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Probabilistic Seismic Hazard Assessment of Himalayan region Using Zoning, Zone-Free and Moment Slip Approaches

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Introduction

- Himalayan region is one of the seismically most active region of the world due to continent-continent collision between the Indian and the Eurasian plate.

- Due to continuous penetration of India plate with the Eurasian plate, stresses are increasing and accumulating progressively in the Himalayas making the Himalayan region seismically very active.

- It is important to carry out seismic hazard analysis of the region because of its high level of natural seismicity and the presence of segments of major tectonic boundary thrusts, namely the Main Central Trust (MCT) and the Main Boundary Thrust (MBT) along with various neo-tectonic faults traversing through this region.

- This region falls within the seismic zone IV and V of the seismic hazard zonation map of India.

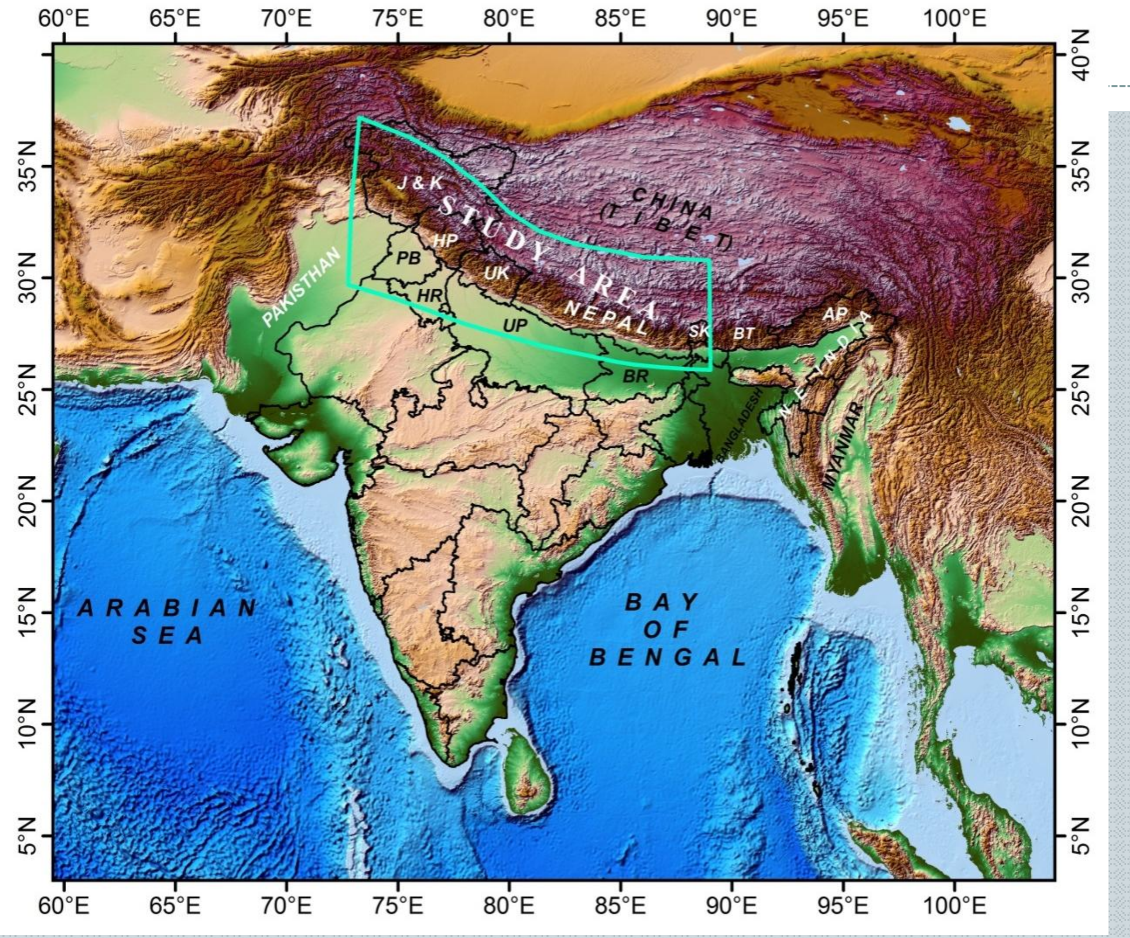
- Two approaches are normally adapted for seismic hazard assessment. First approach is called the deterministic seismic hazard analysis (DSHA) and the second one is known as probabilistic seismic hazard analysis (PSHA).

- The information from seismic hazard analysis of the Himalaya will be helpful to plan and take some preventive steps to reduce casualties and economical loss likely to occur from these natural disasters.

PSHA methods

- PSHA- analysing the seismicity data (Zoning Method)
- PSHA using moment slip rate
- PSHA using Kernel estimation Method (Zone Free Method)

Study Area



Study area showing northwest and central Himalayan belt. J & K–Jammu and Kashmir, HP-Himachal Pradesh, PB-Punjab, HR-Haryana, UK-Uttarakhand, UP-Uttar Pradesh, BR-Bihar, SK-Sikkim, BT-Bhutan, AP-Arunachal Pradesh (relief map Indian continent is a part of relief map of the world available from, http://www.ngdc.noaa.gov/mgg/global/).

Seismicity of NW and Central Himalaya

- Nepal Earthquake (25th April 2015) or Gorkha earthquake killed more than 9,000 people and injured more than 23,000.
- 1945 Chamba Earthquake (m_b=6.5),
- 1986 Dharamshala Earthquake (m_b=5.5),
- Kinnaur Earthquake (m_b=6.5) of 1975,

Event (YYYYMMDD)	**M_W**	**Epicentral Region**	**Deaths**
19050405	7.8	Kangra, northwest Himalayas	20,000
19340115	8.1	Bihar-Nepal, Central Himalayas	10,700
19500815	8.6	Indo China Border	1526
19560721	6.0	Anjar, Gujarat	156
19911020	6.8	Uttarakashi, Northwest Himalayas	2000
19990329	6.6	Chamoli, Northwest Himalayas	103
20010126	7.7	Bhuj, Gujarat	20,000
20051008	7.6	Kashmir ,northwest Himalayas	86000

PSHA- Analyzing the seismicity data (Zoning Method)

Contents

- Earthquake Catalog
- Homogenization of Earthquake catalog
- Declustering of earthquake catalog
- Delineation of seismogenic zone
- Estimation of Seismicity Parameters
  - G-R Parameters
  - Magnitude of Completeness
  - Maximum Magnitude
- Ground motion prediction equation
- Seismic hazard estimation

Earthquake catalog

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- Earthquake data compiled from three agencies: International Seismological Center (ISC), U. K. seismic catalog from 1720-1972, National Earthquake Information Center (NEIC), USGS, USA catalog of seismic events from 1973-2012 and India Meteorological Department (IMD) catalog of seismic data from 1552-2012 have been used.

- In addition to global catalogs, some other catalogs prepared by Oldham (1883), Raghukanth (2010) and Iyengar et al. (1999) are also considered..

Why Unified Earthquake Catalog is required?

- Different earthquake size indicators are in use ($m_{s,}$ $m_{b,}$ $m_{L,}$ M_{w} $_{,}$etc.), differeing in the use of seismic wave and or wave periods.

- The most preferred magnitude is moment magnitude M_w, as it is derived directly from the seismic moment (M_0) which is a fundamental physical property of the source.

- Most of the magnitude scales show saturation for larger earthquakes whereas M_w does not saturate for large magnitude earthquakes.

Homogenization of Earthquake catalogue

- Global relations based on an improved technique towards surface wave magnitude to moment magnitude conversion (Wason et al., 2012).

$$M_w = 0.646 m_{s,obs} + 2.197 \qquad 3.1 \leq m_s \leq 6.1$$

$$M_w = 1.005 m_{s,obs} - 0.0062 \qquad 6.2 \leq m_s \leq 8.4$$

The regional relations for Himalayan region for conversion of body wave magnitude to moment magnitude (Das et al., 2013)

$$M_w = 1.17 m_{b,obs} - 0.74$$

Determination of Magnitude of Completeness

- It is the lowest magnitude at which 100% of the events in a space-time window are detected (Woessner and Wiemer, 2005).

- Entire Magnitude Range Method (EMR) modified by (Woessner and Wiemer, 2005) is adopted to estimate the magnitude of completeness.

- As this method is stable under most conditions and provides a comprehensive seismicity model. ZMAP developed by (Wiemer, 2000) is used.

Declustering

- The declustering involves removal of dependant events represented by foreshocks and aftershocks from the earthquake catalogue.
- Since PSHA is based on the assumption that seismicity follows Poisson process, it is essential to remove any non-Poisonian behaviour from earthquake catalogue.
- Gardner and Knopoff (1974) and Urhammer (1986)

Estimation of Seismicity Parameters

Gutenberg Richter Relationship

$$\lambda_m = 10^{(a - b*m)} = \exp(\alpha - \beta * m)$$

Where $\alpha = 2.303a$ and $\beta = 2.303b$

If earthquakes smaller than a lower threshold magnitude m_o, are eliminated, the mean annual rate of exceedance can be written:

$$\lambda_m = \vartheta \exp[-\beta(m - m_o)]$$

where $m > m_o$, $\vartheta = \exp(\alpha - \beta * m_o)$

Bounded G-R relationship

$$\lambda_m = \vartheta \frac{\exp[-\beta(m - m_o)] - \exp[-\beta(m_{max} - m_o)]}{1 - \exp[-\beta(m_{max} - m_o)]} \qquad m_o < m < m_{max}$$

- Parameter a – Activity Rate
- Parameter b – Seismicity parameter
- Parameter M_c --Magnitude of Completeness
- Parameter M_{max}--- Maximum Magnitude

Maximum Magnitude

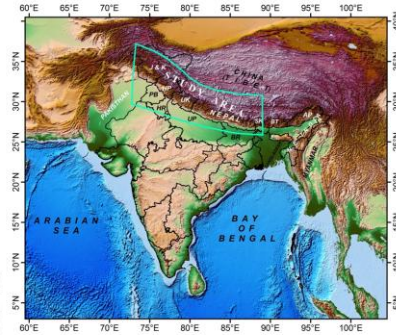
- Maximum magnitude is defined as the upper limit of magnitude for a given seismic source zone or entire region.
- For the present study the non-parametric Gaussian (N-P-G) based estimator equation given by Kijko (2004) is used.
- Kijko's Toolbox written in MATLAB has been used for the computation of maximum magnitude. Both historical and instrumental seismicity data has been used .

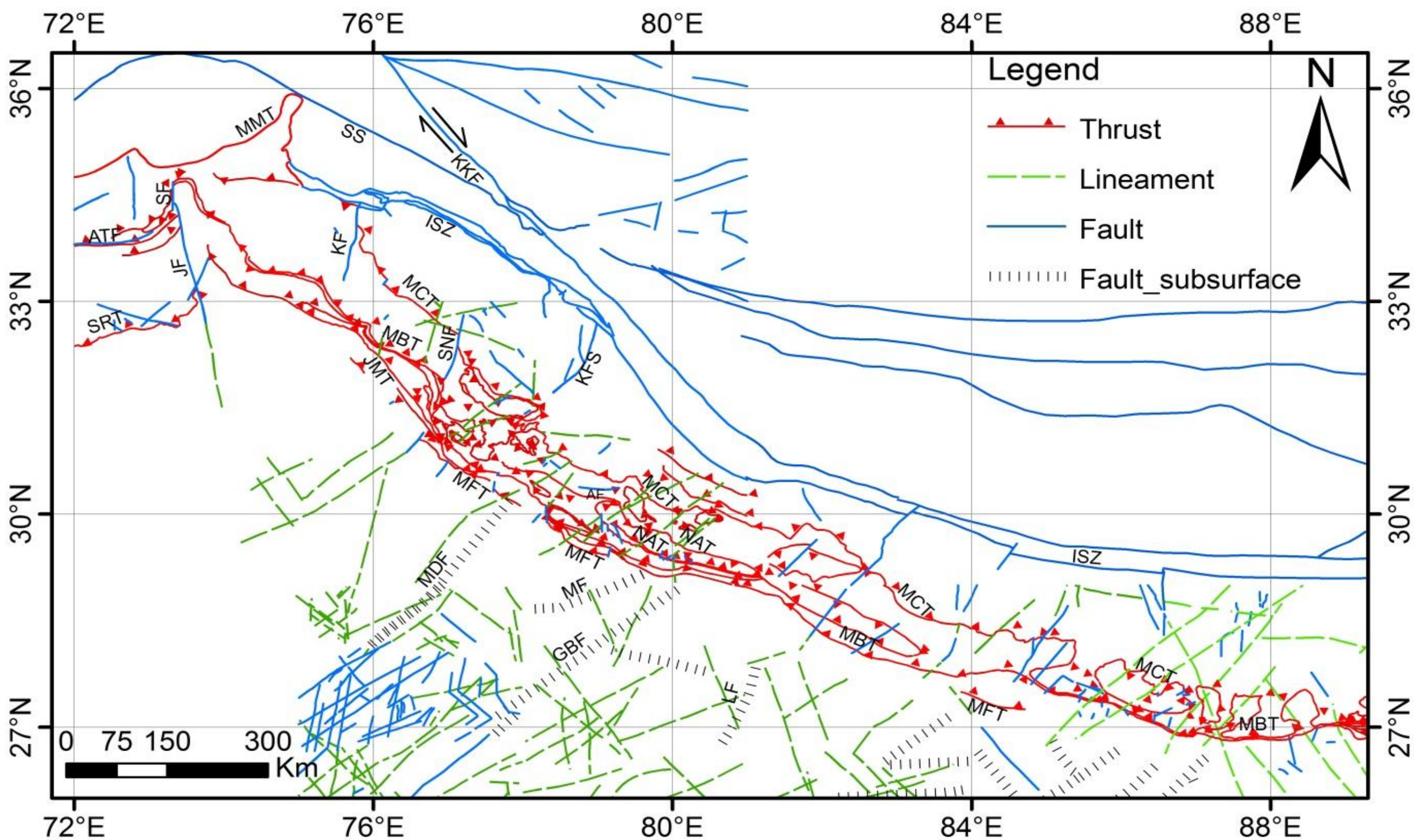
$$m_{max} = m_{\max}^{\text{obs}} + \int_{m_{\min}}^{m_{\max}} \left[\frac{\sum_{i=1}^{n} \left[\emptyset\left(\frac{m - m_i}{h}\right) - \emptyset\left(\frac{m_{min} - m_i}{h}\right) \right]}{\sum_{i=1}^{n} \left[\emptyset\left(\frac{m_{max} - m_i}{h}\right) - \emptyset\left(\frac{m_{min} - m_i}{h}\right) \right]} \right]^{n} dm$$

where h is the smoothing factor

M_{max} is obtained by iterative solution of equation

Tectonics features of the Himalayan belt

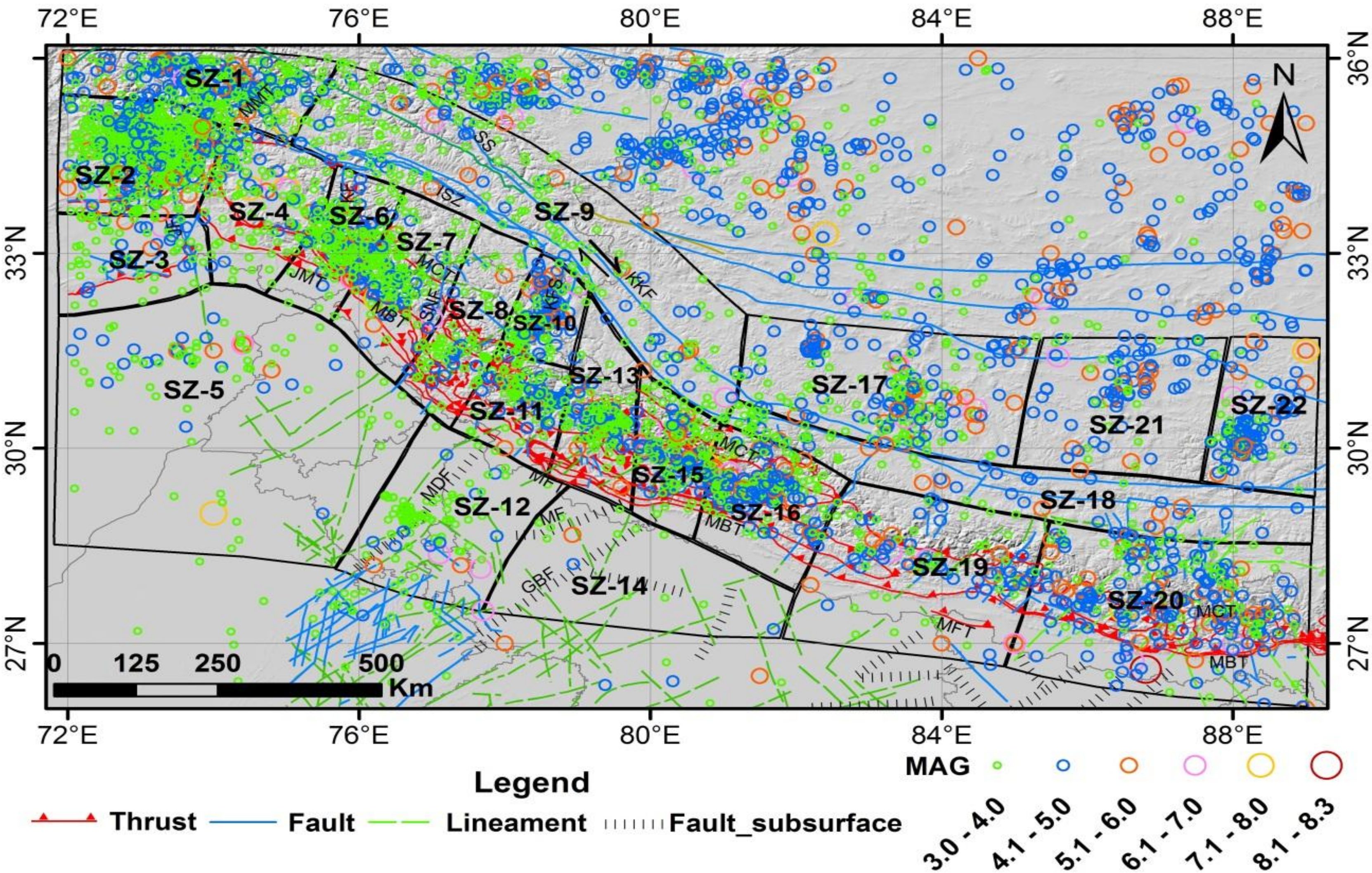




Tectonics features present in and around NW and central Himalayas. KKF- Karakoram Fault, SS-Shyoke Suture, MMT-Main Mantle Thrust, SRT-Salt Range Thrust, ATF-Attok Fault, MCT-Main Central Thrust, MBT-Main Boundary Thrust, ISZ-Indus Suture Zone, KFS-Kaurik Fault System, AF-Alaknanda Fault, NAT-North Almora Thrust, JMT-Jwalamukhi Thrust, MFT-Main Frontal Thrust, JF-Jhelum Fault, SK-Sinkiari Fault, KF-Kishtwar Fault, SNF-Sunder Nagar Fault, MDF-Mahendragarh-Dehradun fault, MF- Moradabad Fault, GBF- Great Boundary Fault. LF-Lucknow Fault, MFT-Main Frontal Thrust. (Tectonic features are adopted from Seismotectonic Atlas of India and its Environs and Tectonic map of Asia).

(Rout et al., 2015)

Seismogenic Zones



Demarcation of 22 seismogenic zones based on geology, tectonics and seismicity (Rout et al., 2015)

Estimated seismicity parameters considering earthquake catalog (1552-2012)

Zone	M_c	M_{max}^{obs}	a	b	β=2.303*b	b error	beta coeff	λ_m
1	4.6	7.70	2.82	0.84	1.93	0.00	0.00	0.09
2	4.5	7.60	2.65	0.77	1.77	0.00	0.00	0.15
3	4.6	6.50	3.35	1.04	2.40	0.30	0.69	0.04
4	4.7	7.70	1.20	0.50	1.15	0.36	0.83	0.07
5	4.3	7.10	2.14	0.70	1.61	0.08	0.18	0.13
6	4.7	7.30	3.68	0.91	2.10	0.18	0.41	0.25
7	4.6	8.00	5.08	1.27	2.92	0.23	0.53	0.17
8	4.5	5.50	2.73	0.89	2.05	0.09	0.21	0.05
9	4.5	6.50	2.66	0.84	1.93	0.00	0.00	0.08
10	4.6	6.30	3.14	0.76	1.75	0.00	0.00	0.44
11	4.5	5.90	3.46	0.98	2.26	0.00	0.00	0.11
12	4.3	6.70	1.35	0.63	1.45	0.00	0.00	0.04
13	4.6	6.80	2.54	0.75	1.73	0.00	0.00	0.12
14	3.9	5.60	1.93	0.84	1.93	0.00	0.00	0.05
15	4.7	6.50	2.20	0.64	1.47	0.00	0.00	0.16
16	4.6	7.50	3.69	0.85	1.96	0.00	0.00	0.60
17	4.7	6.50	2.90	0.72	1.66	0.00	0.00	0.33
18	4.7	6.00	3.50	0.87	2.00	0.00	0.00	0.26
19	4.6	7.00	2.65	0.75	1.73	0.00	0.00	0.16
20	4.8	8.30	3.25	0.76	1.75	0.11	0.25	0.40
21	4.6	6.70	2.84	0.74	1.70	0.03	0.07	0.27
22	4.6	7.10	3.14	0.80	1.84	0.03	0.07	0.29

Ground Motion Prediction Equations

GMPE	Spectral Period Range	Valid distance range (km)	Valid Magnitude range	Distance (km)	Units
Akkar and Boommer (2010)	0 -3.0	1 to 100	5 to7.6	R_{JB}	Cm/sec^2
Boore and Atkinson (2008)	0.01-10	1 to 200	5 to 8	R_{JB}	g
Campbell and Bozorgnia (2008)	0.01-10	0 to 200	4 to 8.5	R_{rup}	g
Chiou and Youngs (2008)	0.01-10	0 to 200	4- 8.5	R_{rup}	g
Zhao et al. (2006)	0.01-5	0.4 to 300	5 to 8.4	R_{rup}	gal

Equal weightage has been given to all the GMPEs and seismic hazard estimated at $V_{s30} \geq 1100$ m/sec.

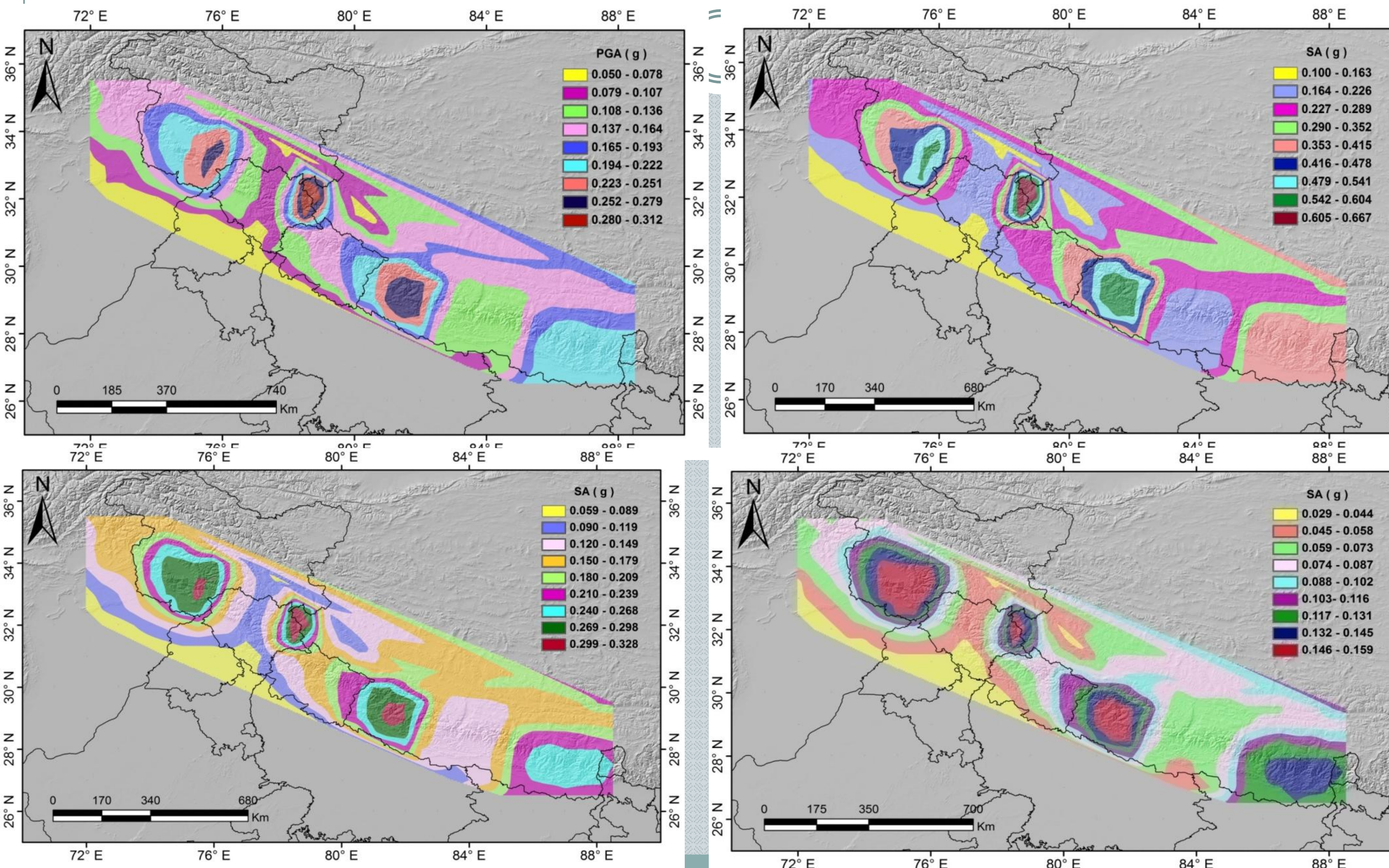
Seismic hazard estimation (Case study)

- The standard methodology developed by Cornell (1968) for PSHA is normally applied for the estimation of seismic hazard in terms of PGA for 10% and 2% probability of exceedance in 50 years.

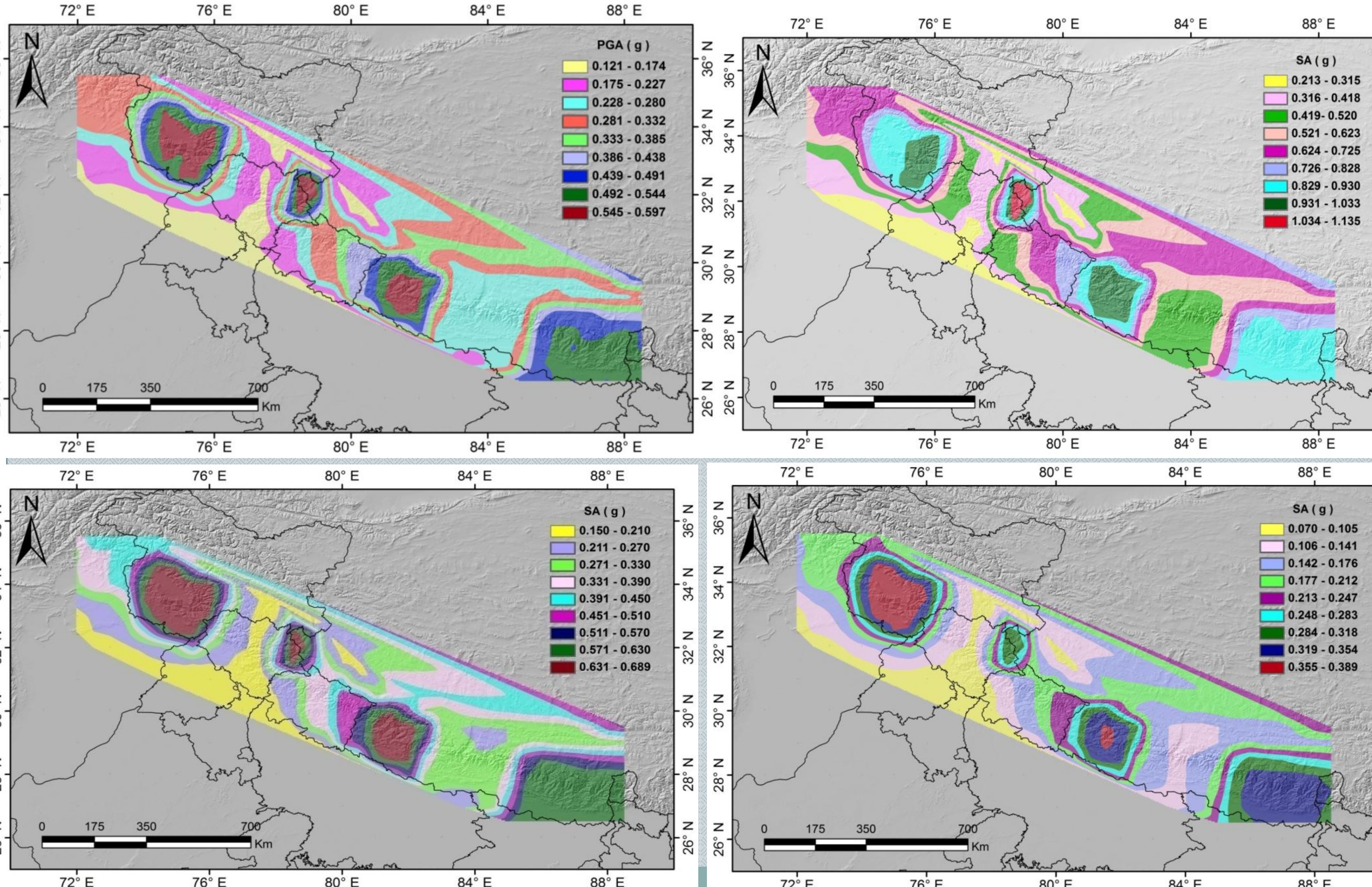
- The probabilistic seismic hazard estimation software CRISIS-2012 developed by Ordaz et al. (2012) has been used.

- In the computational scheme, parameters such as *a*, *b*, Mc , source to site distance, and attenuation models are the input parameters in the CRISIS program and PGA and SA are the output.

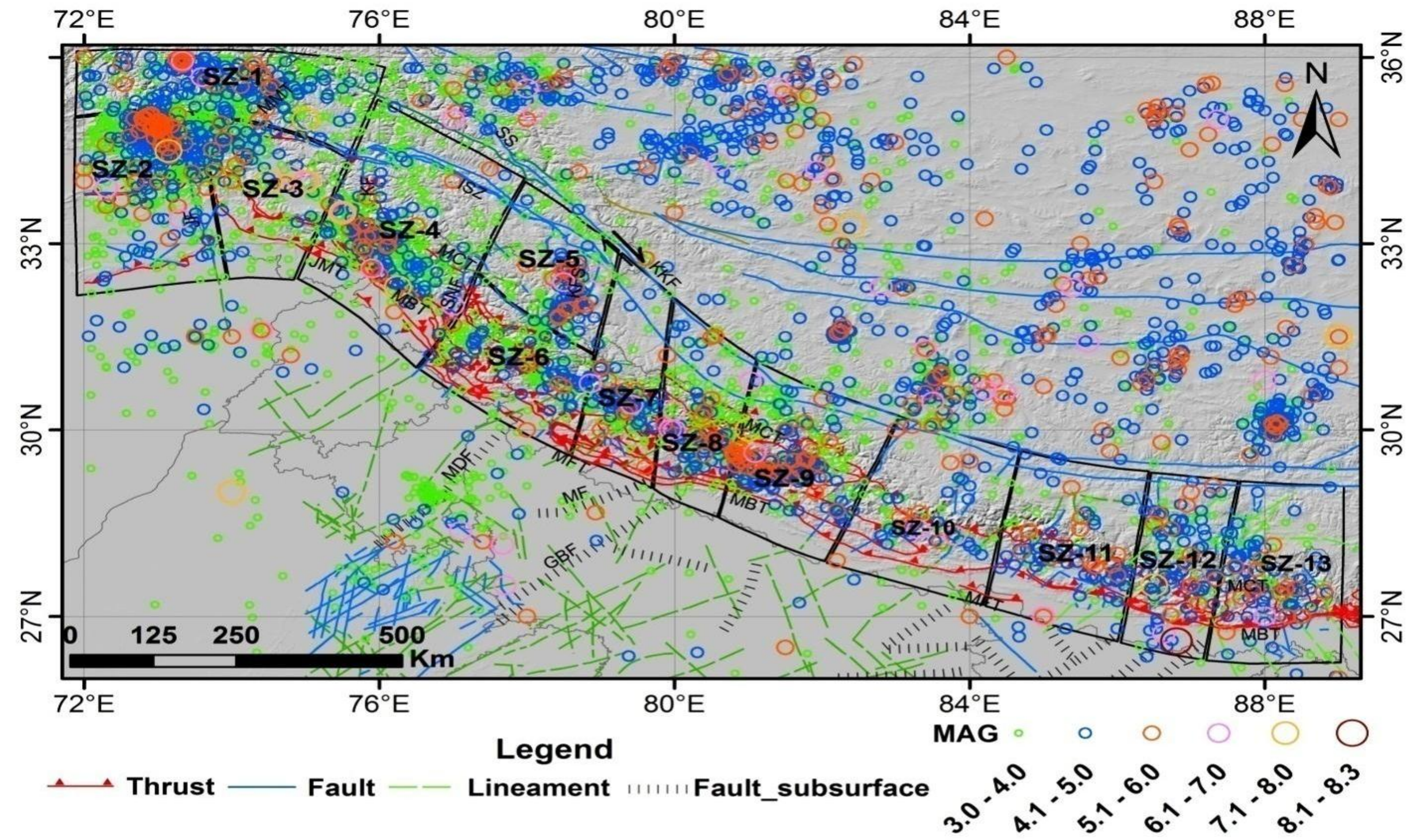
Maps for 10% probability of exceedance in 50 years; (a) Mean PGA, (b) S_a at 0.1sec, (c)) S_a at 0.5 sec and (d) S_a at 1.0 sec (**Rout et al., 2018)**



Maps for 2% probability of exceedance in 50 years; (a) Mean PGA, (b) S_a at 0.1sec, (c)) S_a at 0.5 sec and (d) S_a at 1.0 sec. (**Rout et al., 2018)**

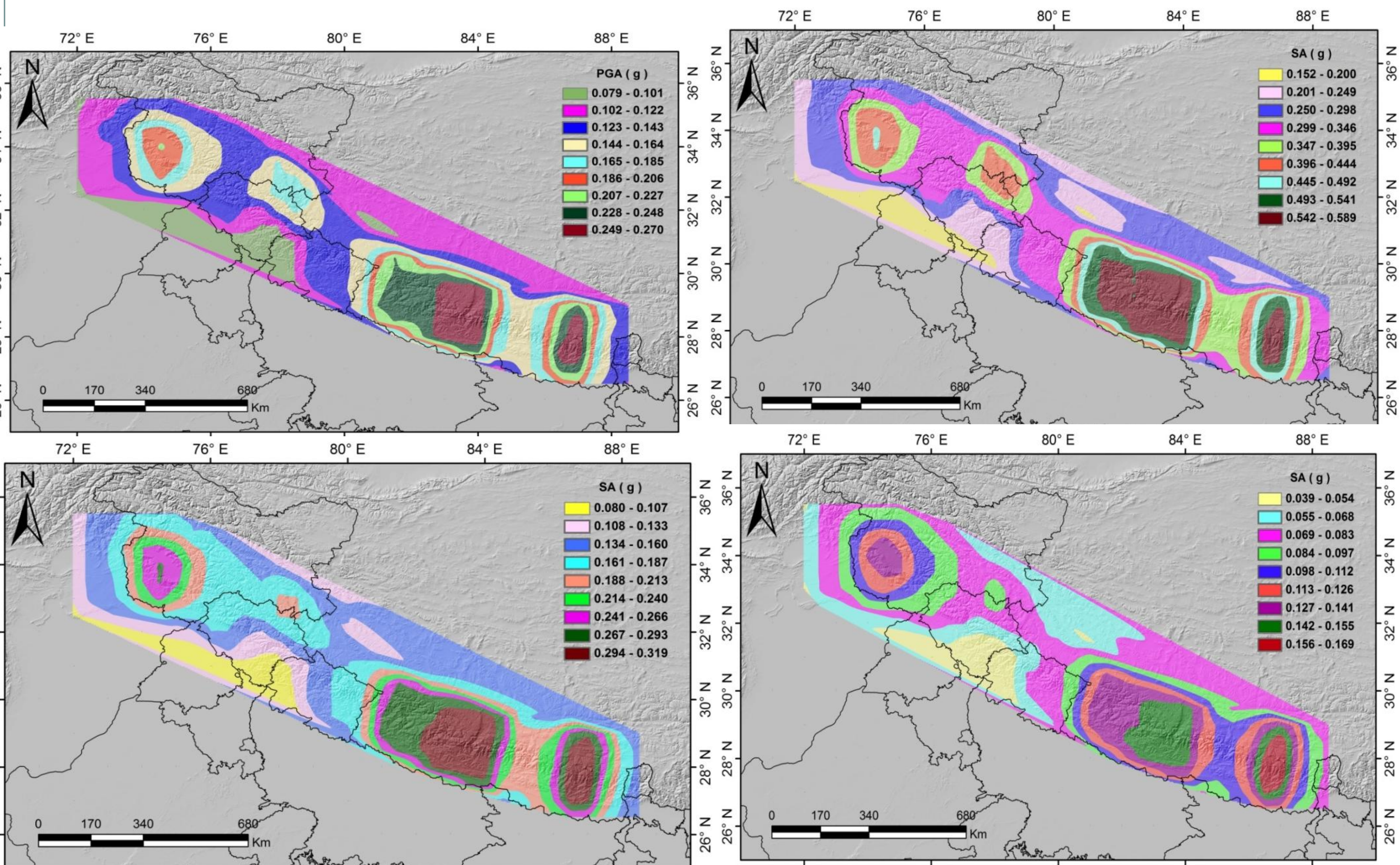


Intermediate Sized Seismogenic Zones: Case-II



Demarcation of 13 seismogenic zones based on geology, tectonics and seismicity

Maps for 10% probability of exceedance in 50 years; (a) Mean PGA, (b) S_a at 0.1sec (c)) S_a at 0.5 sec and (d)) S_a at 1.0 sec. (Intermediates zones)



Zone-free Method

- Zone-free method is also known as kernel estimation as they implement a kernel function for spatial smoothing of seismicity data.
- In this method seismogenic zones are not defined like Cornell's (1968) method. In Zone-free method, a grid of point sources (nodes) has been considered around the site of interest.
- The activity rates for each magnitude interval are determined according to a magnitude-dependent smoothing procedure and this smoothing procedure is applied to the epicenters of earthquake catalog.
- These activity rates are calculated from the probability density and proximity of earthquake events spreading within that magnitude range.
- Woo's (1996) method uses concepts from fractal geometry, and it describes seismicity is spatially non-uniformly distributed.

Kernel density function

- In kernel methods, seismicity is smeared over a distance through a magnitude dependent relation described by a kernel function K.

- In Woo's (1996a) approach, the kernel function is described by a multivariate probability density function.

$$K = \frac{n-1}{\pi H^2} + \left[1 + \left(\frac{r}{H}\right)^2\right]^{-n}$$

Where r is known as the epicentral distance
n is called as "kernel fractal scaling index
H is the bandwidth for normalizing epicentral distances

Calculation of H

- H is the bandwidth for normalizing epicentral distances and is a function of magnitude.

- It represents the average minimum distance among epicenters characterized by the same magnitude and takes the following exponential form:

$$H = ce^{dM}$$

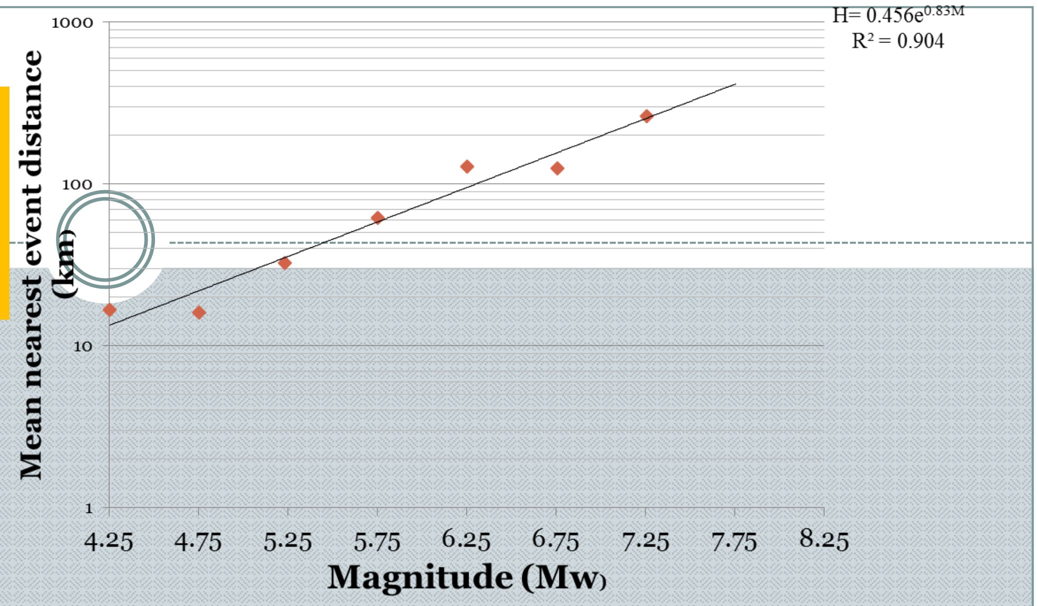
where c and d are two constants to be determined on the basis of the location of the epicenters of the earthquake catalog and M is the moment magnitude.

Estimation of kernel parameters

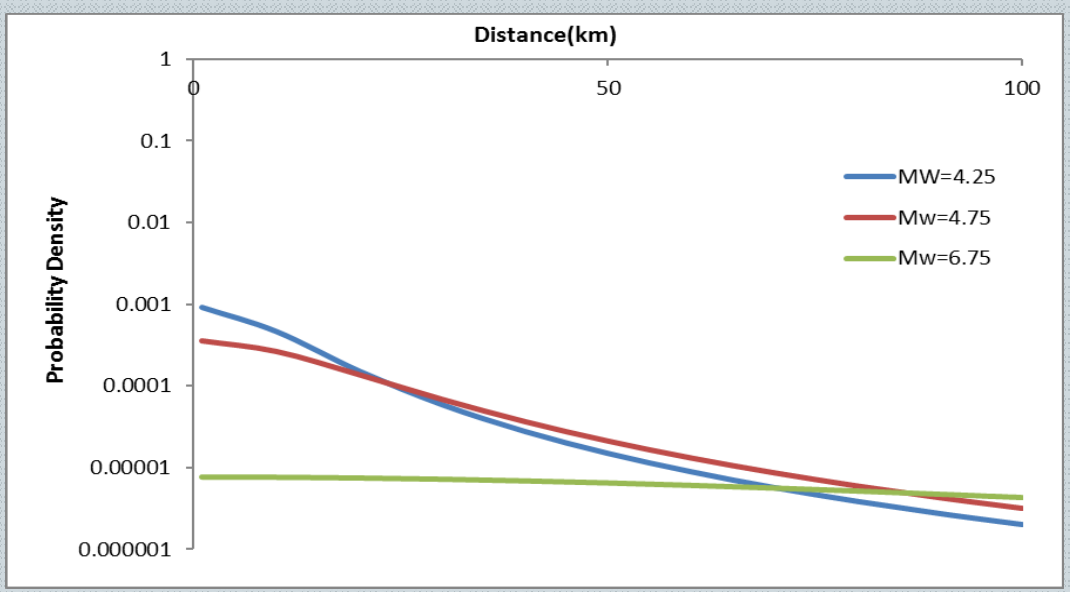
- Earthquake events are divided into groups according to their moment magnitude;
- The nearest epicentral distance for each event within the same magnitude bin is determined.
- all minimum distances calculated from each magnitude bin are averaged;
- a least square fit is implemented to obtain the two parameters c and d.

Earthquake Magnitude Interval and Mean nearest event distance

Earthquake Magnitude Interval	No of dataset	Mean Nearest Event distance
4.1-4.5	927	16.6
4.5-5.0	817	16.129
5.1-5.5	273	32.584
5.5-6.0	109	61.983
6.1-6.5	36	129.647
6.5-7.0	14	125.1829
7.1-7.5	10	262.479
7.6-8.0	4	167.732
8.0-8.5	1	-



Magnitude-bandwidth relation to estimate parameters c and d of the kernel bandwidth function



Spatial kernel function K with epicentral distance

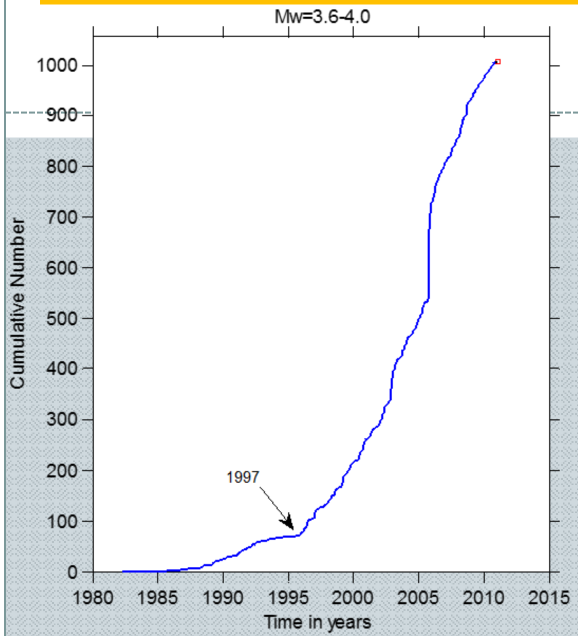
Cumulative activity rate density

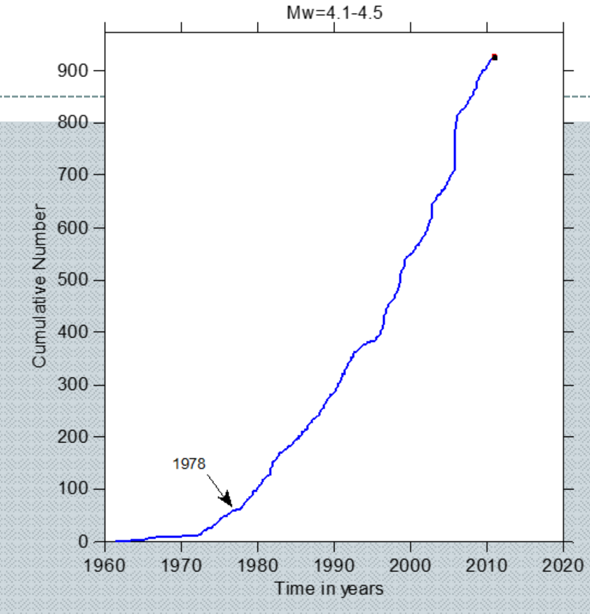
- By summing over all events of the earthquake catalog, the cumulative activity rate density, λ, is computed for each magnitude bin, and for each point source of the mesh, x:

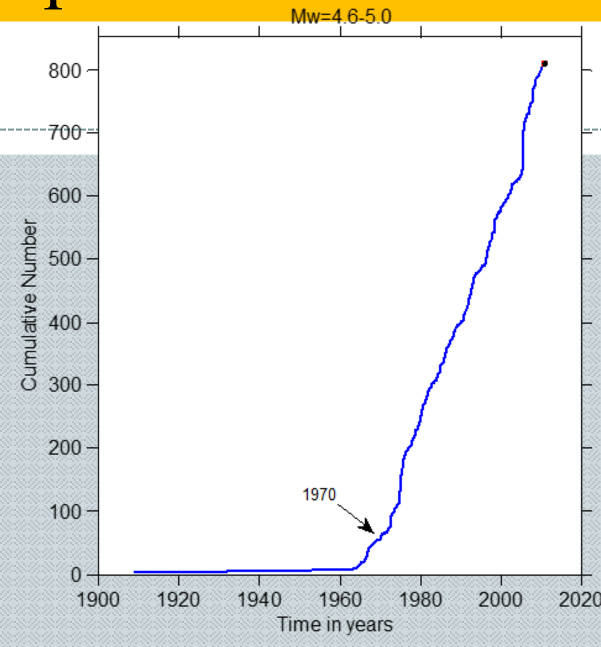
$$\lambda(M,X) = \sum_{i=1}^{N} K(M,X - x_i) \,/\, T(x_i)$$

where N is the number of events in the catalog,
x_i represents the coordinates of the epicenter being considered,
$T(x_i)$ is the effective observation time period.

Effective observation time period







Estimation of completeness period using VC Method: (Tinti and Mulargia, 1985).

The completeness period for the magnitude ranges are as follows: 15 years for 3.6-4.0, 34 years for 4.1-4.5, 42 years for 4.6-5.0, 50 years for 5.1-5.5, 80 years for 5.6-6.0, 92 years for 6.1-6.5, 152 years for 6.6-7.0, 152 years for 7.1-7.5, 362 years for >7.5.

Input for the KERGRID Program

For each event, the following input information is required.

- The recorded latitude of the event.
- The recorded longitude of the event.
- The magnitude of the event
- Directional smoothing parameter

Directional smoothing parameter is the angle representing the direction of an active lineament associated with the event epicenter (Woo, 2001).

In this study the directional smoothing parameter has been considered for regions from 72^o-73.5^o are 180^o, 75^o-78^o is 135^o, 78^o-85.4^o is 160^o and 85.4^o to 89^o is 180^o based on the orientation of tectonic features of the Himalayan tectonic belt.

- kernel fractional scaling index for infinite kernel is 1.75,
- kernel bandwidth parameters for infinite kernel is c=0.45, d=0.83,
- minimum and maximum radii (in km) for finite kernel:25.0, 200.0,
- parameter for azimuthal concentration of activity:100.0,
- number of total latitude and longitude wise grid rectangles in main block: 40, 64,
- main block south west corner latitude, longitude position: 26.0^{o}, 72.0^{o},
- latitudinal width (degrees) of grid rectangle: 0.25,
- longitudinal height (degrees) of grid rectangle: 0.25,
- mesh size (kms) of sub-grid within a rectangle: 0.5.

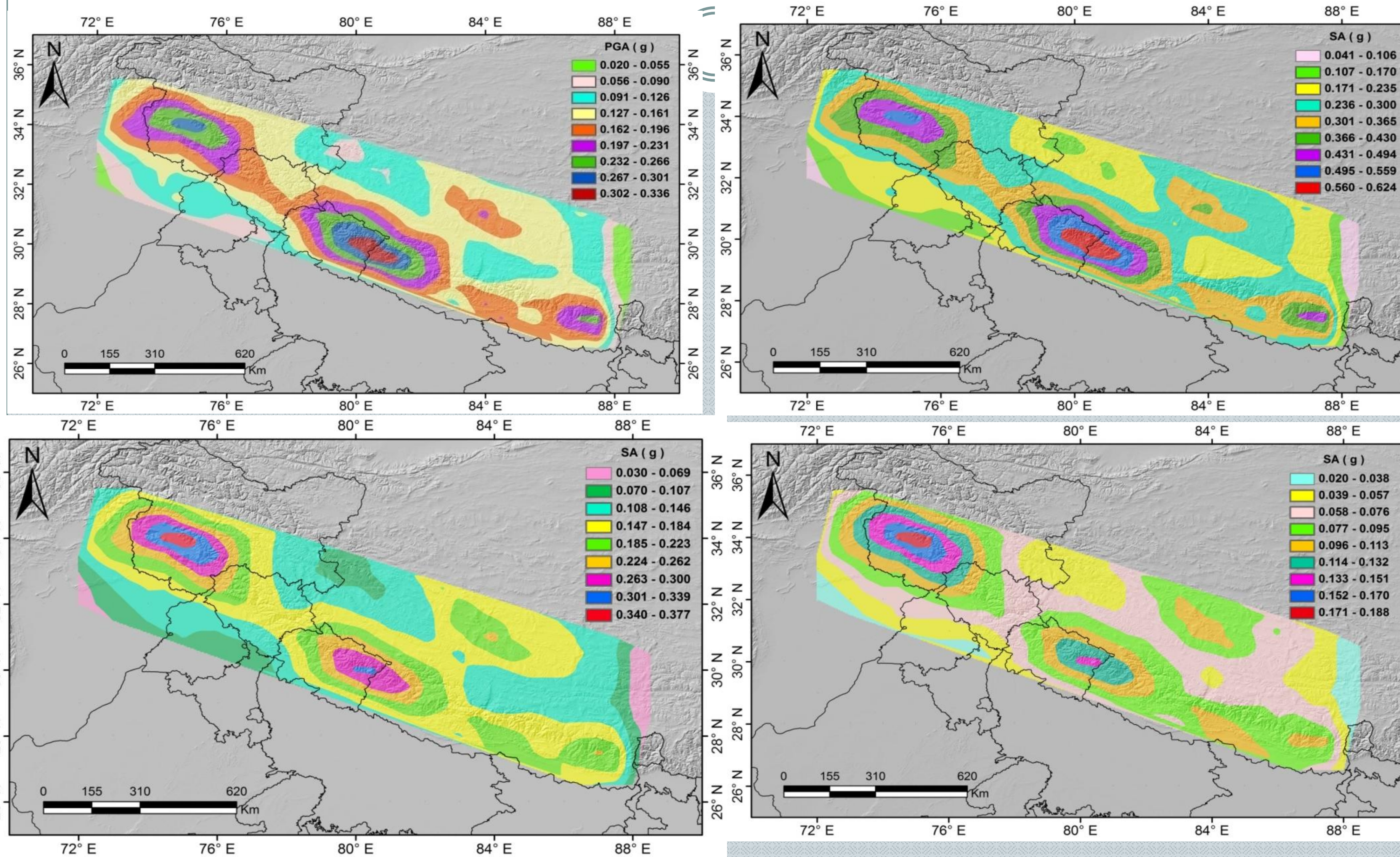
Seismic Hazard Estimation

- The output result from the KERGRID program is the activity rate of each magnitude bin at each grid location.

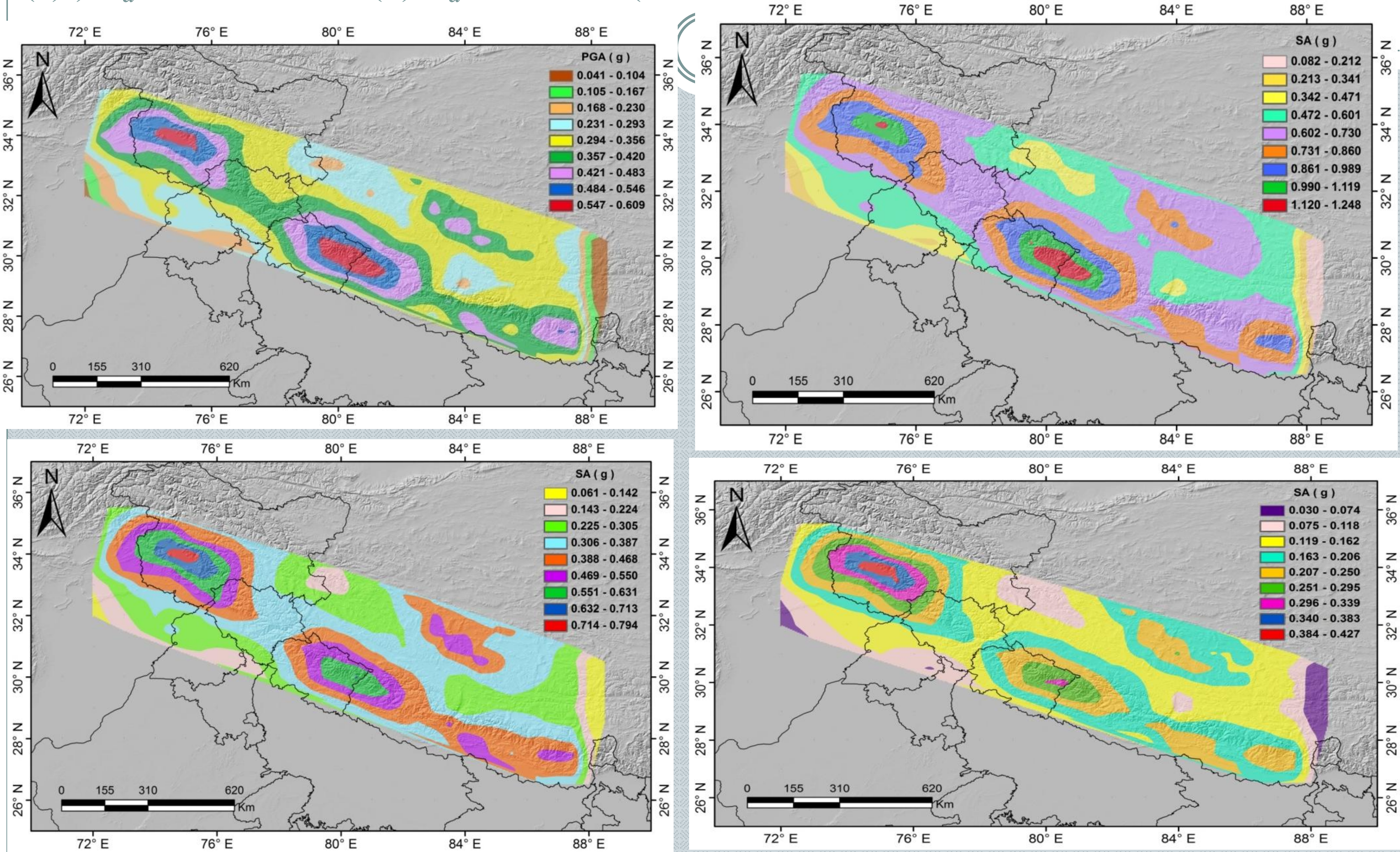
- Geometry of the point source and annual occurrence rates of the different bins of magnitudes of each point source have been generated.

- The source geometry, the annual occurrence rates of the different bins of magnitude of each point source is known as the seismicity parameter, spectral ordinates, attenuation equation and global parameters are input into the CRISIS Program.

Maps for 10% probability of exceedance in 50 years; (a) Mean PGA, (b) S_a at 0.1sec, (c) S_a at 0.5 sec and (d) S_a at 1.0 sec (Rout et. al 2018)



Maps for 2% probability of exceedance in 50 years; (a) Mean PGA, (b) S_a at 0.1sec, (c)) S_a at 0.5 sec and (d) S_a at 1.0 sec (Rout et. al 2018)



- PSHA using moment slip rate

Estimation of Fault activity rate from slip rates

- The earthquake occurrence rate or mean annual rate of exceedance is related to the geological slip rates.
- The details of these occurrence models have been discussed by Anderson and Luco (1984) and Young's and Coppersmith(1985)
- These Models behave differently close to higher magnitude.
- Model 1 of the Anderson and Luco (1984) is the most conservative model showing a sudden cutoff and allowing more moment release close at higher magnitude, resulting in a higher activity rate.

Model-1

$$N_1(M) = \left(\frac{\bar{d}-\bar{b}}{\bar{d}}\right)\left(\frac{S}{\beta}\right) e^{\bar{b}(M_{max}-M)} e^{-((\bar{d}/_2)M_{max})}$$

Where $\bar{b} = b(\ln(10))$ $\bar{d} = d(\ln(10))$ $\beta = \sqrt{(\alpha M_0(0))/(\mu W)}$

, α=D/L and $M_0(0)$ is the seismic moment for M_s=0

μ =rigidity or shear modulus

D is known as total average displace across fault

A=LW=Rupture area L is fault length

W is Fault width

S= annual slip rate

d is the magnitude scaling coefficient in the well known log-linear relation between moment and magnitude

Model-2

This Model has a more smooth transition towards $N(M_{max})=0$

$$N_1(M) = \left(\frac{\bar{d}-\bar{b}}{\bar{d}}\right)\left(\frac{S}{\beta}\right)\left[e^{\bar{b}(M_{max}-M)} - 1\right] e^{-\left(\left(\bar{d}/_2\right)M_{max}\right)}$$

Model-3

$$N_3(M) = \frac{\bar{d}(\bar{d}-\bar{b})}{\bar{b}}\left(\frac{S}{\beta}\right)\left\{\frac{1}{\bar{b}}\left[e^{\bar{b}(M_{max}-M)}-1\right]-(M_{max}-M)\right\}e^{\left(\left(\bar{d}/_{2}\right)M_{max}\right)}$$

Model-4

$$N_4(m^0) = \frac{\mu A_f S(d-b)\left[1-e^{-\beta(m^u-m^0)}\right]}{bM_0^u e^{-\beta(m^u-m^0)}}$$

Where m^0 is some arbitrary reference magnitude, m=b(ln(10)), A_f =LW is fault area and m^u is an upper bound magnitude.

Slip rate in the northwest and central Himalayan region

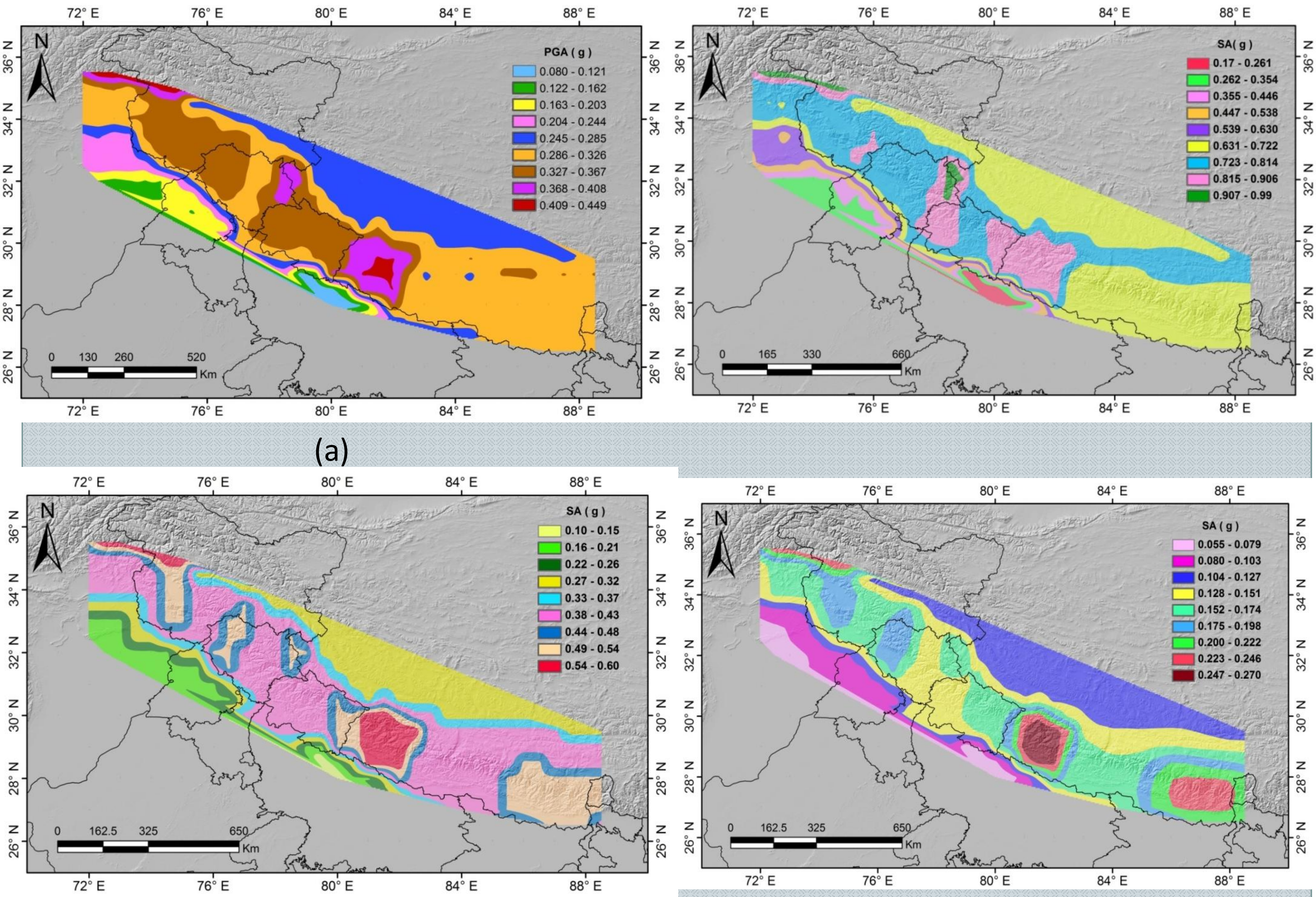
Fault/Region	Slip rate (mm/yr)	Research Reference
Western Himalaya	14±1	Banerjee and Burgmann (2002)
Kangra reentrant	14±2	Powers et al.(1998)
Dehradun reentrant	11±5	Powers et al.(1998)
Tertiary sediments	20	Lyon and Molnar (1985)
Along HFT (Chandigarh)	6.3±2	Malik and Nakata (2003)
MFT	6-18	Kumar et al. (2006)
Higher and Lesser Himalaya	9-18	Jackson and Bilham (1994)
Chandigarh and West of Nepal	6-18	Kumar et al.(2006)
Hajipur Fault (HFT)	7.6±1.7	Malik et al. (2010)
Eastern Nepal	17±1.5	Lave et al. (2005)
Karakoram Fault	11±4	England and Molar (1997)
MFT	>13.8±3.6	Kumar et al.(2001)

INPUT PARAMETERS FOR THE COMPUTER PROGRAM "MOMENT _SLIP"

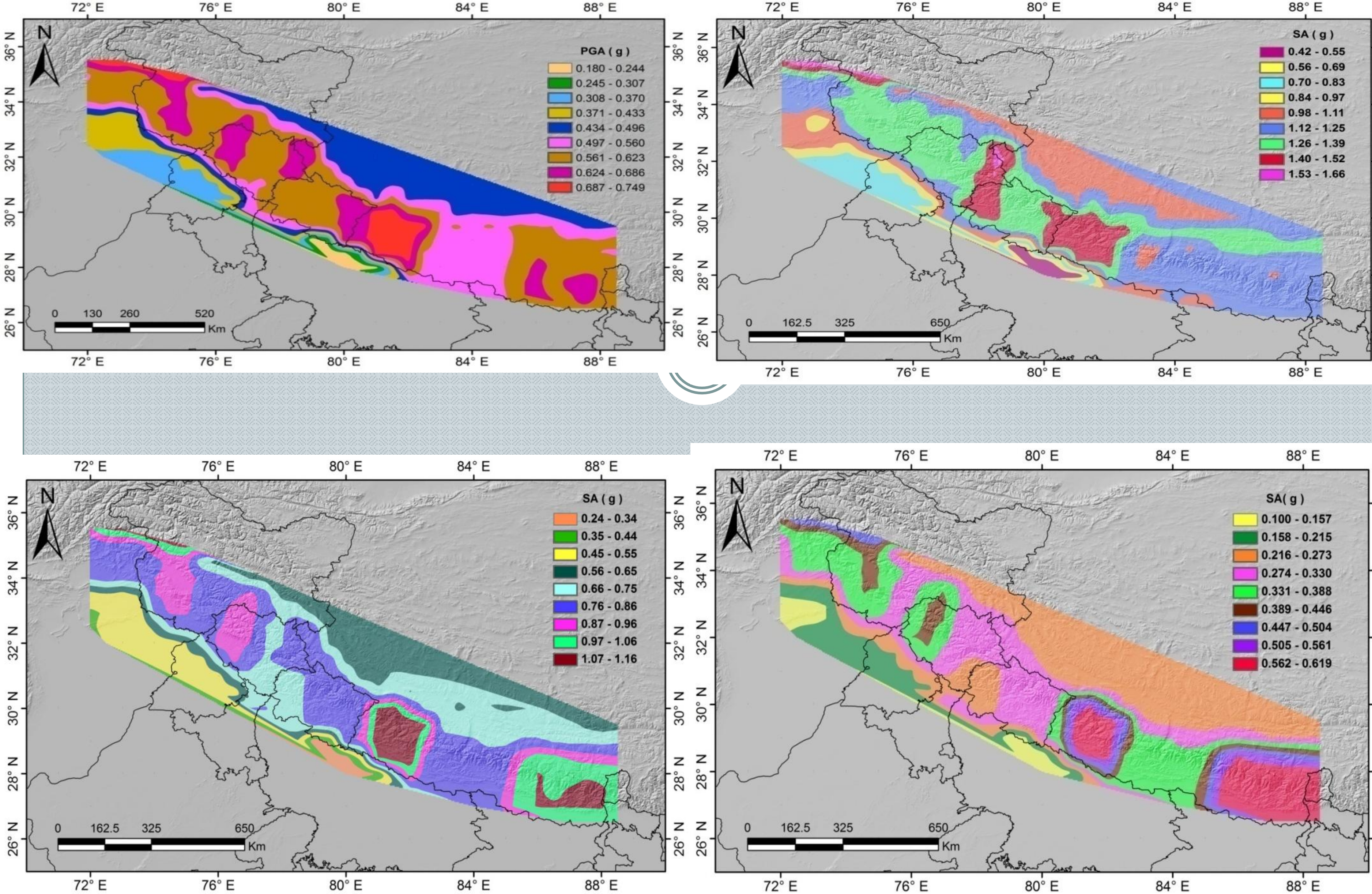
Line	Parameter	Input value		
1	Type of Model: By Anderson and Luco (1983) from 1 to 3: By Youngs and Coppersmith (1985) model 4; Average of the models 1 to 4 i.e. 5	5		
2	Slip rate of the fault (mm/yr)	20		
3	Range of fault length: min, max and step length (km)	50	300	10
4	b-value in log (N) = a - b*M	0.80		
5	Reference magnitude for calculation of N-value	4.7		
6	Type of magnitude (1: M_W, 2: M_S, 3: user-defined)	1		
7	Moment magnitude relation: log $(M_{0)}$ = c +d.M	c=16. 05	d=1. 5	
8	Relation between area of fault to M_{max}: log(A)=a+ b*M_{max}	a= -4.15	b=0. 80	
9	Slip across the fault to length of the fault ratio	10^{-4}		
10	Ration between length of fault and width of fault (L/W)	2.0		
11	Shear modulus (GPa)	30		

Seismicity parameter from Moment slip Model

Source Zone	Fault Length (Km)	Avg. N value	M_{max}		Source Zone	Fault Length (Km)	Avg. N value	M_{max}
1	-	1.20	7.27		12	-	1.07	7.45
2	192	0.55	7.41		13	129	0.43	7.05
3	71	0.25	6.40		14	-	0.49	6.2
4	178	0.55	7.40		15	148	0.49	7.25
5	-	0.54	7.88		16	288	0.77	7.7
6	124	0.42	7.05		17	222	0.63	7.5
7	176	0.55	7.40		18	602	1.10	8.4
8	128	0.42	7.05		19	311	0.77	7.8
9	806	1.10	8.60		20	401	0.90	8.0
10	126	0.42	7.05		21	-	0.81	7.3
11	232	0.61	7.50		22	-	1.68	7.5



Maps for 10% probability of exceedance in 50 years; (a) Mean PGA, (b) S_a at 0.1sec, (c) S_a at 0.5 sec and (d) S_a at 1.0 sec

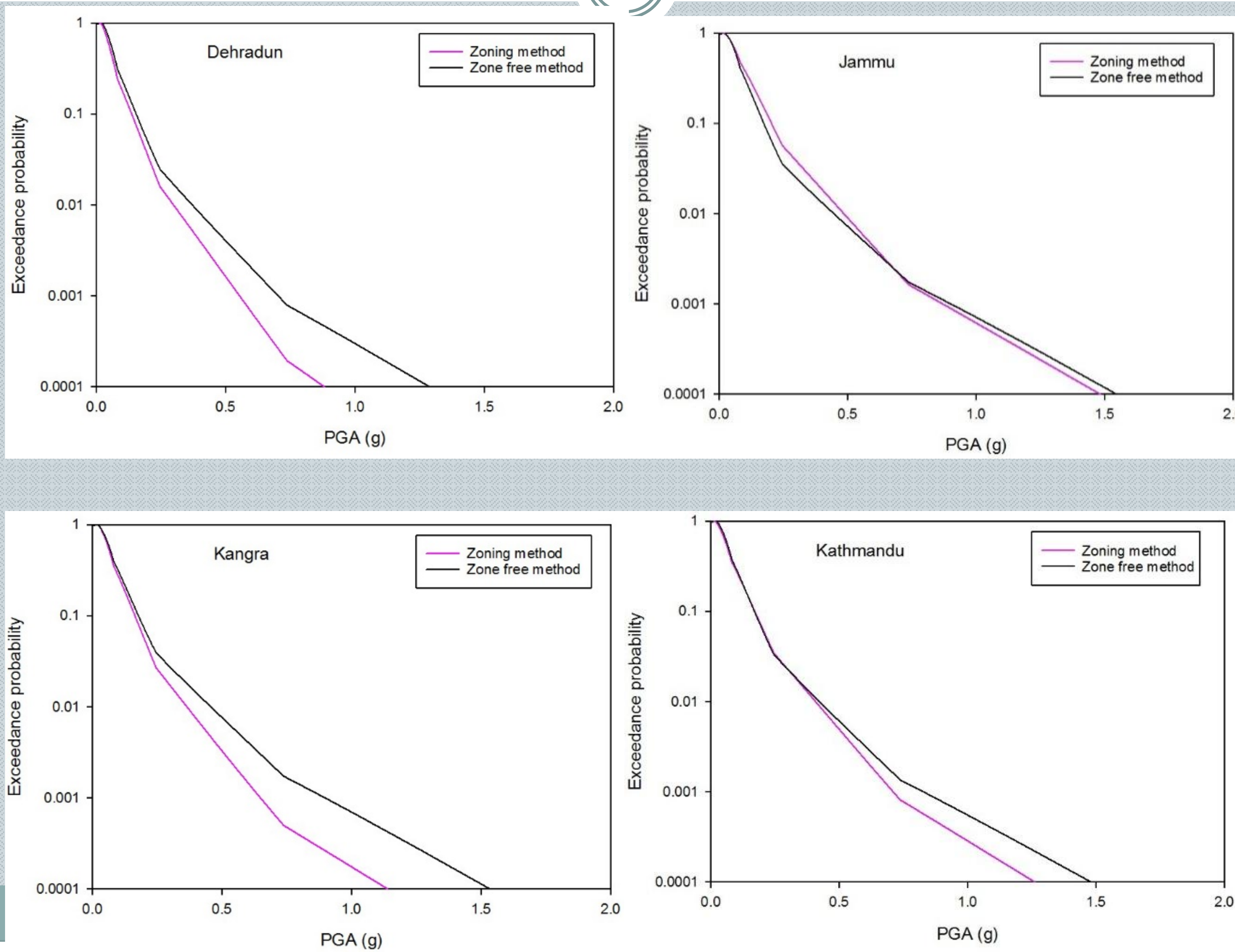


Maps for 2% probability of exceedance in 50 years; (a) Mean PGA, (b) S_a at 0.1sec, (c) S_a at 0.5 sec and (d) S_a at 1.0 sec

Estimated PGA for return periods of 475 year from different studies

Approach	Max PGA(g)	Reference
PSHA	0.70	(Khattri et al., 1984)
PSHA	0.40	(Bhatia et al., 1999)
PSHA	0.75	(Mahajan et al., 2010)
PSHA	0.18	(NDMA, GOI 2011)
PSHA	0.60	Nath and Thingbaijam 2011
PSHA	0.36	(Rout et al., 2015)
PSHA	0.31 0.33 0.45	Zoning method (Rout et al., 2018) Zone free method (Rout et al., 2018) moment slip method

The seismic hazard curves computed for selected cities of the study area



Conclusions

- Zone free and moment slip approaches employed for the first time for Himalayan region in this research work.
- Zoning method with two different geometry and dimensions of the delineated seismogenic zones predicted ground motions differently.
- Smaller sized seismogenic zones (case 2): Predicted maximum ground motion in the westernmost part of Nepal, in the north-eastern part of Himachal Pradesh and a small part of Tibet and Kashmir valley region (0.545g to 0.597g) for 2475 return period. Second maximum predicted ground motion area falls on the easternmost part of Nepal.
- Intermediate sized seismogenic zones: Predicted maximum ground motion in easternmost part of the Nepal (0.504g to 0.549g) and second maximum in west-central part of Nepal (0.459g to 0.503g) for 2475 return period.
- The ground motion parameters in all the cases increases with the increase in annual rate of exceedance for the seismogenic zones.

- The area coverage and occurrences of predicted maximum ground motion is governed by the size of zones.
- Zone free method predicted maximum ground motion in two areas falling in Kashmir valley and eastern part of Uttarakhand and westernmost part of Nepal. Ground motion ranges from 0.547g to 0.609g for 2475 return period. The predicted hazard zones possess an elongated shape following the Himalayan structural features and geometrical structure of seismicity.
- Anisotropic parameter (delta) of the kernel revealed a degree of correlation between the tectonic feature trend and shape of predicted hazard zones.

- In zoning method the ground motion concentrated inside the seismogenic zone.

- Moment slip method with 22 seismogenic zones also predicted maximum ground motion (0.687g to 0.749g for 2475 years return period) in the westernmost part of Nepal. Higher ground motion estimated because there are uncertainties in calculation of fault length which tend to increase the maximum magnitude.

- Highest predicted ground motion of about 0.6g for MCE and 0.36g for DBE conditions as predicted in this research work appears to be meaningful and justifiable in view of expected earthquake potential of the Himalayan tectonic belt.

- The strong ground motion estimated at the bed rock level can be used for the estimation of ground motion at the surface wherever required by incorporating the site amplification factor.

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Thank
You