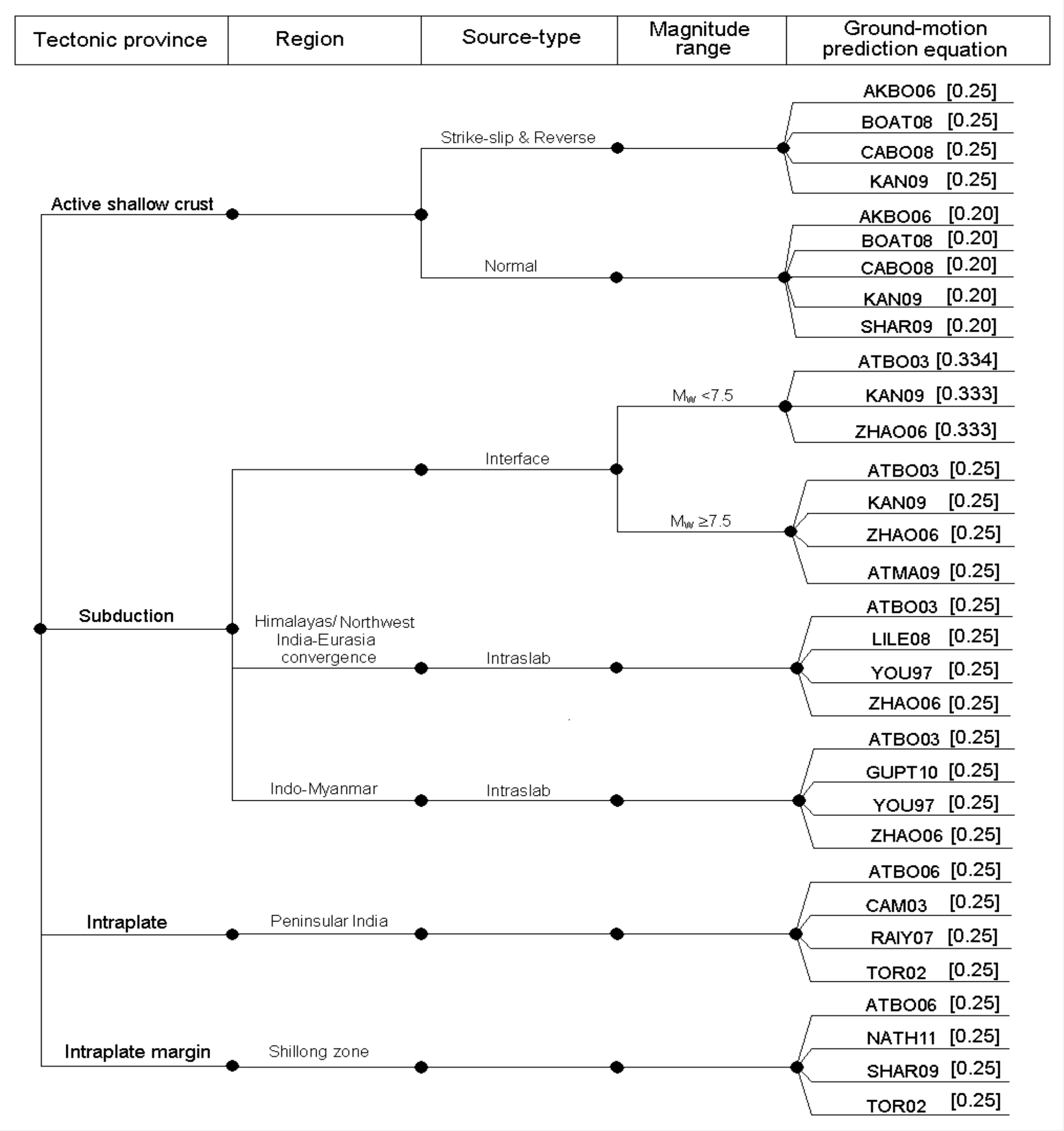
S_{VFS}=1 (Firm soil, S_{SR}=1 (Soft rock), S_{FR}=1 (Firm rock), S_{VFS}= S_{SR}=S_{FR}=0 (Firm soil.
F_{TH}=1 (Thrust faulting), F_{RV}=1 (Reverse), F_{RV}=F_{TH}=0(Strike slip and normal)

Typical Ground Motion Prediction Equations used for Seismic Hazard Estimation in Indian conditions developed for various tectonic provinces

Sl. No.	Region	Relationship	Reference
1.	Sikkim Himalaya, Shallow active tectonic crust	First order attenuation relation: $\ln(Y) = -3.6 + 0.72M - 1.08\ln r + 0.007r$ Where 'Y' is the strong motion parameter (PGA), '*M*' is earthquake magnitude, 'r' is a measure of source to site distance. $\ln(PGA) = \ln(SA) - a_1 - (a_2 - a_3 M) + a_4 h - a_5 \ln(SR)$ Second order attenuation relation: Where 'h' is the site elevation, 'SR' the site response, 'SA' spectral acceleration at respective frequencies.	Nath *et al.* (2005)
2.	Peninsular India, SCR	$\ln(y_{br}) = C_1 + C_2(M-6) + C_3(M-6)^2 - \ln(r) - C_{4r} + \ln(\varepsilon_{br})$ Where C_1, C_2,…,C_4 are regression coefficients, *ybr* = (*Sa/g*) stands for the ratio of spectral acceleration at bedrock level to acceleration due to gravity, '*M*' and '*r*' refers to moment magnitude and hypocentral distance respectively, $\ln(\varepsilon_{br})$ is the error term.	Raghukanthand Iyengar (2007)
3.	Himalayas and Zagros region, Shallow active tectonic crust	$\log A = b_1 + b_2 M_w - b_3 \log\sqrt{R_{jb}^2 + b_4^2} + b_5 S + b_6 H$ Where b_1, b_2, ….., b_6 are regression coefficients, 'A' is the spectral acceleration in terms of m/sec2, 'S' is 1 for rock site and 0 otherwise, 'H' is 1 for strike slip mechanism and 0 for reverse mechanism, 'M_w' is the magnitude and 'R_{jb}' represents the distance to the surface projection of the rupture.	Sharma *et al.* (2009)
4.	Gujarat, SCR	$\ln(Y) = -7.9527 + 1.4043M_w - \ln(r_{jb}^2 + 19.822)^{1/2} - 0.0682S$ For 3.1 < Mw ≤ 7.7 std.dev. (σ): ± 0.8243 Where 'Y' is peak horizontal acceleration in 'g', 'M_w' is moment magnitude, 'r_{jb}' is the closest distance to the surface projection of the fault rupture in kilometers, 'S' is a variable taking the values of 0 and 1 according to the local site geology, 'S' is 0 for a rock site, and, 'S' is 1 for a soil site.	Mandal *et al.* (2009)
5.	Northeast India, Active intraplate deformation	Spectral attenuation relation: $\ln(PGA) = C_1 + C_2 M + C_3(10-M)^3 + c_4\ln[r_{rup} + C_5\exp(C_6 M)] + C_7 S_v + C_8\ln(SR) + C_9\ln(SA)$ Where *PGA* is in 'g', '*M*' is the earthquake moment magnitude, 'r_{rup}' is the rupture distance (km), 'S_v' represents the effective shear wave velocity averaged over the top 30 meters overburden, '*SR*' is the site response, and '*SA*' is the spectral acceleration.	Nath *et al.* (2009)

Ground Motion Prediction:

Select a suitable ground motion prediction (attenuation) equation valid for the study region from the list provided in Table 14B. In the event of availability of more than one relation, all the relations should be considered based on the logic tree framework indicated by Nath and Thingbaijam (2011b)



The logic tree framework for the ground motion prediction equations; the assigned weights are given inside the square brackets and the references for the codes used for the equations (after Nath and Thingbaijam 2011b).

Computational model for PSHA:

A logic tree framework implementing the fundamental PSHA formulation developed by Cornell (1968) and Esteva (1970):

$$\nu_i(a > A) = \lambda_i \int_m \int_r \int_\sigma P(a > A \mid m, r, \sigma) f_m(m) f_r(r) f_\sigma(\sigma)\, dm\, dr\, d\sigma$$

(a>A) : annual frequency of exceedance of ground motion amplitude A,

λ : the activity rate for i^{th} *source*

P:probability of a exceeding A given magnitude m at source-to-site distance r.

$f_m(m)$

$f_r(r)$ probability density functions

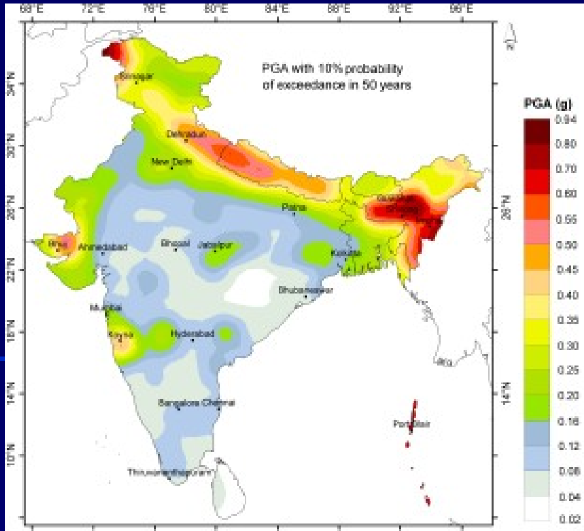
$f_\sigma(\sigma)$

$f_\sigma(\sigma)$ Log - normal distribution

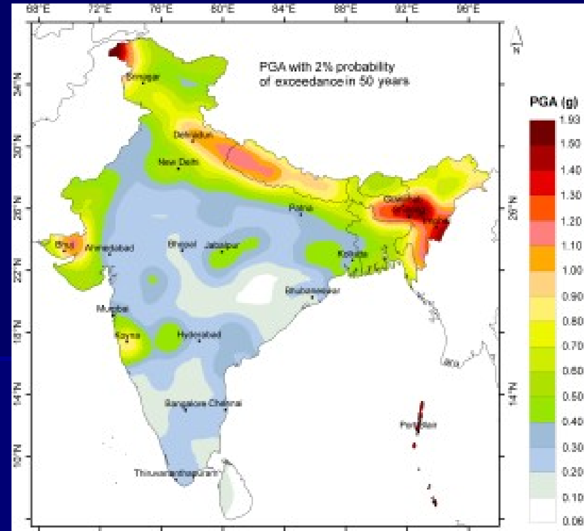
(Aleatory unceratainity)

$$f_m(m) = \frac{\beta \exp[-\beta(m - m_{\min})]}{1 - \exp[-\beta(m_{\max} - m_{\min})]}$$

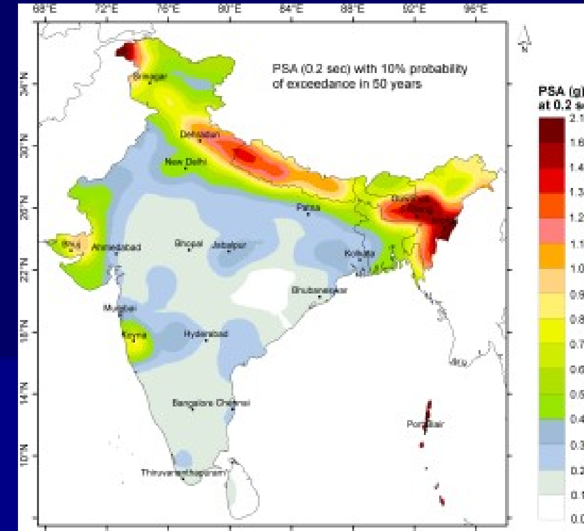
Where, $\beta = b \ln(10)$, and b refers to the *b-value* of GR relation, m_{min} and m_{max} *is the Mi*nimum magnitude and Maximum magnitude



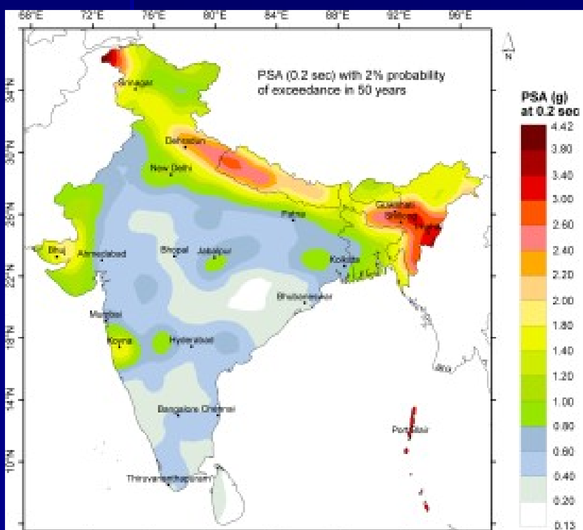
(a)



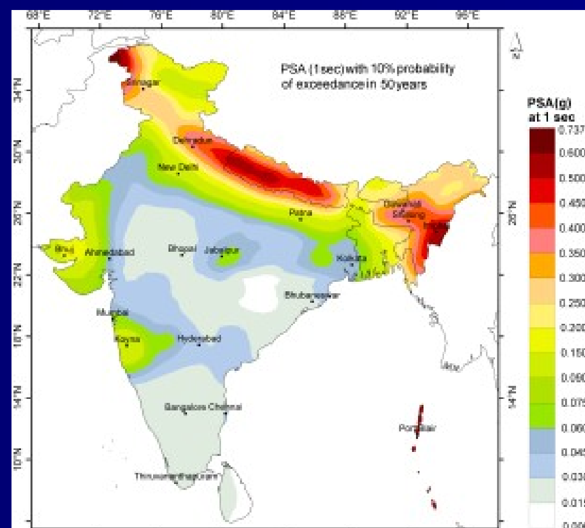
(b)



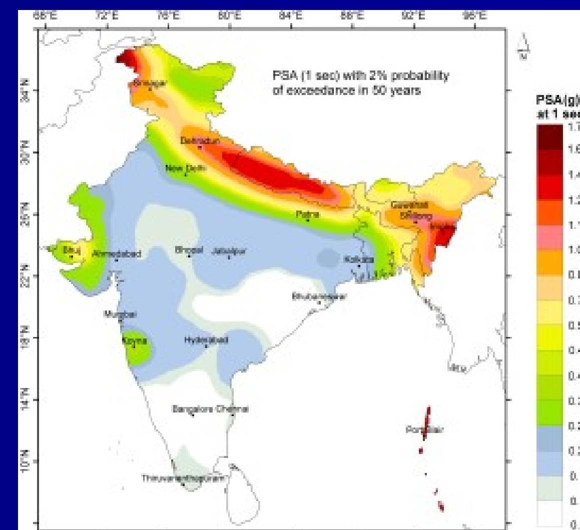
(c)



(d)



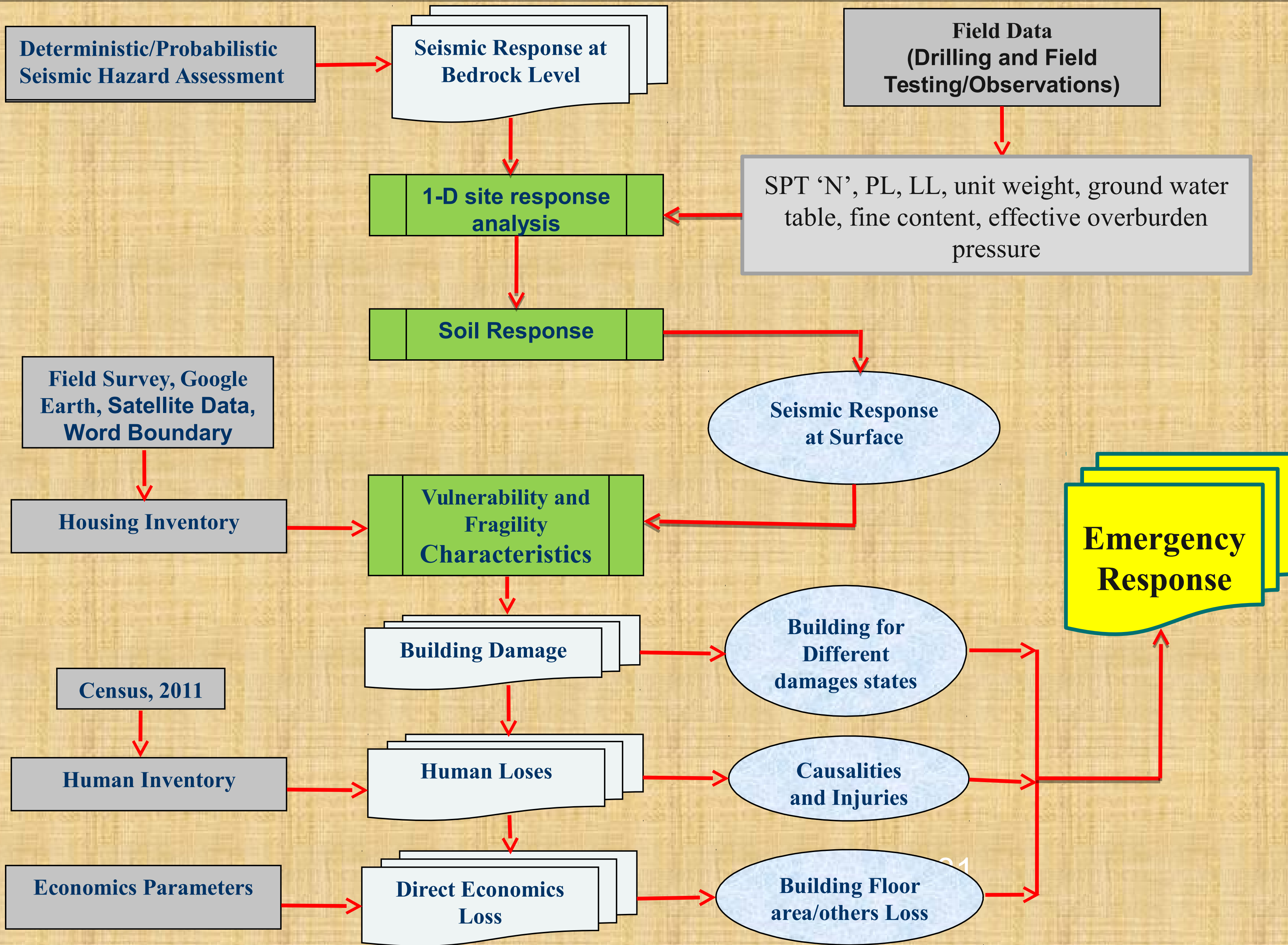
(e)



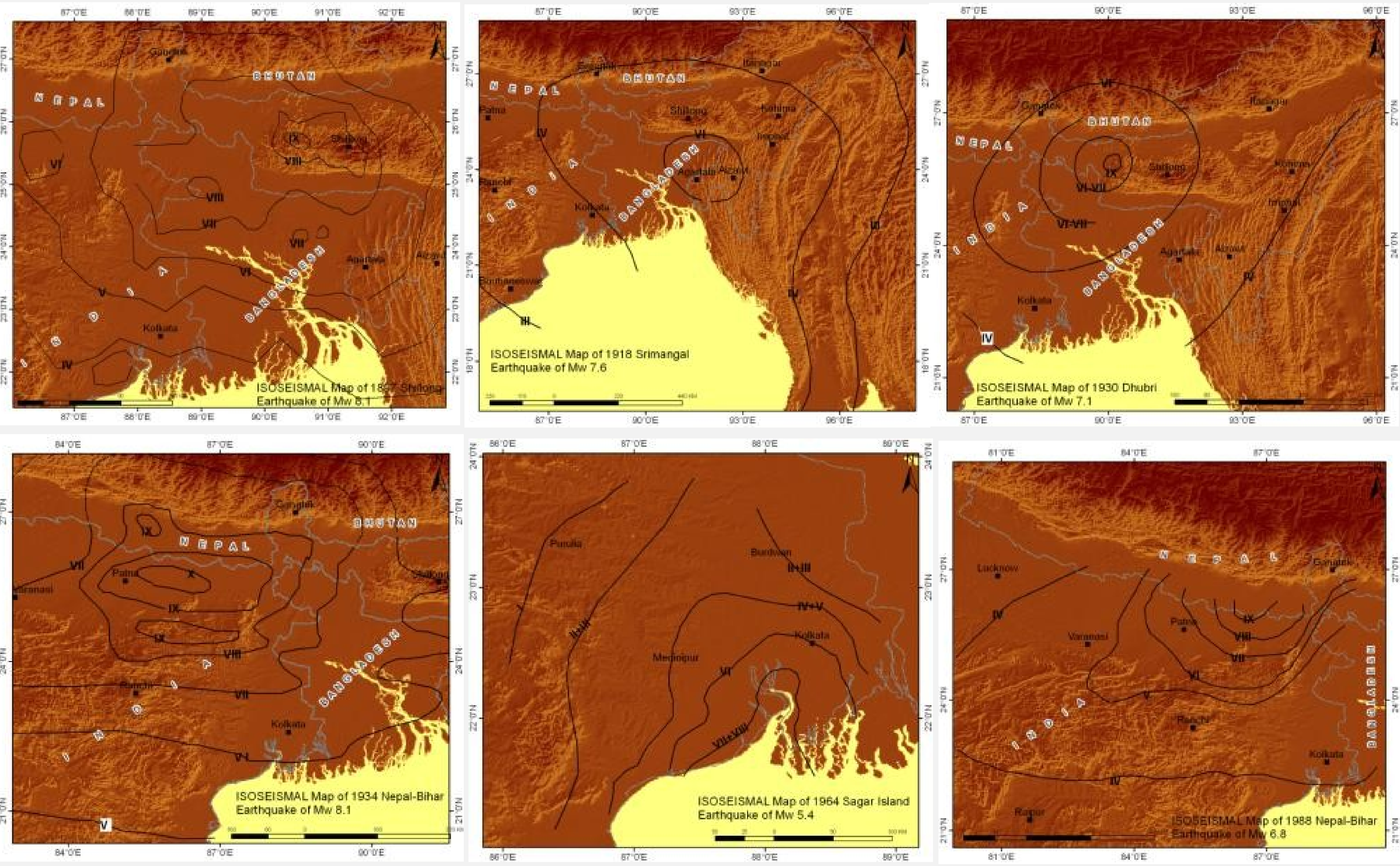
(f)

Seismic hazard distribution in India in terms of PGA, PSA at 0.2 sec. and 1sec. for firm rock site conditions. Also included in the maps are the data for Nepal, Bhutan, Bangladesh and Srilanka (after Nath and Thingbaijam 2012, SRL).

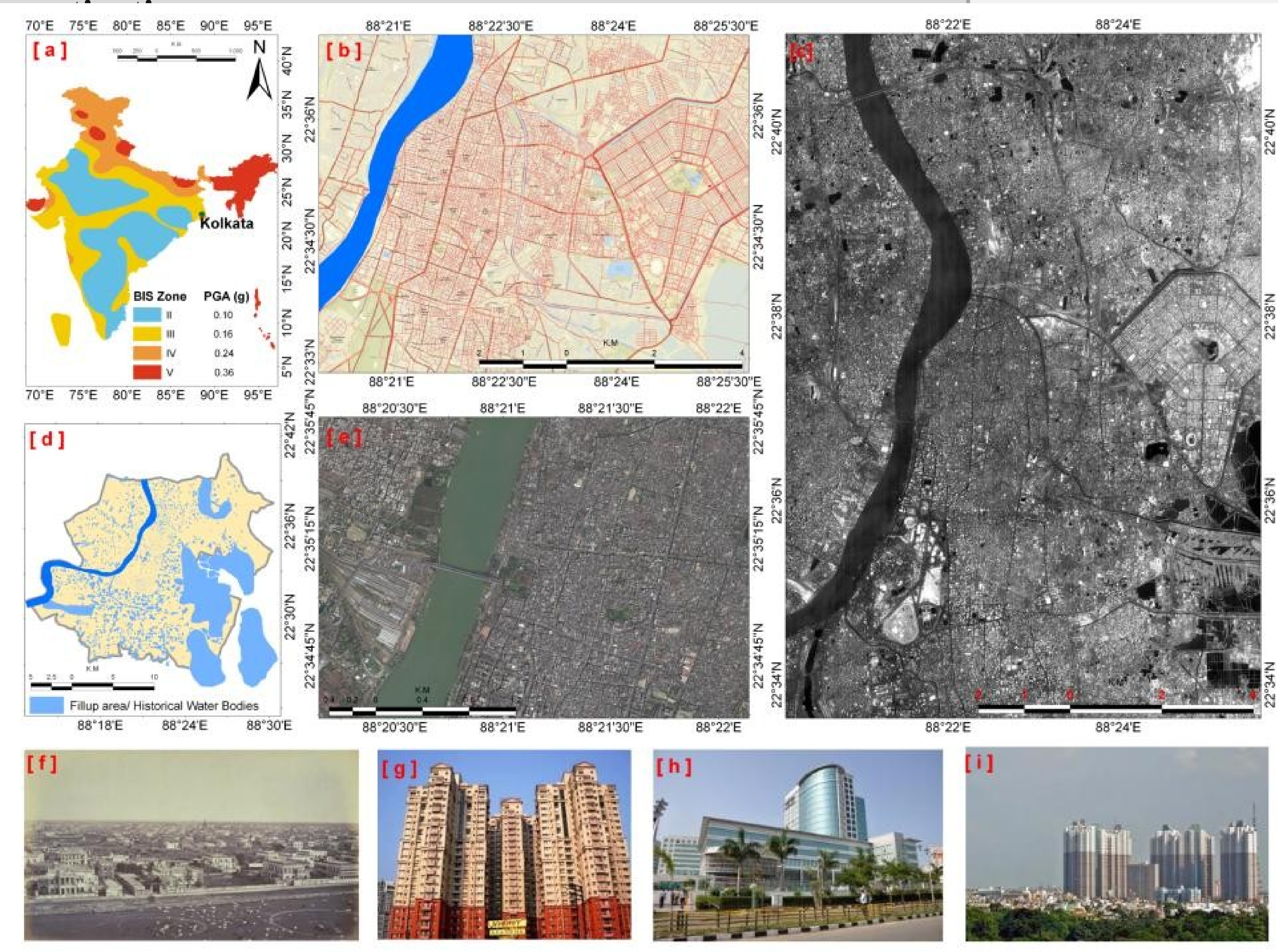
SELENA based Seismic Vulnerability and Loss Assessment :



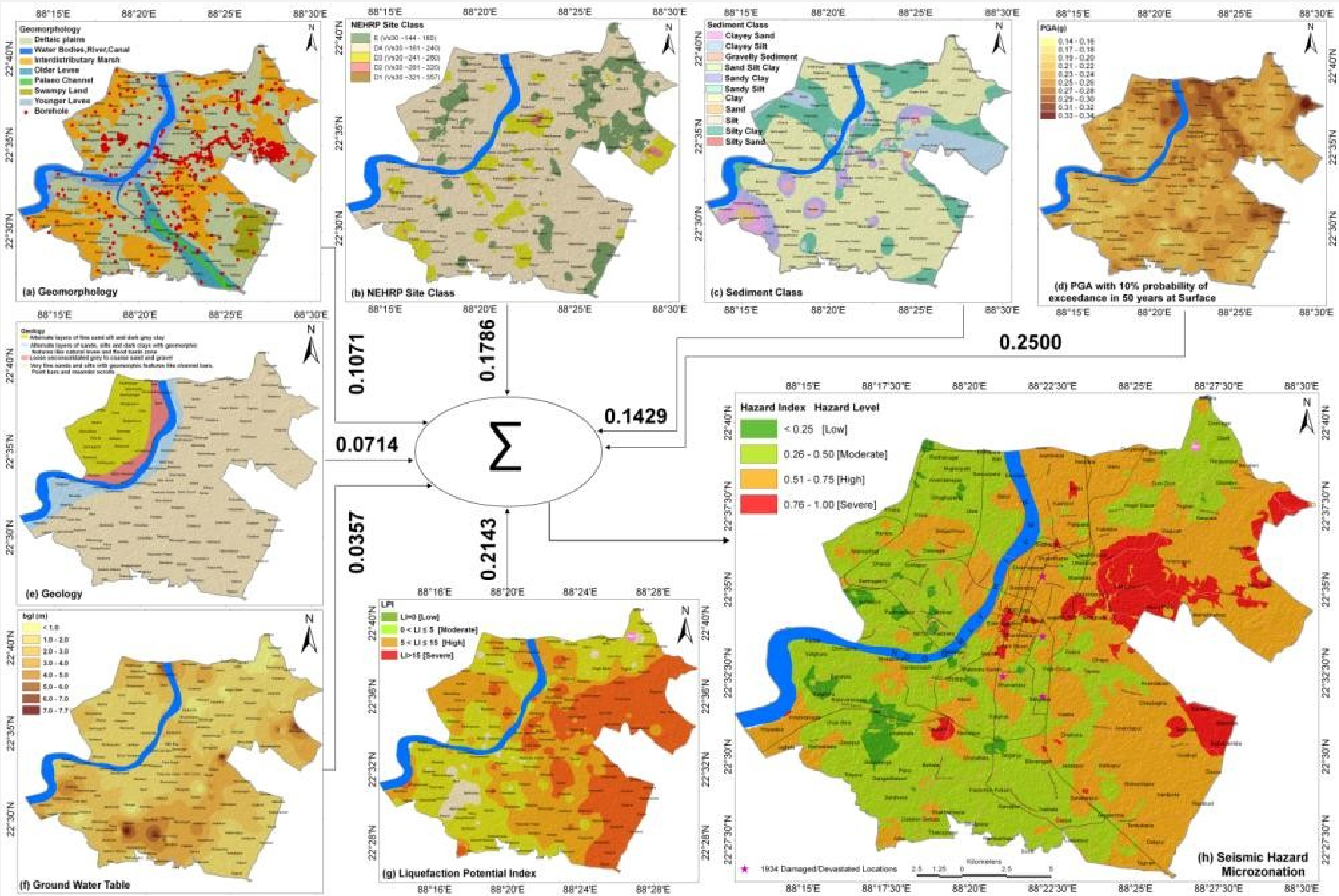
Observed Isoseismal map of Kolkata and adjoining region due to (a) 1897 Shillong Earthquake of Mw 8.1 (b) 1918 Srimangal Earthquake of Mw 7.6, (c) 1930 Dhubri Earthquake of Mw 7.1 (d) 1934 Nepal-Bihar Earthquake of Mw (e) 1964 Sagar Island Earthquake of Mw 5.4 and (f) 1988 Nepal-Bihar Earthquake of Mw 6.8.



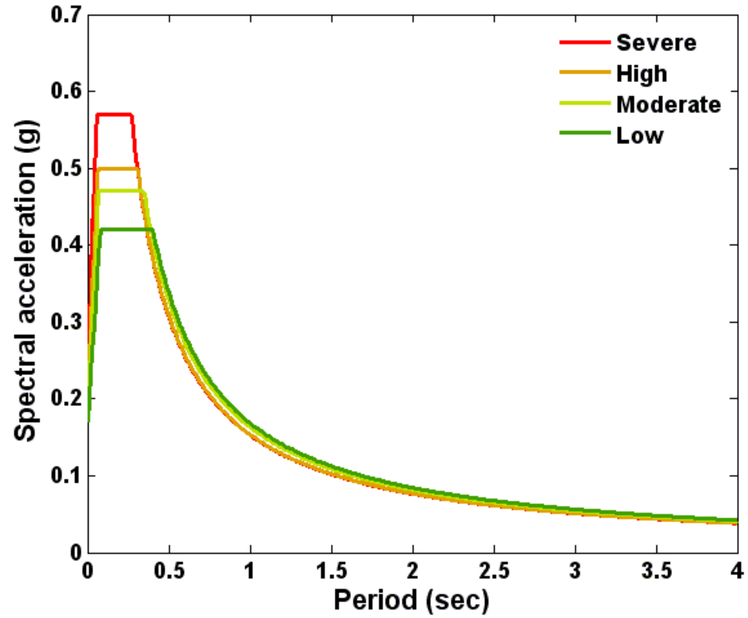
Urban Kolkata, the study region of the present i



Seismic Hazard Microzonation protocol for Kolkata

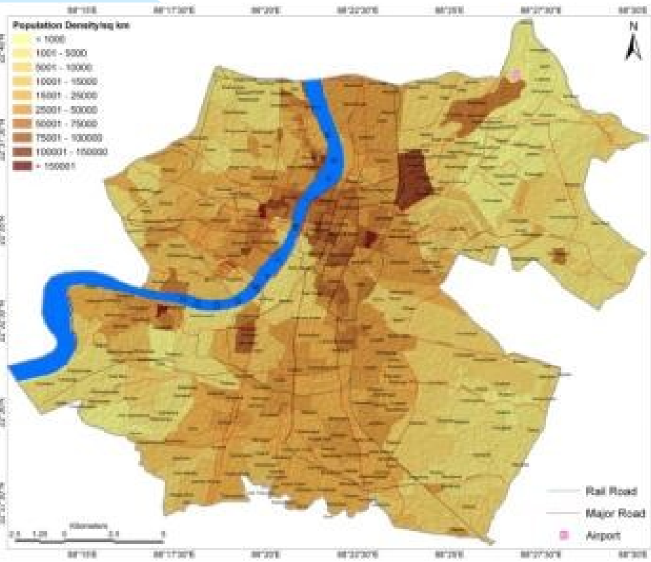


The proposed Zone Factors (ZF) for Seismic Hazard subzones in Kolkata with corresponding Design Response Spectra and Liquefaction Susceptibility (LS)

Hazard Level	Z_F (g)	L_S	Design Response Spectra (IBC, 2009)
Low	0.20	LPI=0	
Moderate	0.27	0< LPI≤7	
High	0.30	4< LPI≤16	
Severe	0.34	LPI> 15	

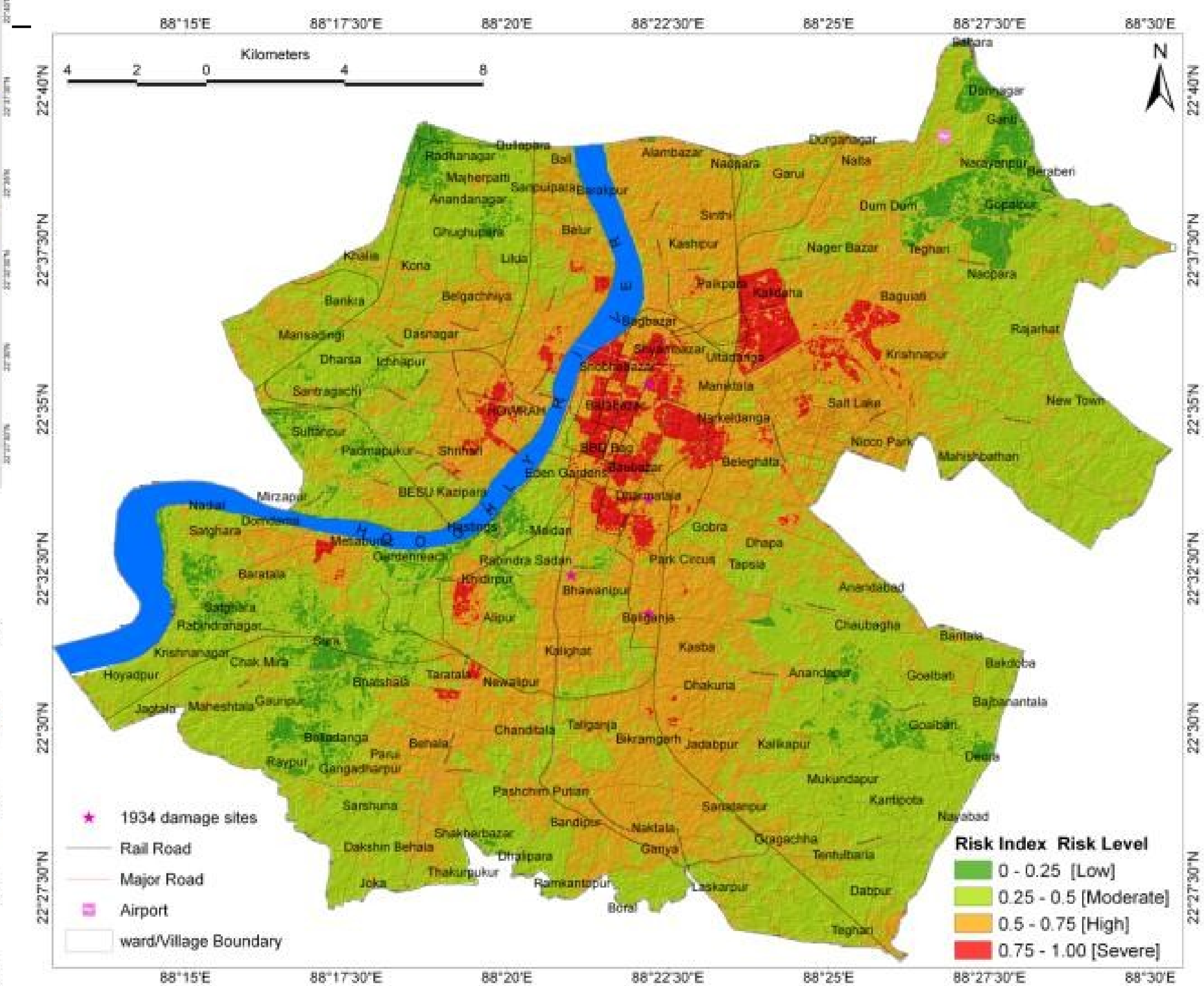
Socio-economic Seismic Risk Assessment

Population Density, Census, 2011

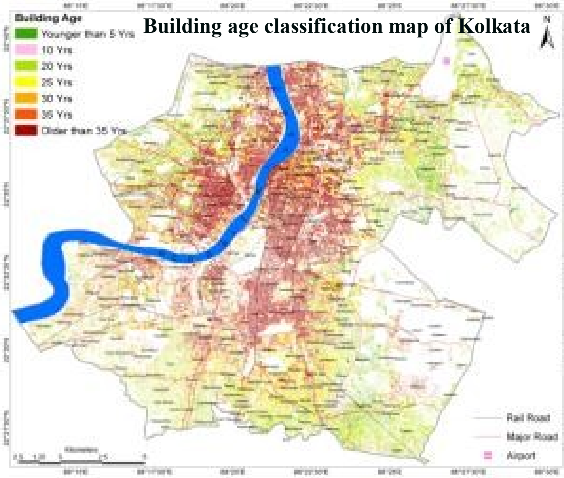


Landuse/landcover map of Kolkata

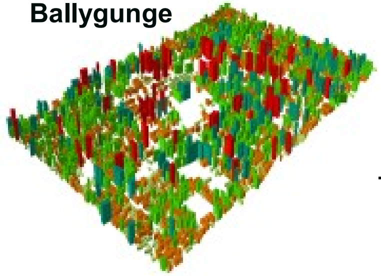
Probabilistic Seismic Socio-Economic Risk Map of Kolkata



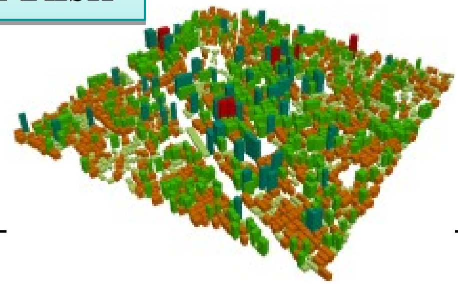
Seismic Structural Risk



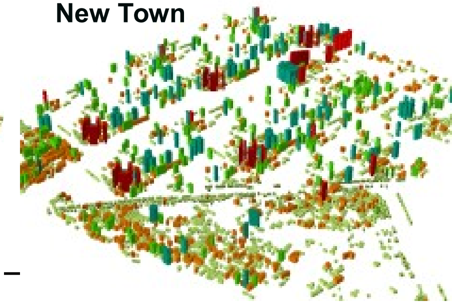
Ballygunge



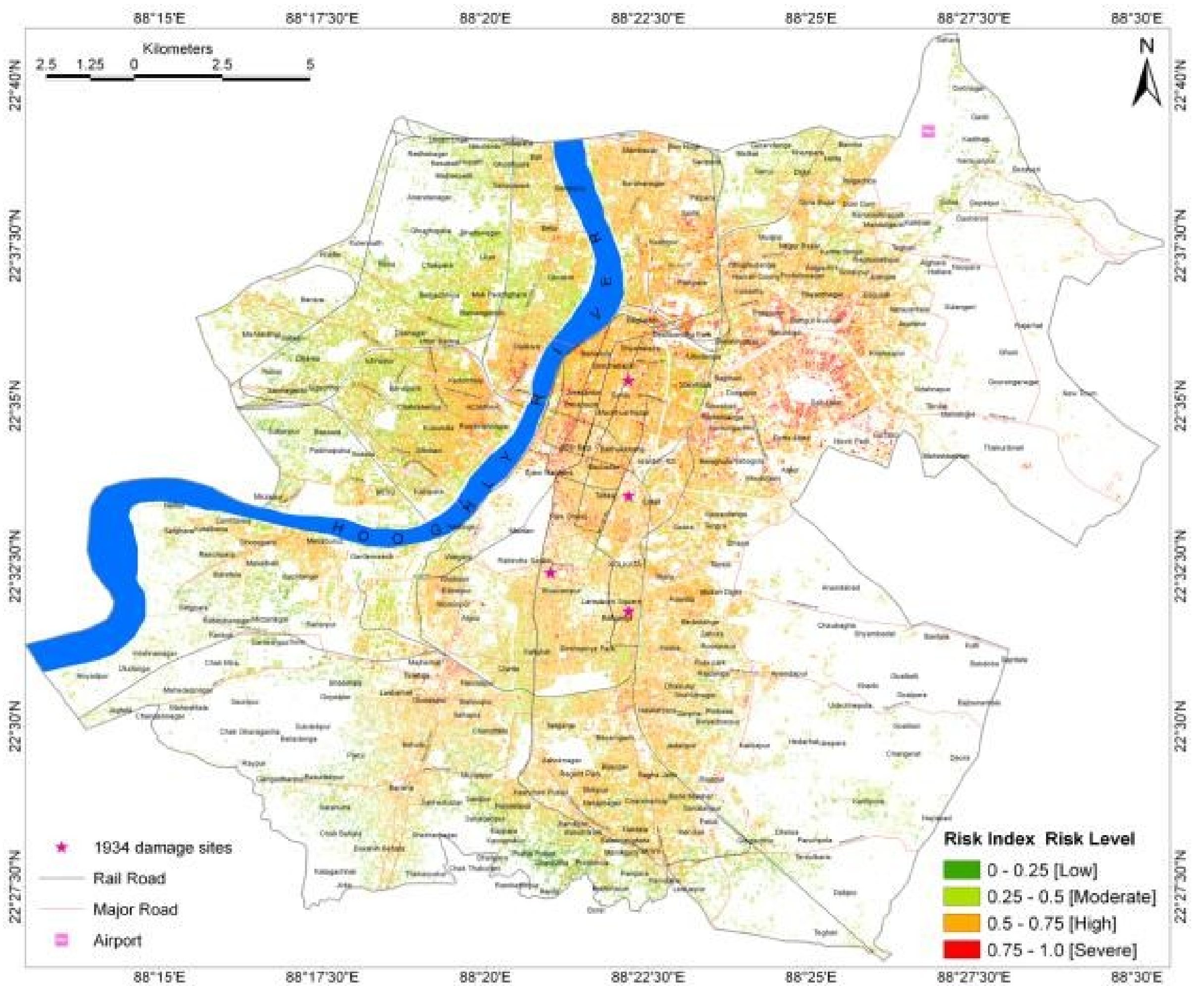
South Kolkata



New Town



Probabilistic Seismic Structural Risk Map of Kolkata

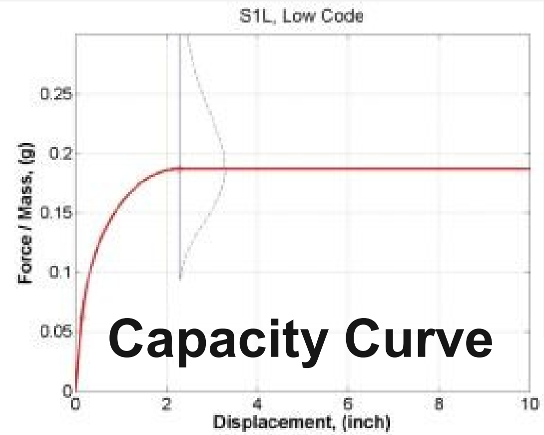


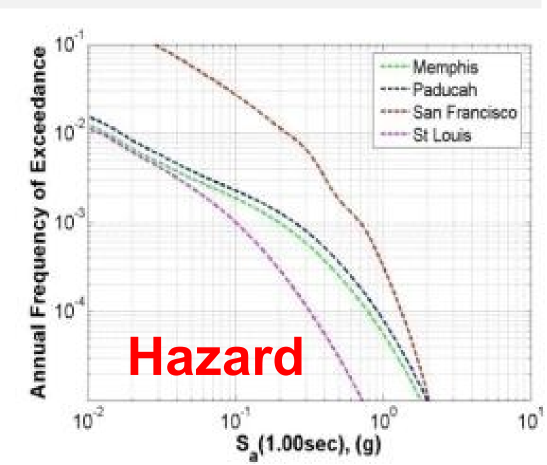
Vulnerability Exposures:

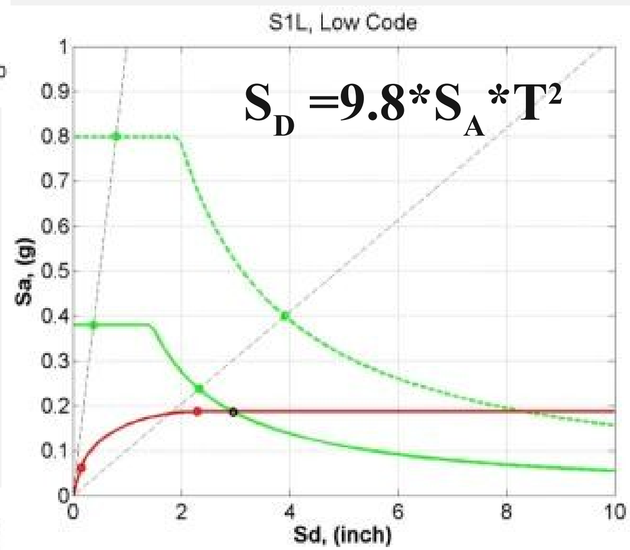
Selected Model Building Types:

Model Building Type	Description	Height	Stories	References
C1L	Ductile reinforced concrete moment frame with or without infill	Low-Rise	1 – 3	FEMA, 2000
C1M		Mid-Rise	4 - 7	
C1H		High-Rise	8+	
C3L	Non-ductile reinforced concrete frame with masonry infill walls	Low-Rise	1 - 3	
C3M		Mid-Rise	4 - 7	
C3H		High-Rise	8+	
A1	Adobe block, mud mortar, wood roof and floors	Low-Rise	1	WHE-PAGER project, 2007
RS2	Local field stones with mud mortar.	Low-Rise	1-2	
UFB5-1	Unreinforced fired brick masonry, cement mortar, but with reinforced concrete floor and roof slabs	Low-Rise	1-2	
UFB5-2		High-Rise	2-4	
HER	Heritage building	-	-	-

SELENA based Building Damage Assessment

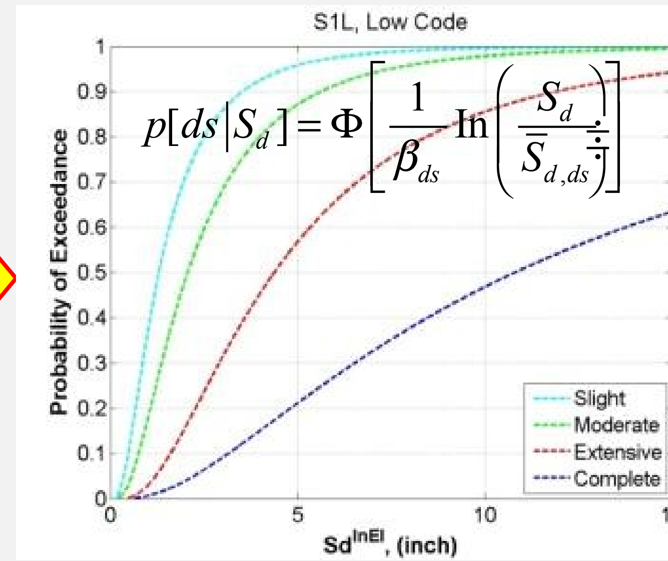






Capacity Spectrum Method

Damage State Definition

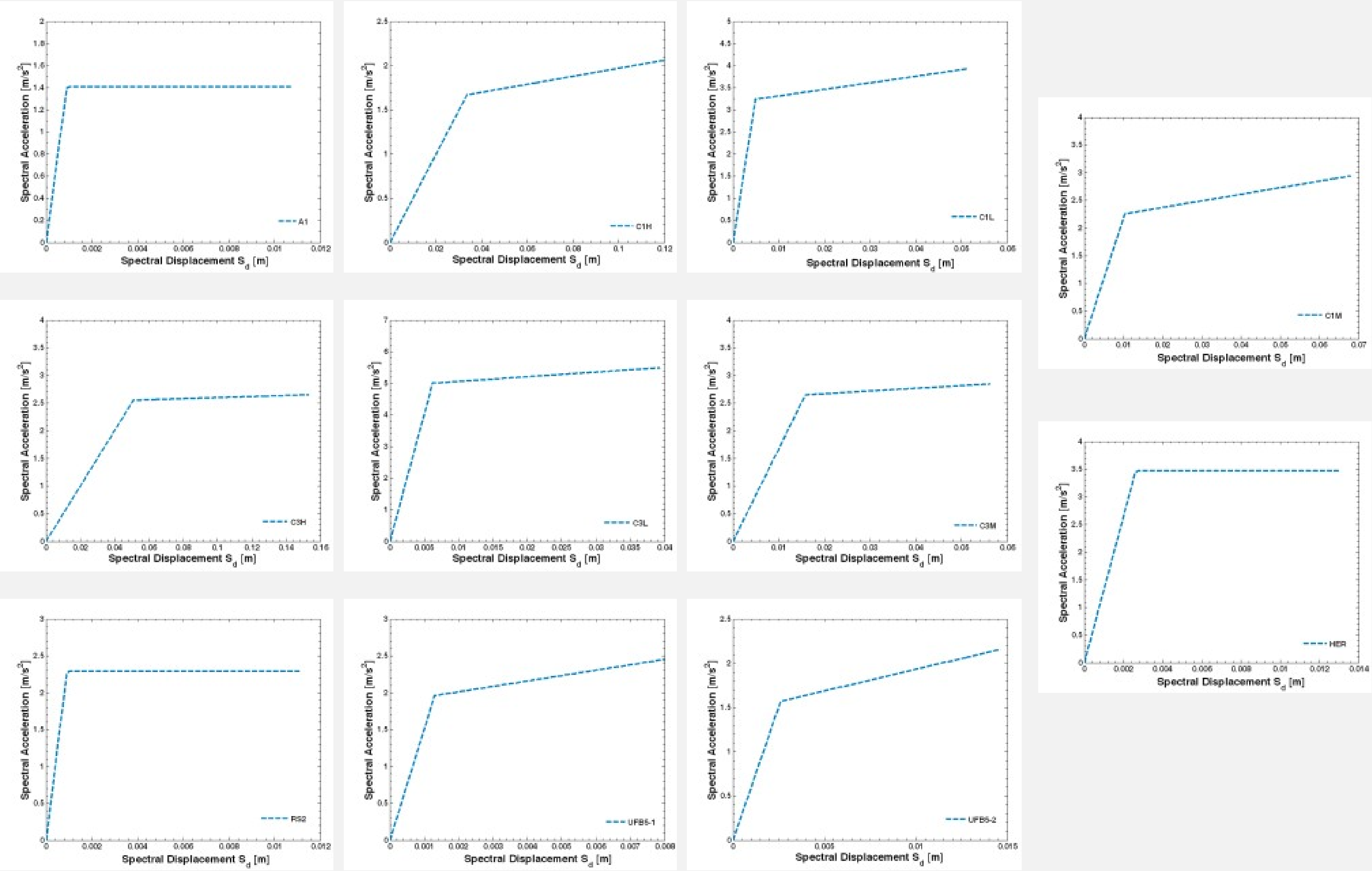


Fragility Curve Input:
Inelastic Spectral Displacement

Where, $p[ds|S_d]$ = Probability of being in or exceeding a damage state, d_s; S_d= Given spectral displacement (inches); $\overline{S}_{ds}$= Median value of S_d at which the building reaches threshold of damage state d_s; β_{ds} = Lognormal standard deviation of spectral displacement of damage state, d_s; and Φ = Standard normal cumulative distribution function

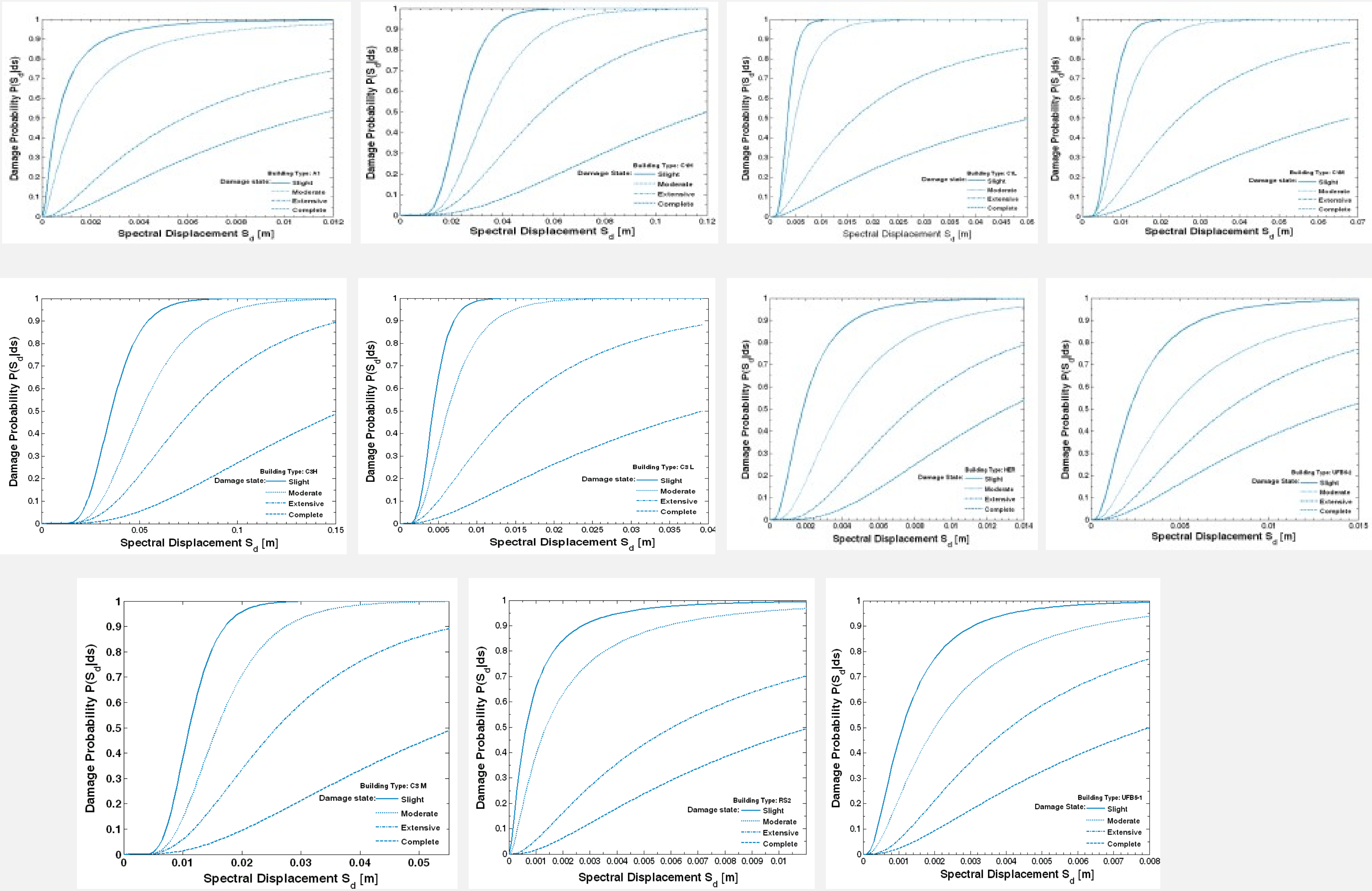
Molina, S., D. H. Lang, C. D. Lindholm (2010). SELENA—an open-source tool for seismic risk and loss assessment using a logic tree computation procedure, Computers & Geosciences. 36, 257–69.

Capacity Curve of eleven model building type's i.e. A1, RS2, UFB5-1, UFB5-2, C1L, C1M, C1H, C3L, C3M, C3H and HER for Kolkata city



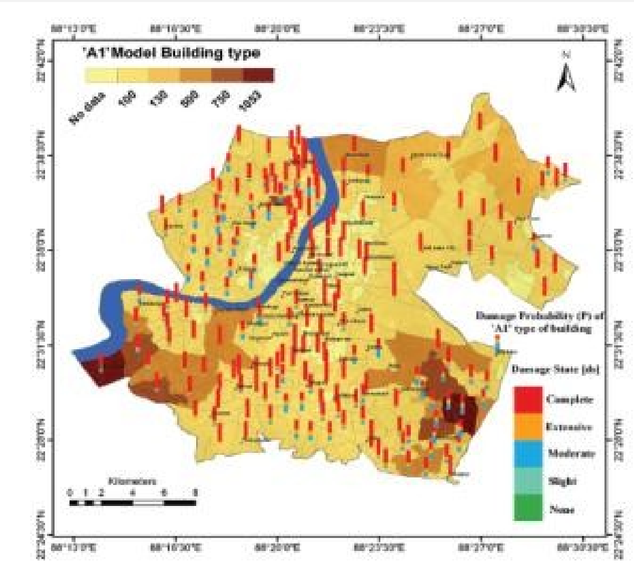
FEMA (2001). HAZUS99 Estimated Annualized Earthquake Loss for the United States, Report FEMA 366, Federal Emergency Management Agency, Washington, DC, U.S.A.

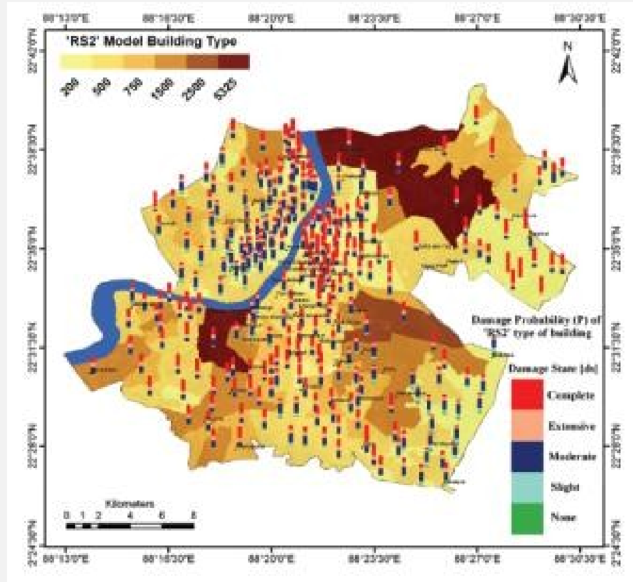
Fragility curves of eleven model building type's i.e. A1, RS2, UFB5-1, UFB5-2, C1L, C1M, C1H, C3L, C3M, C3H and HER for Kolkata city

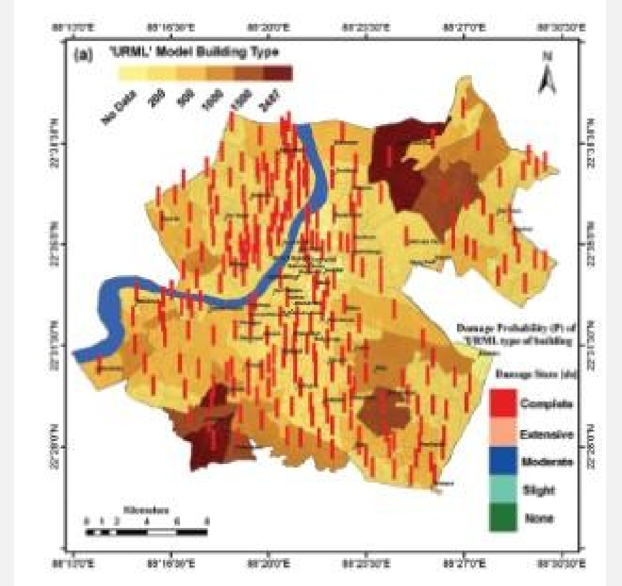


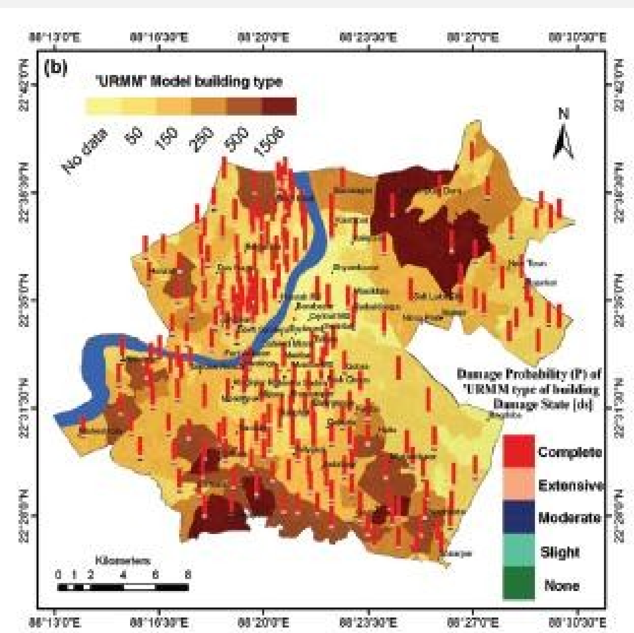
FEMA (2001). HAZUS99 Estimated Annualized Earthquake Loss for the United States, Report FEMA 366, Federal Emergency Management Agency, Washington, DC, U.S.A.

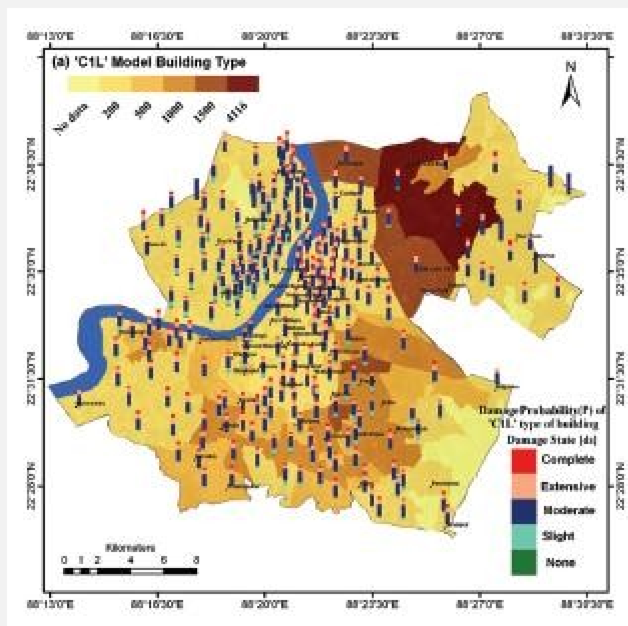
Quantification of structural damage of eleven Model Building types using SELENA:

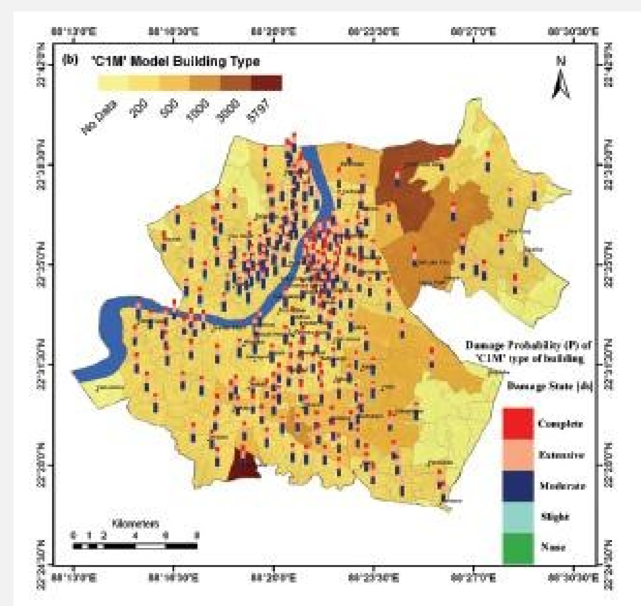


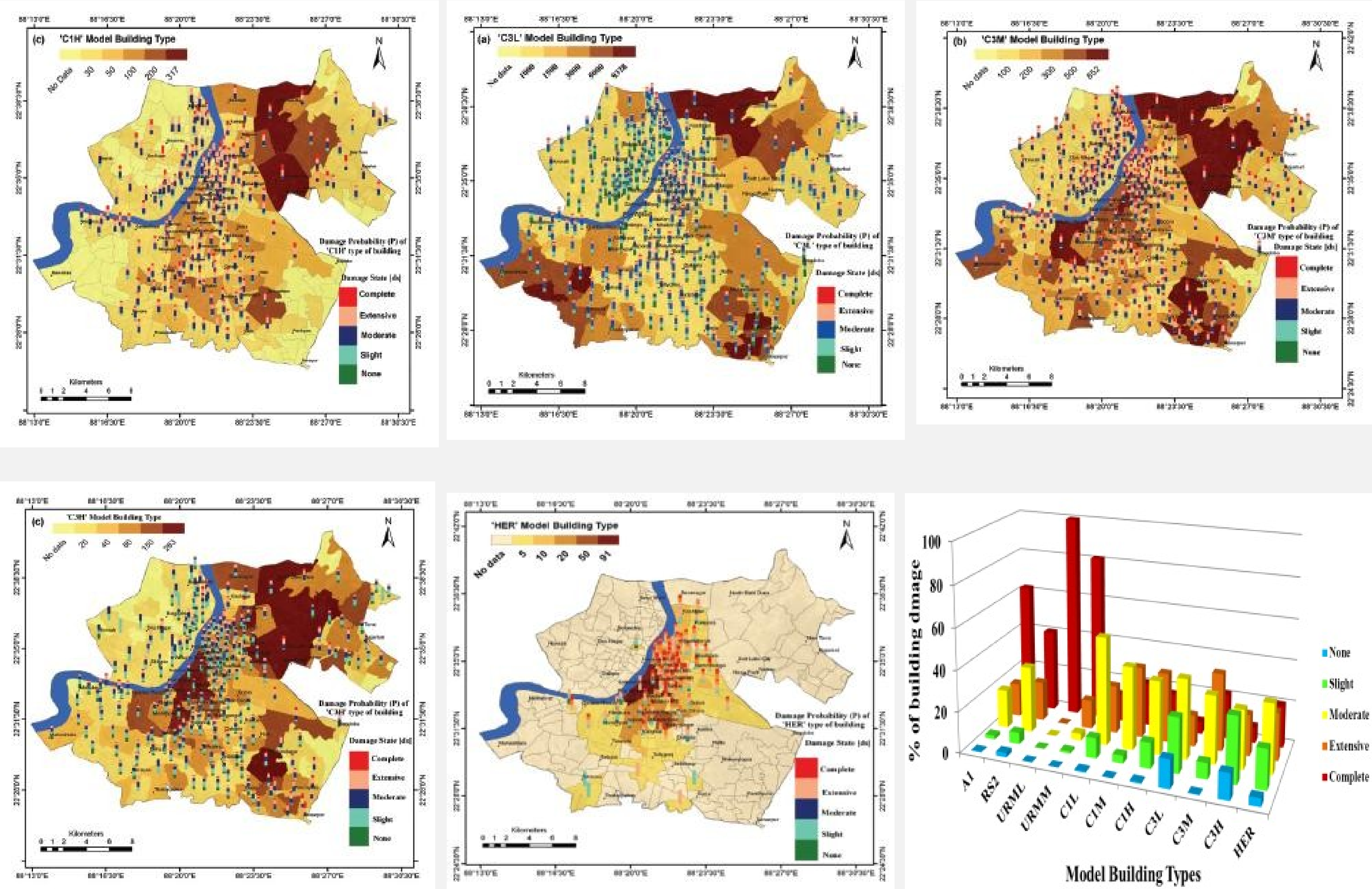












Predicted damage probability in terms of 'None', 'Slight', 'Moderate', 'Extensive', 'Complete' for the identified model building types in the City

Economic losses Assessment:

The economic losses for building repair (mostly for damage states *slight* and *moderate*) and replacement (mostly for damage states *extensive* and *complete*) has been computed by the following expression:

$$\mathrm{L}_{\mathrm{eco}} = \sum_{i=1}^{N_{OT}} \sum_{j=1}^{N_{BT}} \sum_{k=1}^{N_{DS}} A_{i,j} P_{j,k} C_{i,j,k}$$

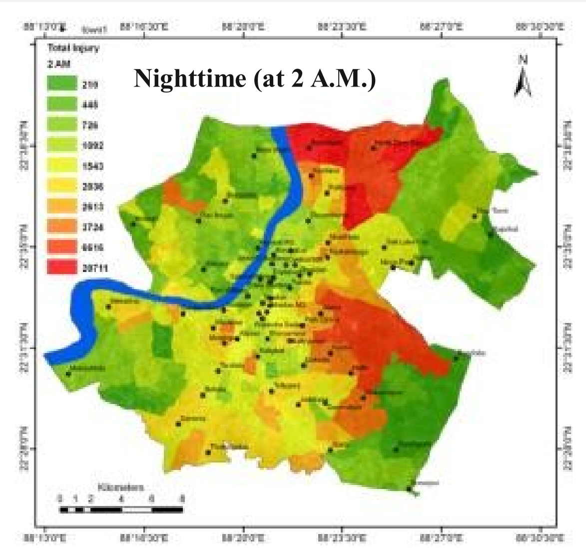
N_{OT} = number of occupancy types; N_{BT} = number of building typologies,
N_{DS} = number of damage states ds,
$\mathrm{A}_{\mathrm{i,j}}$ = built area of the model building type *j* in the occupancy type *i* (in [m^2])
$P_{j,k}$ = damage probability of a structural damage *k* (*slight*, *moderate*, *extensive* or *complete*) for model building type *j,*
$C_{i,j,k}$- = cost of repair or replacement (per [m²]) in the provided input currency of structural damage *k* for occupancy type *i* and model building type *j*

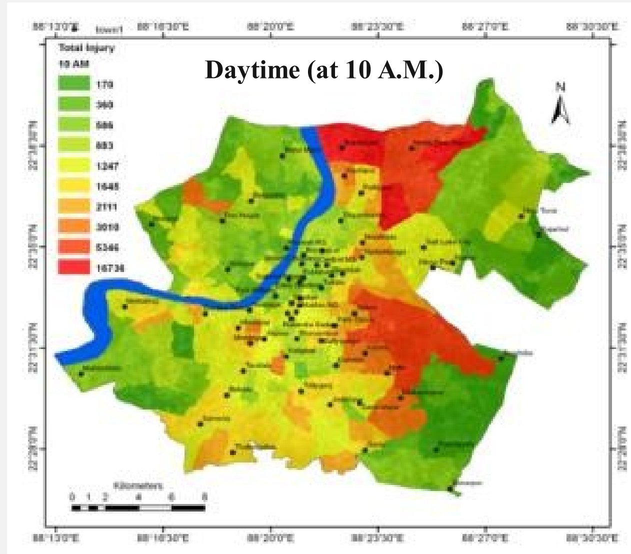
Construction cost (per square meter) for different Building typology of Kolkata

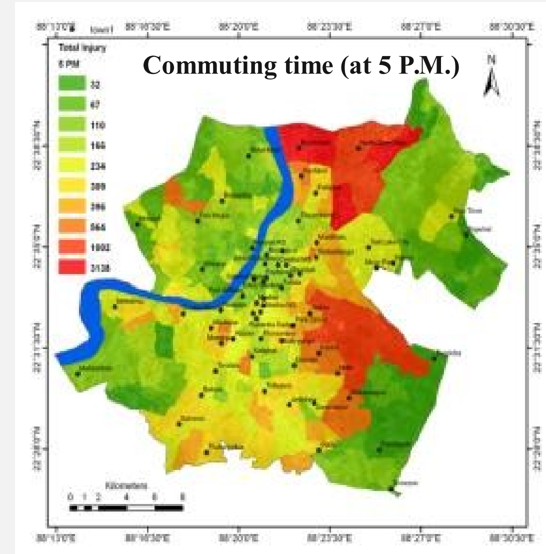
Building Types/Stories	Stories 1	Stories 2	Stories 3	Stories 4	Stories 5	Stories 6	Stories 7	Stories 8+
C1L	15441	9157	9695					
C1M				10104	10138	10332	10462	
C1H								41175
C3L	14928	11261	10039					
C3M				9768	9325	9035	8986	
C3H								10350
A1	8608							

Molina, S., D. H. Lang, C. D. Lindholm (2010). SELENA—an open-source tool for seismic risk and loss assessment using a logic tree computation procedure, Computers & Geosciences. 36, 257–69.

Estimated Total injured persons considering nighttime (at 2 A.M.), daytime (at 10 A.M.) and Commuting time (at 5 P.M.) population

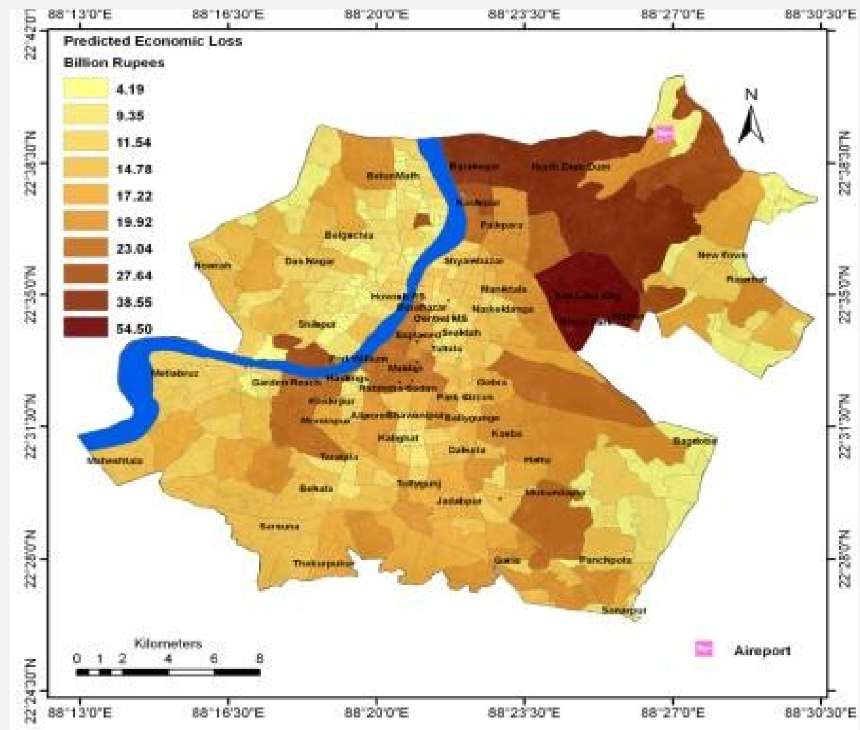






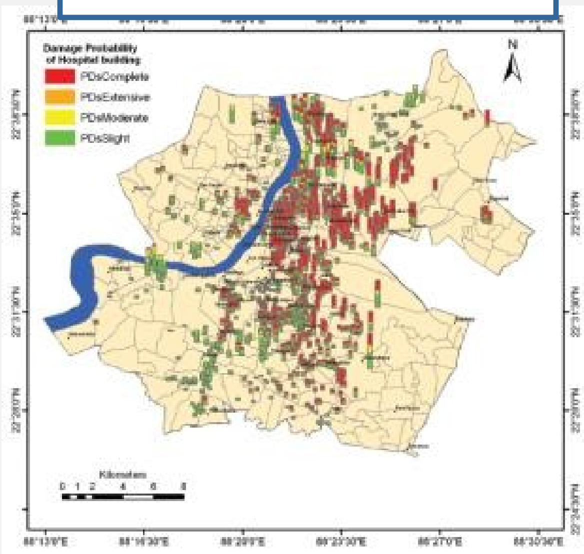
Economic losses Assessment:

Estimated economic loss due to structural damage for different damage states in term of slight, moderate, extensive and complete

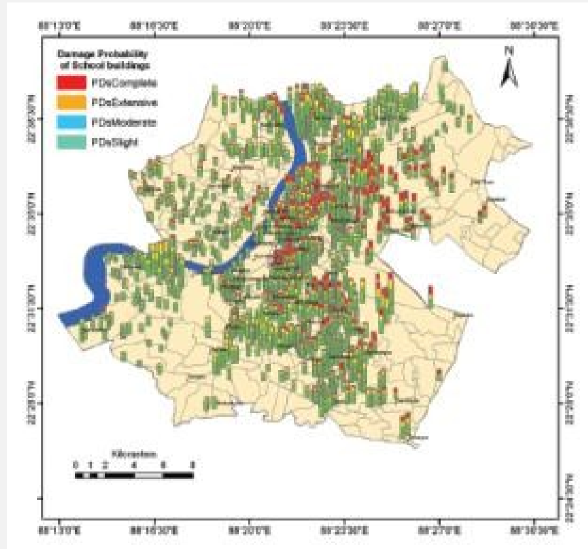


Damage and Loss Estimation of essential facilities using H

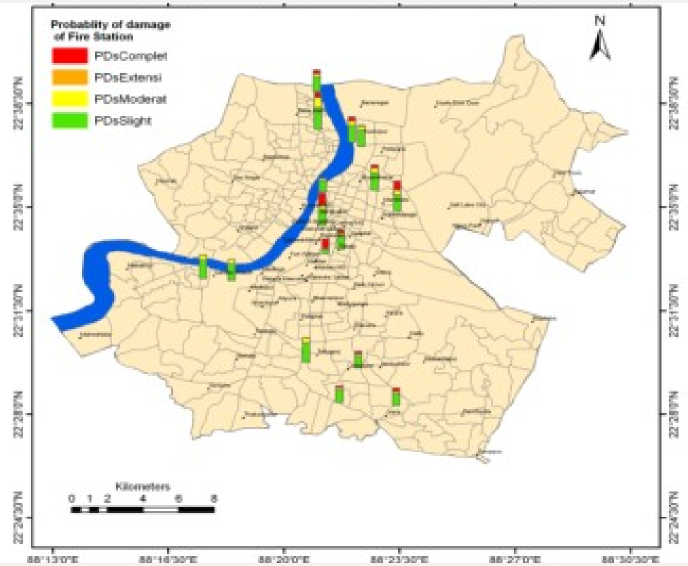
Damage to Medical care facilities



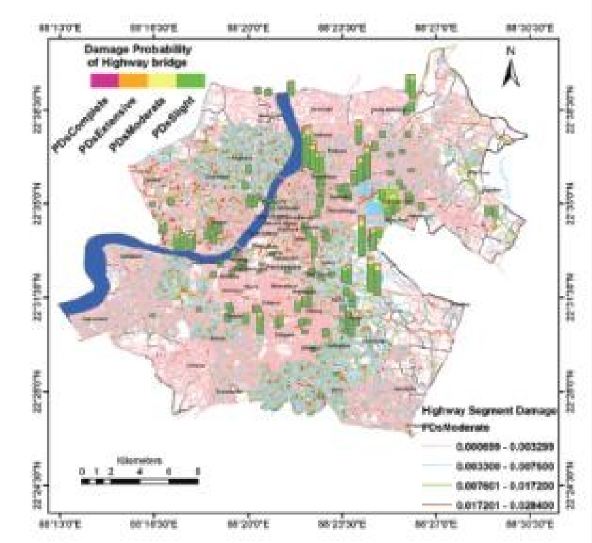
Damage to schools



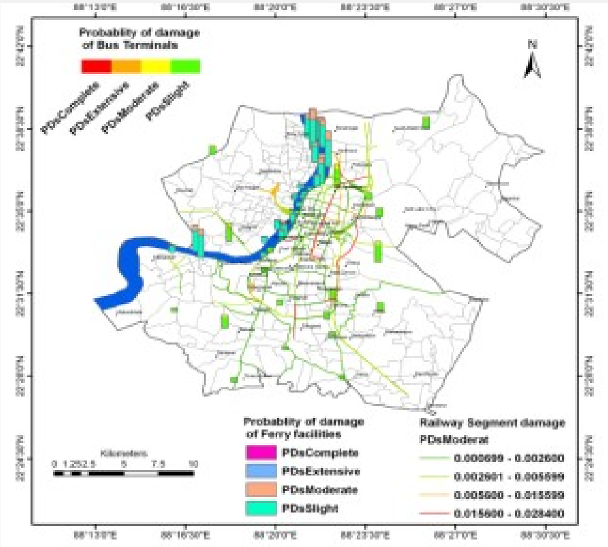
Damage to fire stations

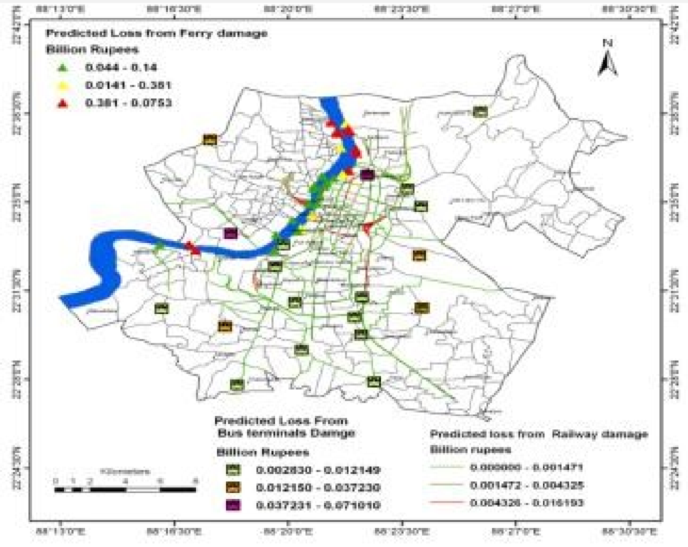


Damage and Loss estimation for highway segment

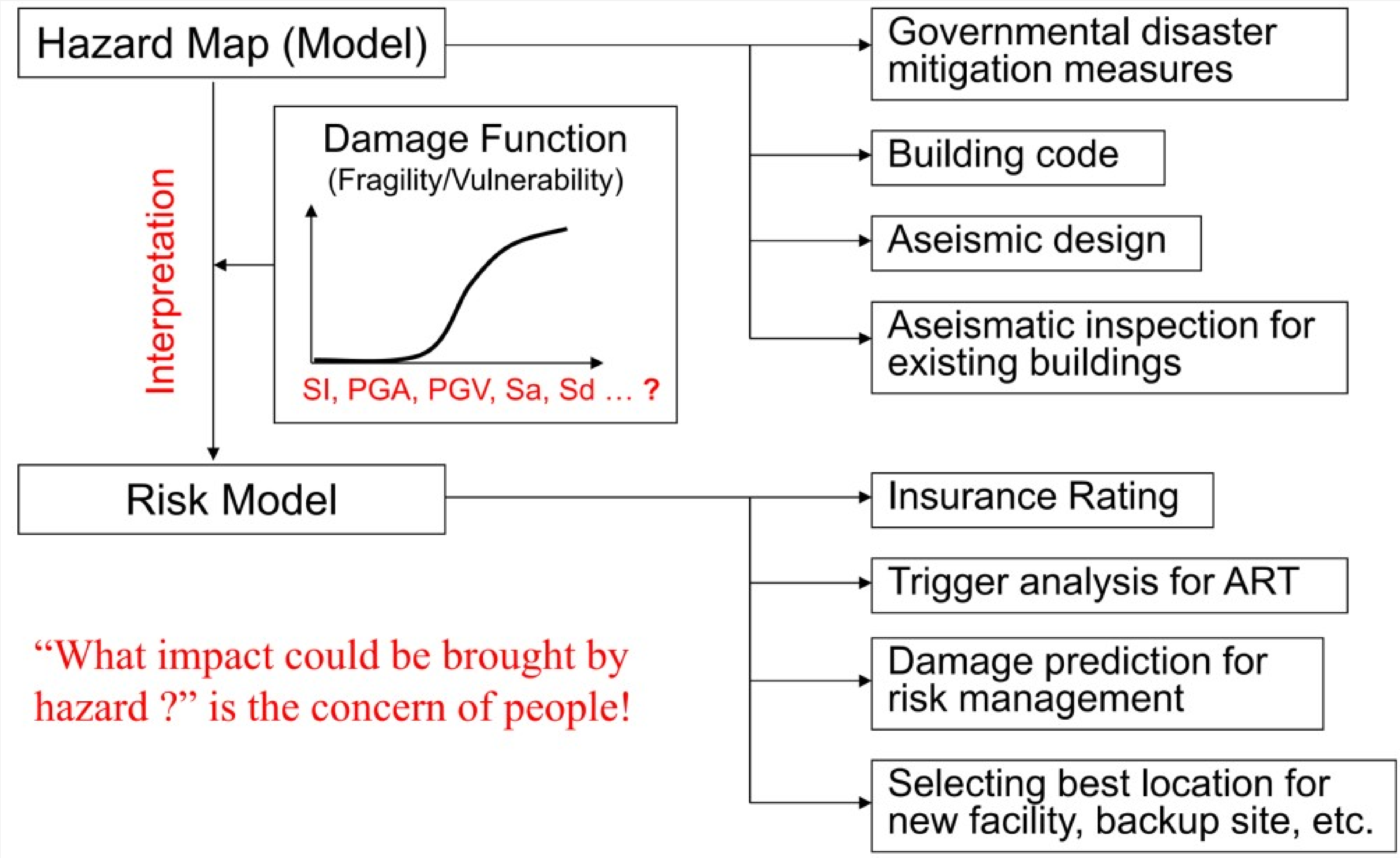


Predicted Damage distribution of the railway segments, bus terminals and ferry facilities of the City of Kolkata

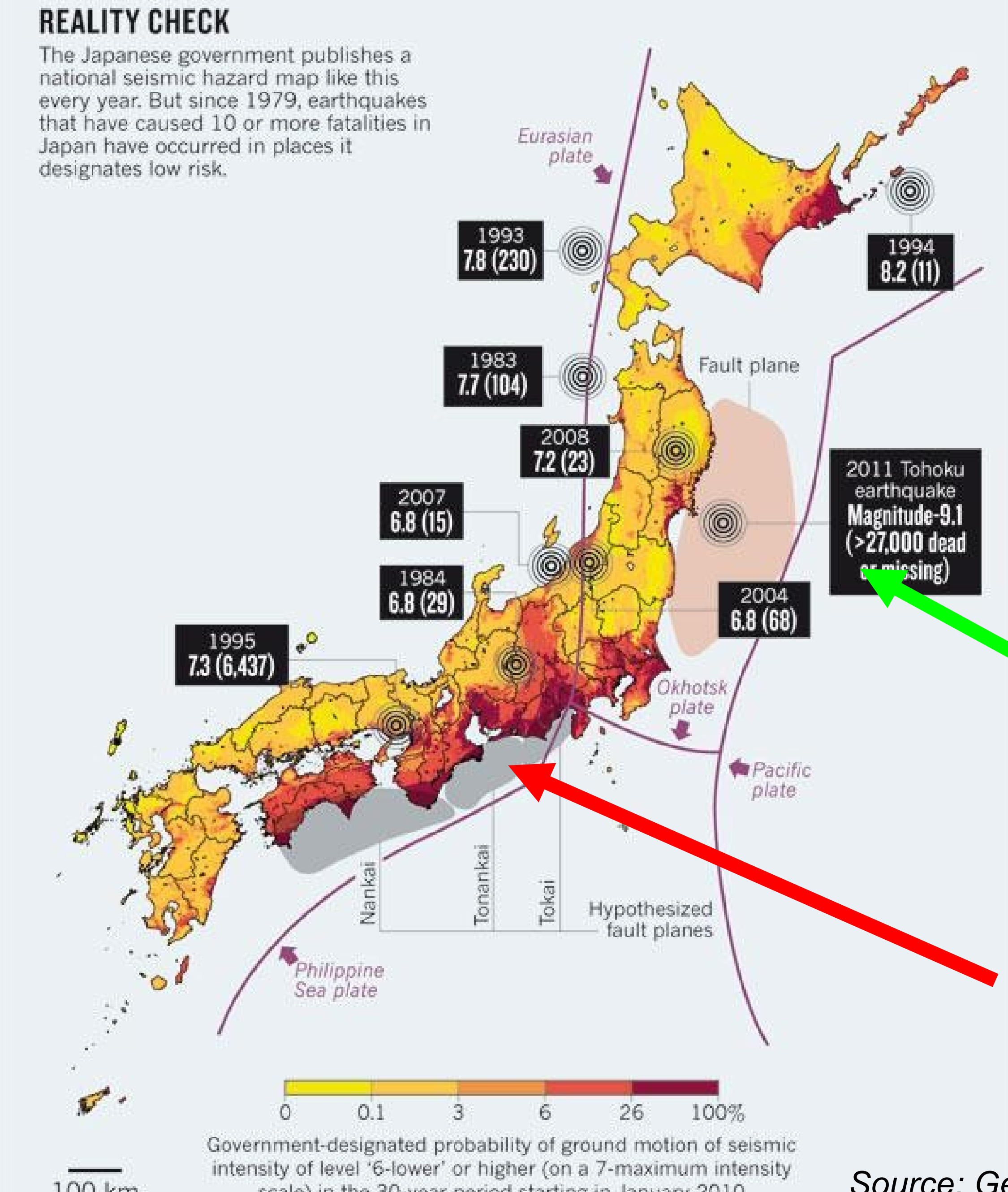




ication and capability of Hazard Map



smic Hazard Map of Japan:



Source: Geller, 2011

- **Probability-of-exceedance for JMA 6– in Japan for the 30-year period starting January 2010.**
- **This is an update of the 2005 maps prepared by Japan HERP (2005)**

Japan spent lots of effort on national hazard map, but

2011 M 9.1 Tohoku, 1995 Kobe M 7.3 & others in areas mapped as low hazard

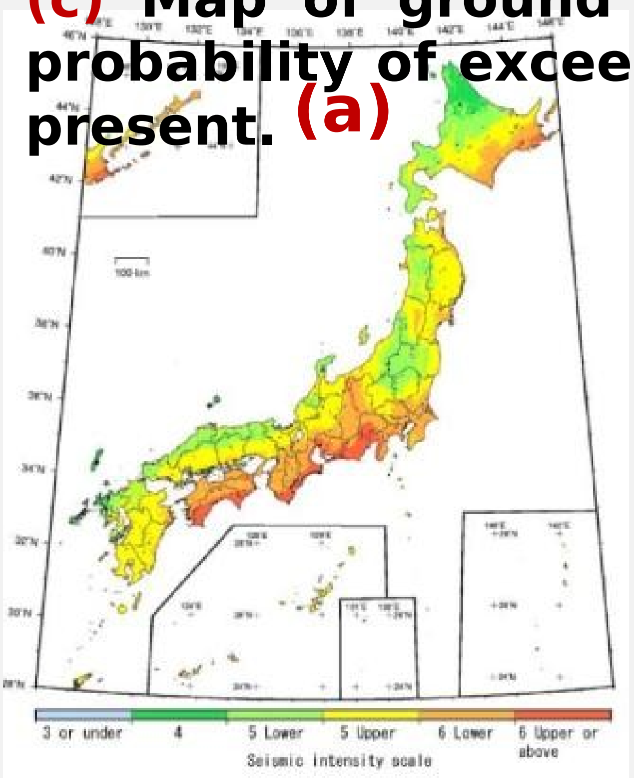
In contrast: map assumed high hazard in Tokai "gap"

abilistic Seismic Hazard Map of Japan:

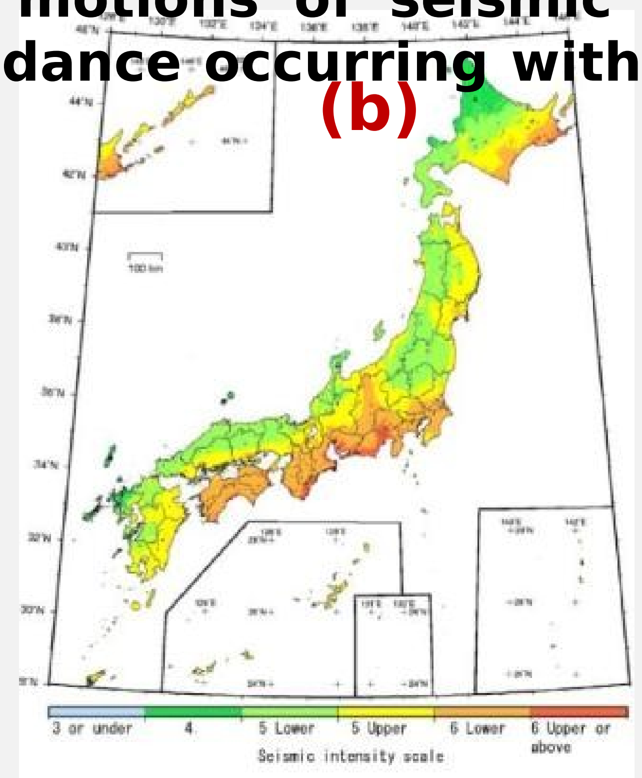
(a) **Map of ground motions of seismic intensity for a 5% probability of exceedance occurring within 50 years from the present.**

(b) **Map of ground motions of seismic intensity for a 10% probability of exceedance occurring within 50 years from the present.**

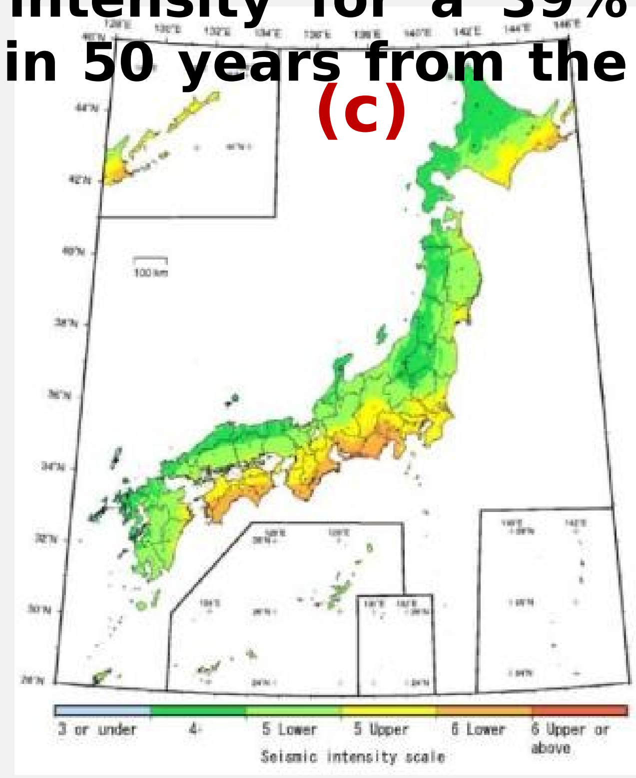
(c) **Map of ground motions of seismic intensity for a 39% probability of exceedance occurring within 50 years from the present.**



(a)



(b)

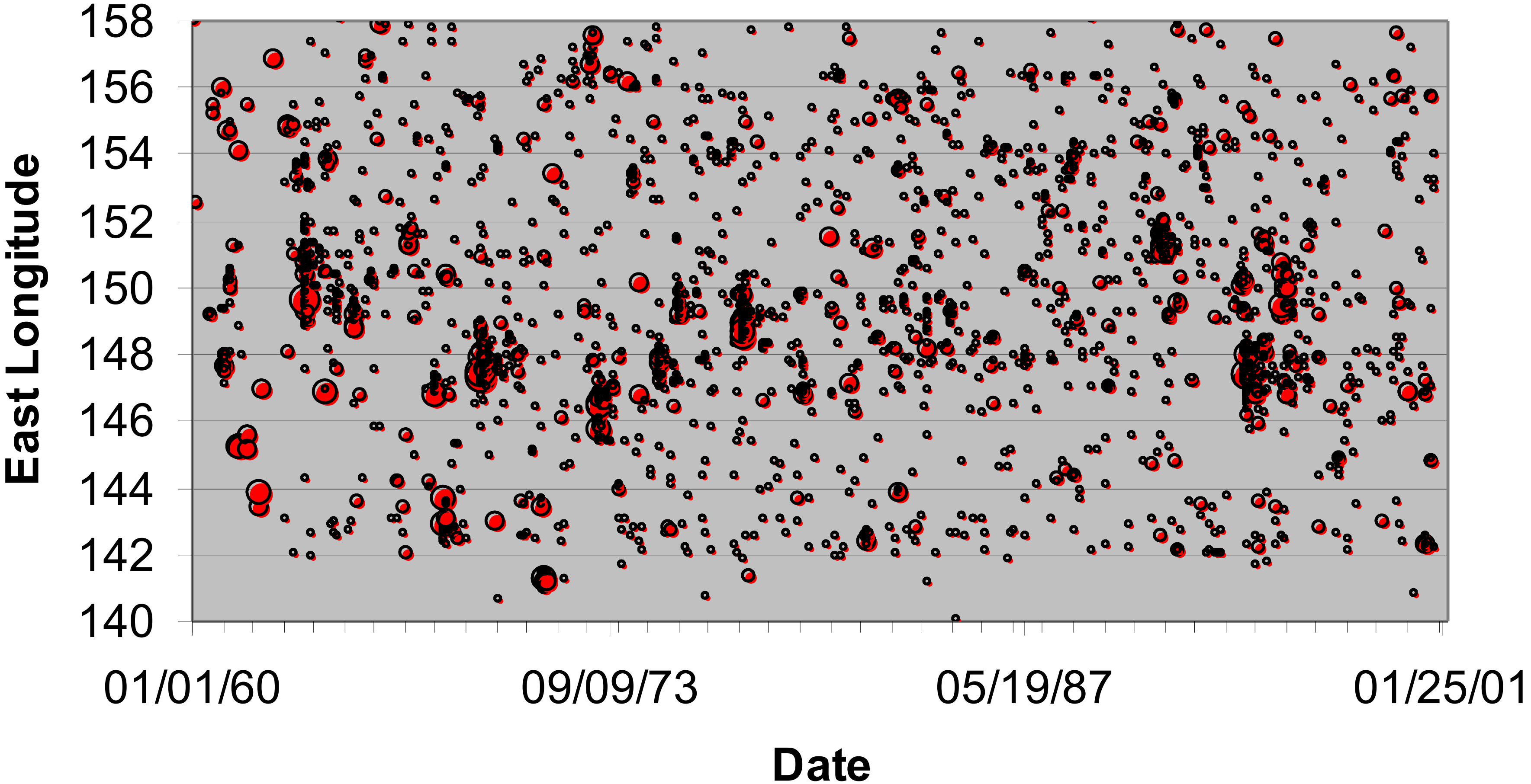


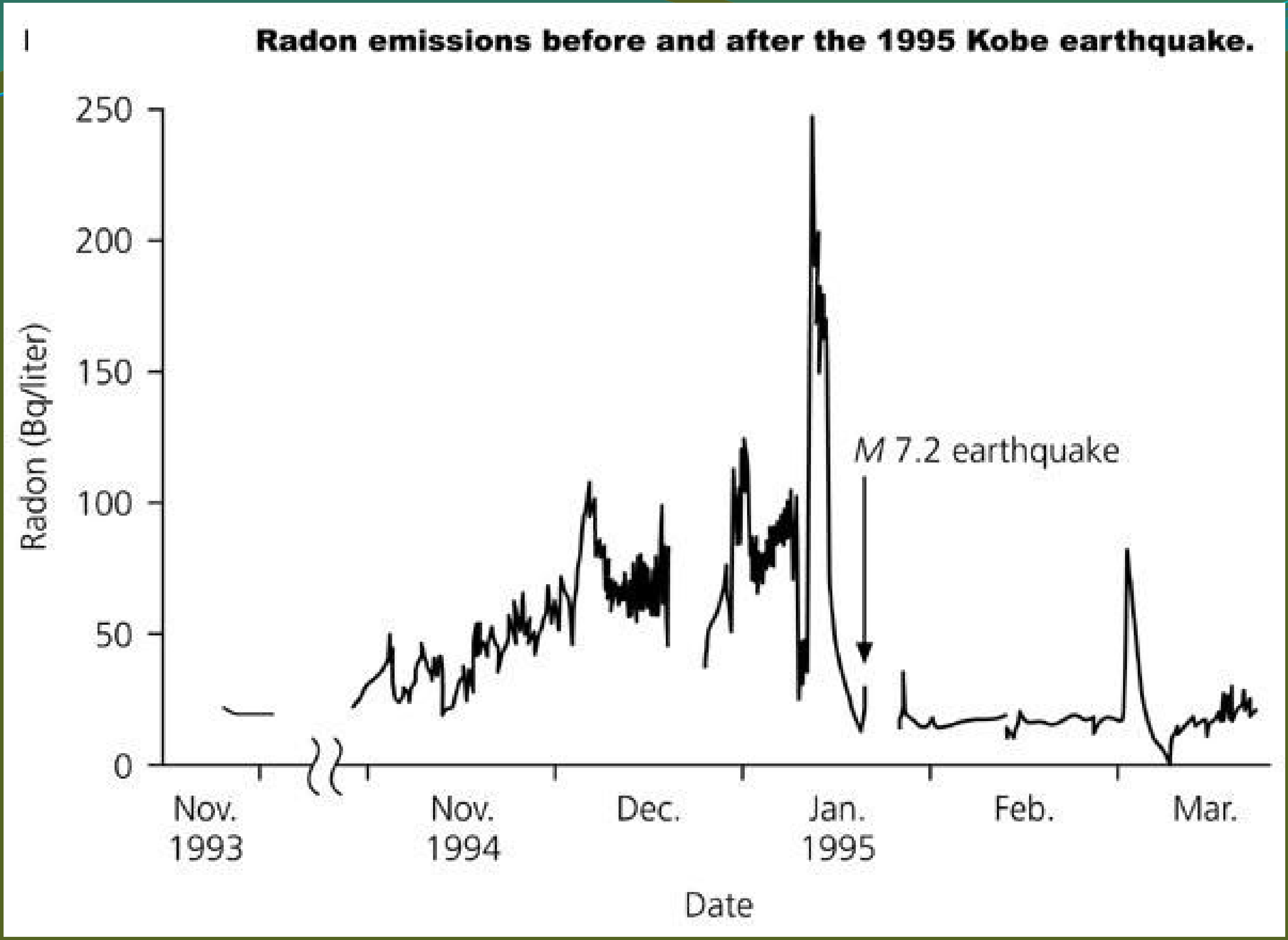
(c)

Earthquake forecasting and prediction:

- *Frequency – magnitude relationship (probabilistic forecasting)*
- *Seismic gap*
- *Progression of main shocks*
- *Foreshocks*
- *Premonitory sequences (accelerated energy release, precursory chains)*
- *Other (EM signals, Radon gas emissions, animal behavior, etc.)*

Kurile Islands Earthquakes: Space-Time Plot





Also: Resistivity, water pressure and well levels, geyser activity, changes in seismicity

Structural Design Criteria :

1. Classification criterion of sites in Asian country codes:

Site type	Japan	India	Nepal	Indonesia: Average shear wave velocity $\bar{v}_s$ (m/s)	Indonesia: Average SPT $\bar{N}$	Indonesia: Average undrained shear strength $\bar{S}_u$ (kPa)
I	Ground consisting mainly of rock mass or hardened gravel beds from the Tertiary Era or earlier	Rock or Hard soil	Rock or Stiff soil sites	$\bar{v}_s \geq 350$	$\bar{N} \geq 50$	$\bar{S}_u \geq 100$
II	Ground types other than Type 1 and Type 3	Medium soil	Medium soil sites. Sites not described as either Type I or Type III	$175 \leq \bar{v}_s < 350$	$15 \leq \bar{N} < 50$	$50 \leq \bar{S}_u < 100$
III	Alluvial layers consisting mainly of humus, mud or similar materials, to a depth of approximately 30 meters or more, marshland or mud sea, etc.	Soft soil	Soft soil sites	$\bar{v}_s < 175$	$\bar{N} < 15$	$\bar{S}_u < 50$
				Or,any soil profile with more than 3m of soft clays with PI>20， wn≥40% and Su<25kPa		

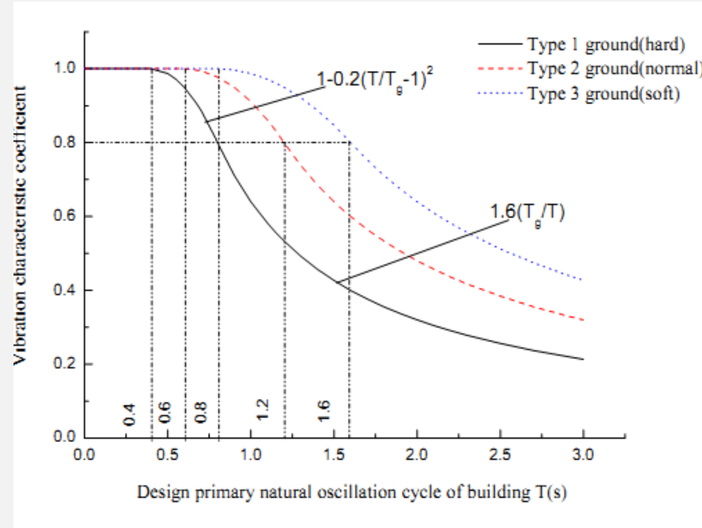
2. Seismic effective coefficient formulas and numerical results based on different

Country	Base shear method	Equivalent seismic influence coefficient formula	Structural natural periods	α results
Japan	$V_i = \alpha_i W_i$	$\alpha_i = A \cdot R_t \cdot S_i \cdot E_0$	$0.0731\,h^{3/4}$	0.21
Korea	$V = \alpha W$	$\alpha = \frac{AI\beta}{R}$	$0.07\,h^{3/4}$	0.035
Turkey	$V = \alpha W$	$\alpha = \beta(T_1)/R_a(T_1) \geq 0.10AI$	$0.07\,h^{3/4}$	0.056
Iran	$V = \alpha W$	$\alpha = \frac{A\beta I}{R}$	0.075 h0.75	0.114
India	$V = \alpha W$	$\alpha = \frac{AI\beta}{2R}$	$0.06\,h^{3/4}$	0.157
Nepal	$V = \alpha W$	$\alpha = C(T_i)AIK$	$0.0731\,h^{3/4}$	0.116
Indonesia	$V = \alpha W$	$\alpha = \frac{CI}{R}$	$2\pi\sqrt{\frac{\sum_{i=1}^{n} W_i d_i^2}{g\sum_{i=1}^{n} F_i d_i}}$	0.141
China	$V_{EK} = \alpha_i W_i$	seismic influence coefficient curve	$(0.08 \sim 0.10)N$	0.21

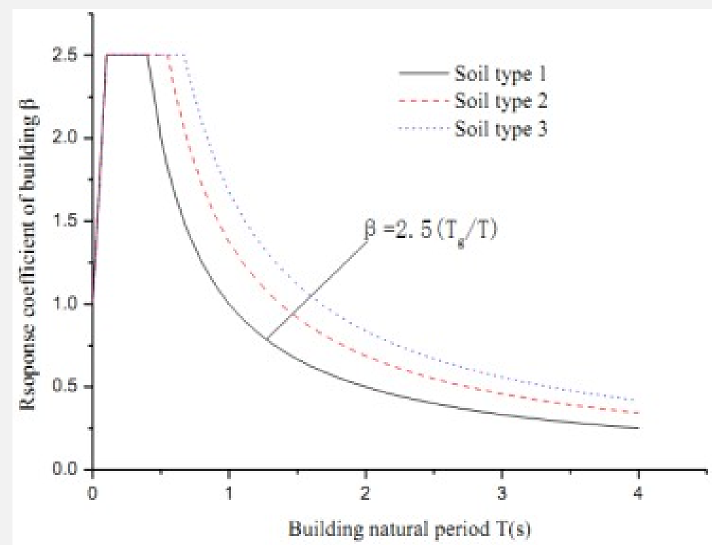
V_i: the floor horizontal seismic force; α_i: seismic influence coefficient; W: floor weight; the Wi: weight of the i-th floor; A: earthquake partition coefficient; I: importance factor; R: seismic response reduction coefficient; C: Structural reaction coefficient; β: dynamic coefficient; K: the structure performance coefficient; R_t: Vibration characteristics coefficient; S_i: i floors horizontal shear distribution coefficient; E_0: Standard shear coefficient; F_i: equivalent seismic action of the i-th floor; d_i: i-th floor lateral seismic displacements;; g: gravity acceleration; h: Height of building; N: total layer number of Structure.

Design Seismic Response Spectrur

Japan

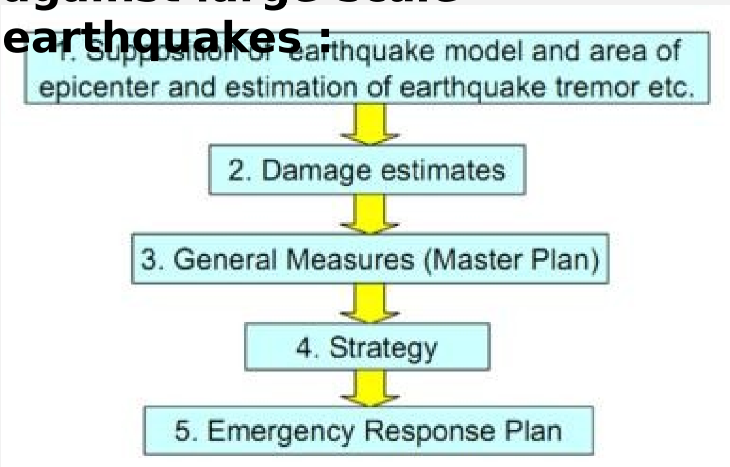


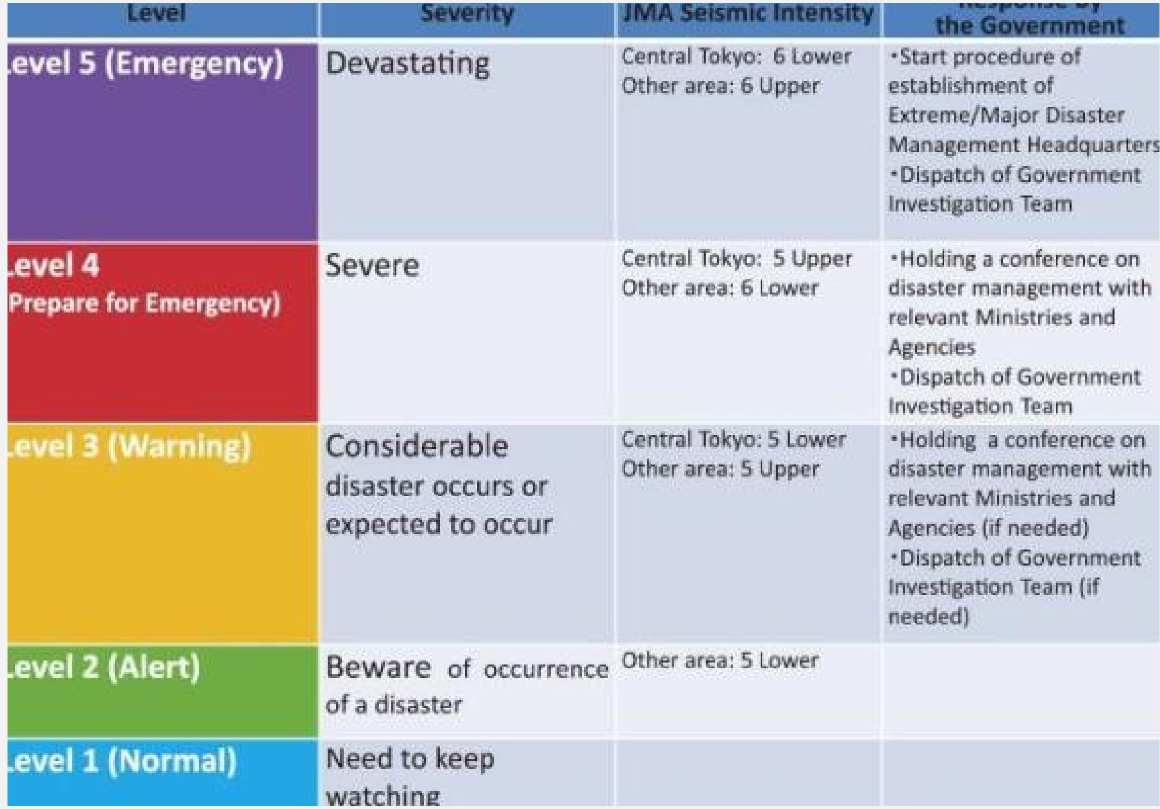
India



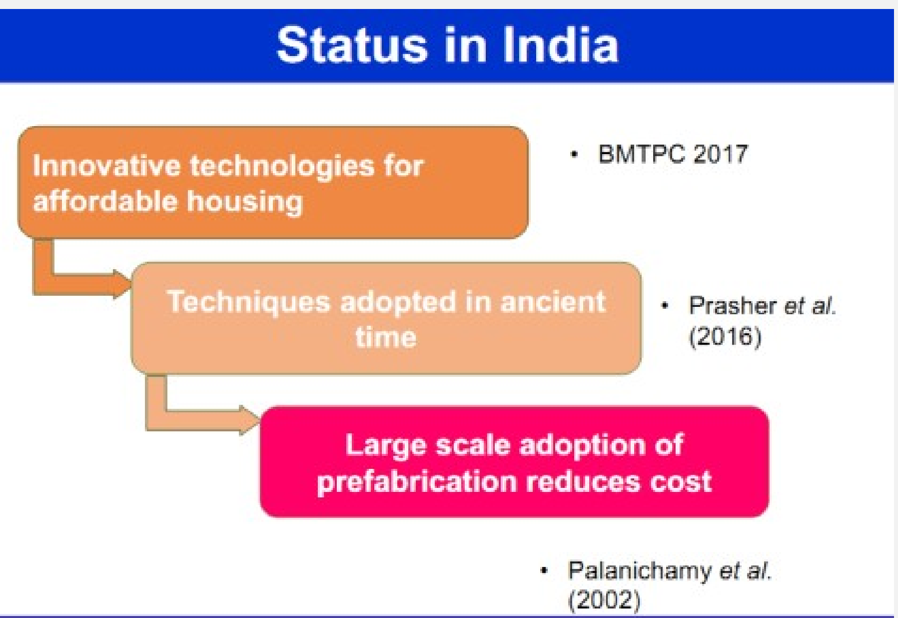
Earthquake Disaster Management in Japan

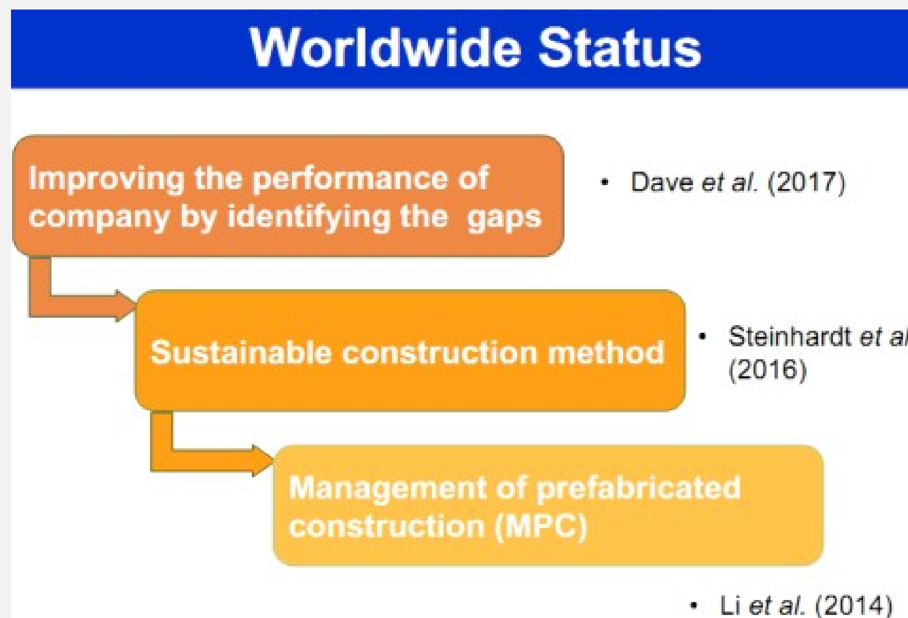
Flow of planning countermeasures against large-scale earthquakes :

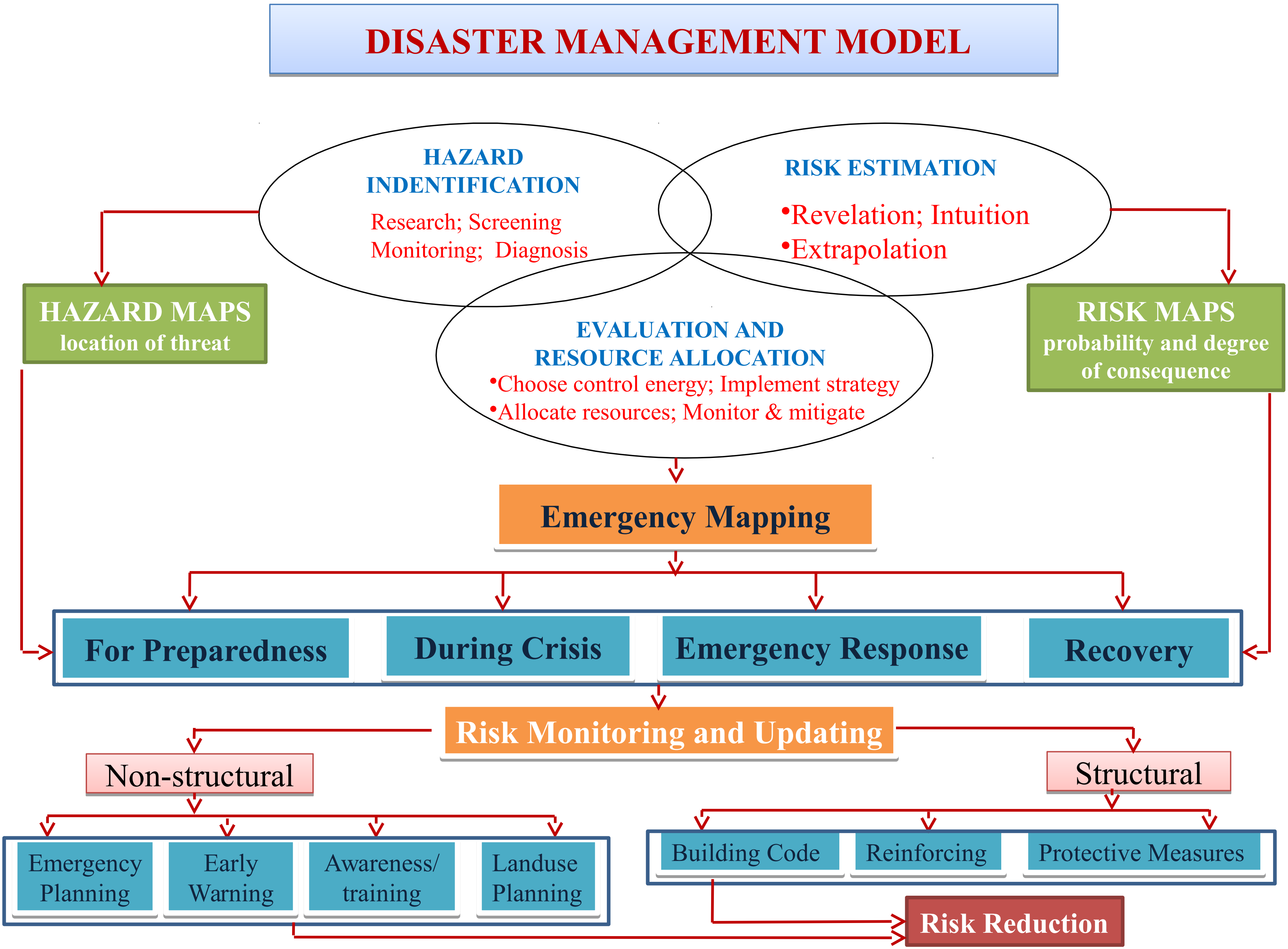




Level	Severity	JMA Seismic Intensity	Response by the Government
Level 5 (Emergency)	Devastating	Central Tokyo: 6 Lower Other area: 6 Upper	•Start procedure of establishment of Extreme/Major Disaster Management Headquarters •Dispatch of Government Investigation Team
Level 4 Prepare for Emergency)	Severe	Central Tokyo: 5 Upper Other area: 6 Lower	•Holding a conference on disaster management with relevant Ministries and Agencies •Dispatch of Government Investigation Team
Level 3 (Warning)	Considerable disaster occurs or expected to occur	Central Tokyo: 5 Lower Other area: 5 Upper	•Holding a conference on disaster management with relevant Ministries and Agencies (if needed) •Dispatch of Government Investigation Team (if needed)
Level 2 (Alert)	Beware of occurrence of a disaster	Other area: 5 Lower	
Level 1 (Normal)	Need to keep watching		






DISASTER MANAGEMENT MODEL
HAZARD INDENTIFICATION
Research; Screening
Monitoring; Diagnosis
RISK ESTIMATION
•Revelation; Intuition
•Extrapolation
EVALUATION AND RESOURCE ALLOCATION
•Choose control energy; Implement strategy
•Allocate resources; Monitor & mitigate
HAZARD MAPS
location of threat
RISK MAPS
probability and degree of consequence
Emergency Mapping
For Preparedness
During Crisis
Emergency Response
Recovery
Risk Monitoring and Updating
Non-structural
Structural
Emergency Planning
Early Warning
Awareness/ training
Landuse Planning
Building Code
Reinforcing
Protective Measures
Risk Reduction

THANK

YOU