Seismic Hazard Assessment

Probabilistic Seismic Hazard Analysis (PSHA)

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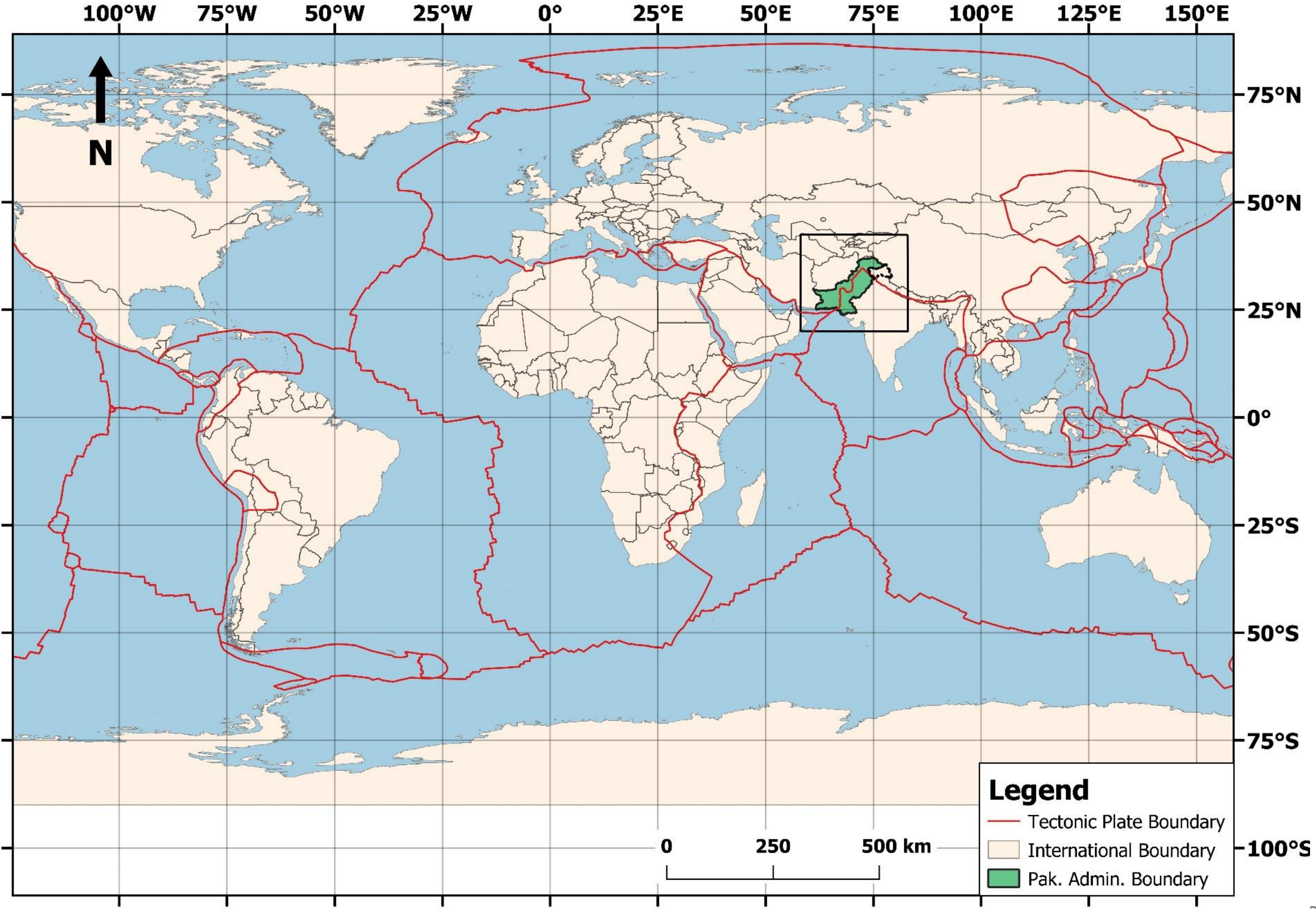
Probabilistic Seismic Hazard Assessment of Pakistan

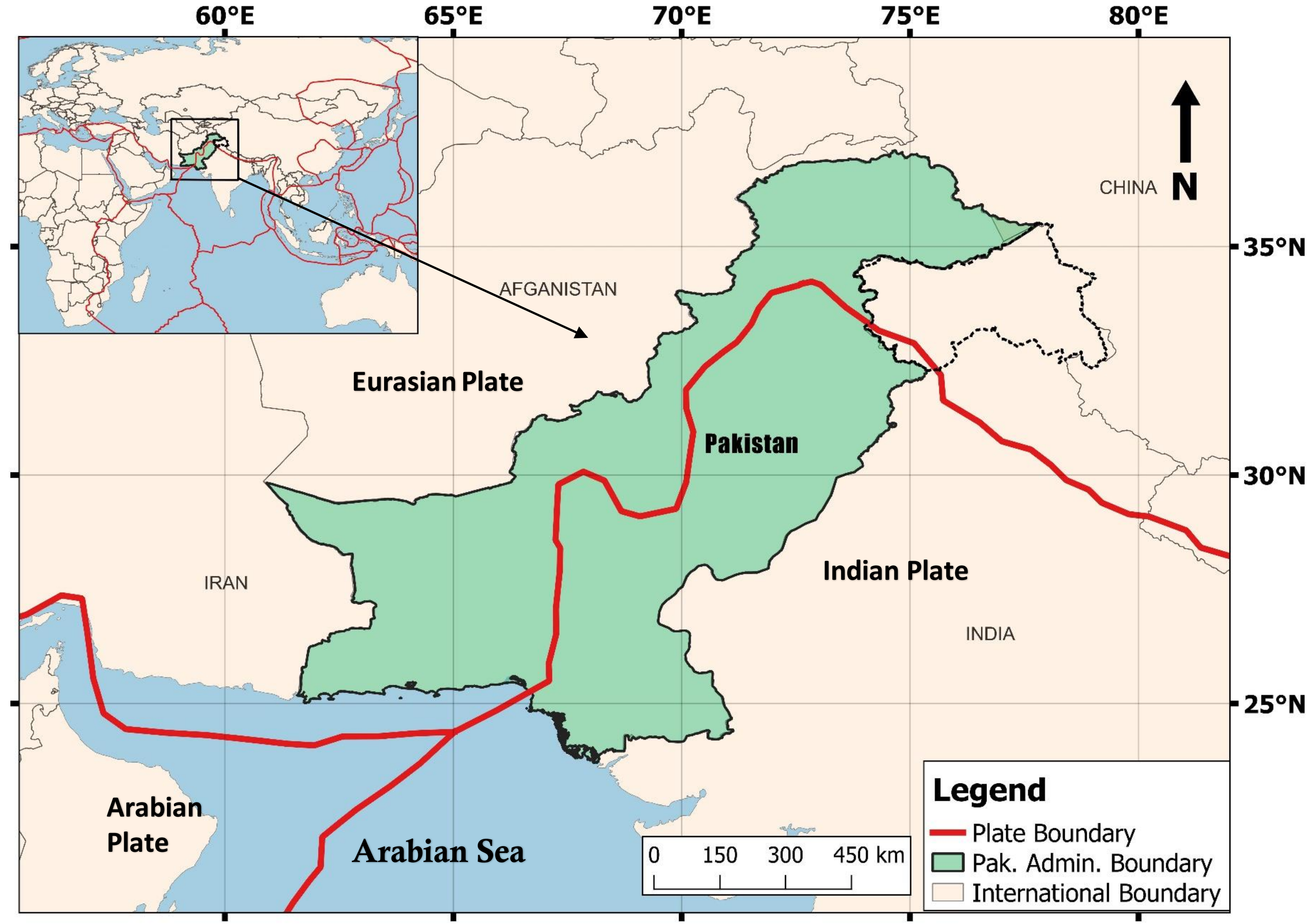
- Seismic Hazard Assessment of Pakistan (A Quick Review of Existing Studies)
- An Overview of Few PSHA Studies for Pakistan
  - PSHA by NESPAK for BCP 2007
  - PSHA of Pakistan using Spatially Smoothed Background Seismicity and Crustal Faults Model (Zaman and Warnitchai, 2016)
  - PSHA by Waseem et al., (2020)
  - Probabilistic Seismic Hazard and Deaggregation Analysis of Pakistan using Area Source Model (Atif, 2019)
  - Updated PSHA of Pakistan using both the conventional and Spatially Smoothed Background Seismicity and Crustal Faults Model (Rahman et al., 2021)

SHA of Pakistan (A Quick Review of Existing Studies)

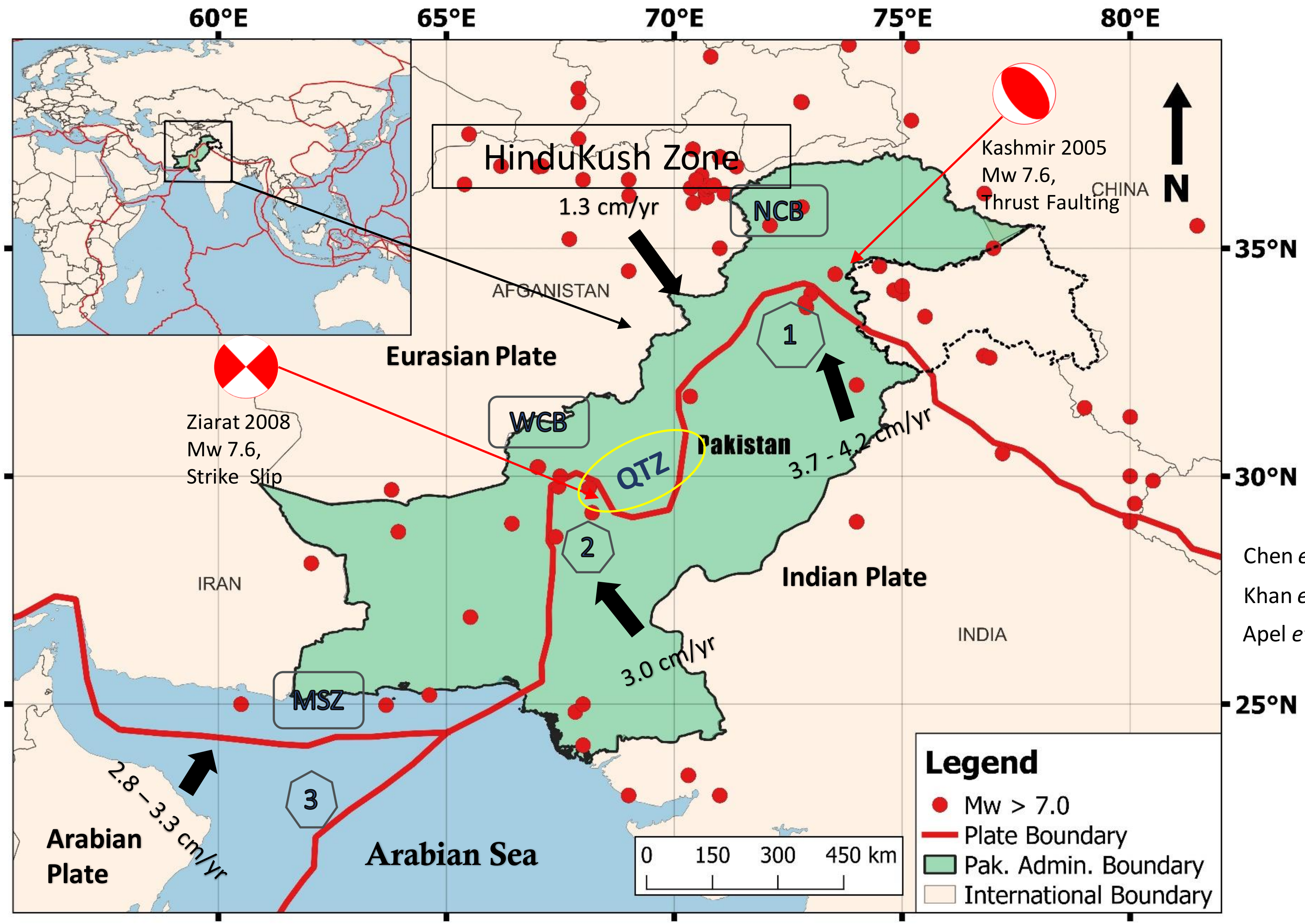
Location of Pakistan and the tectonic setting around



Tectonic Environment of Pakistan



NCB North Collision Boundary
WCB West Collision Boundary
MSZ Makran Subduction zone
QTZ Quetta Transverse Zone



Chen *et al.*, 2000

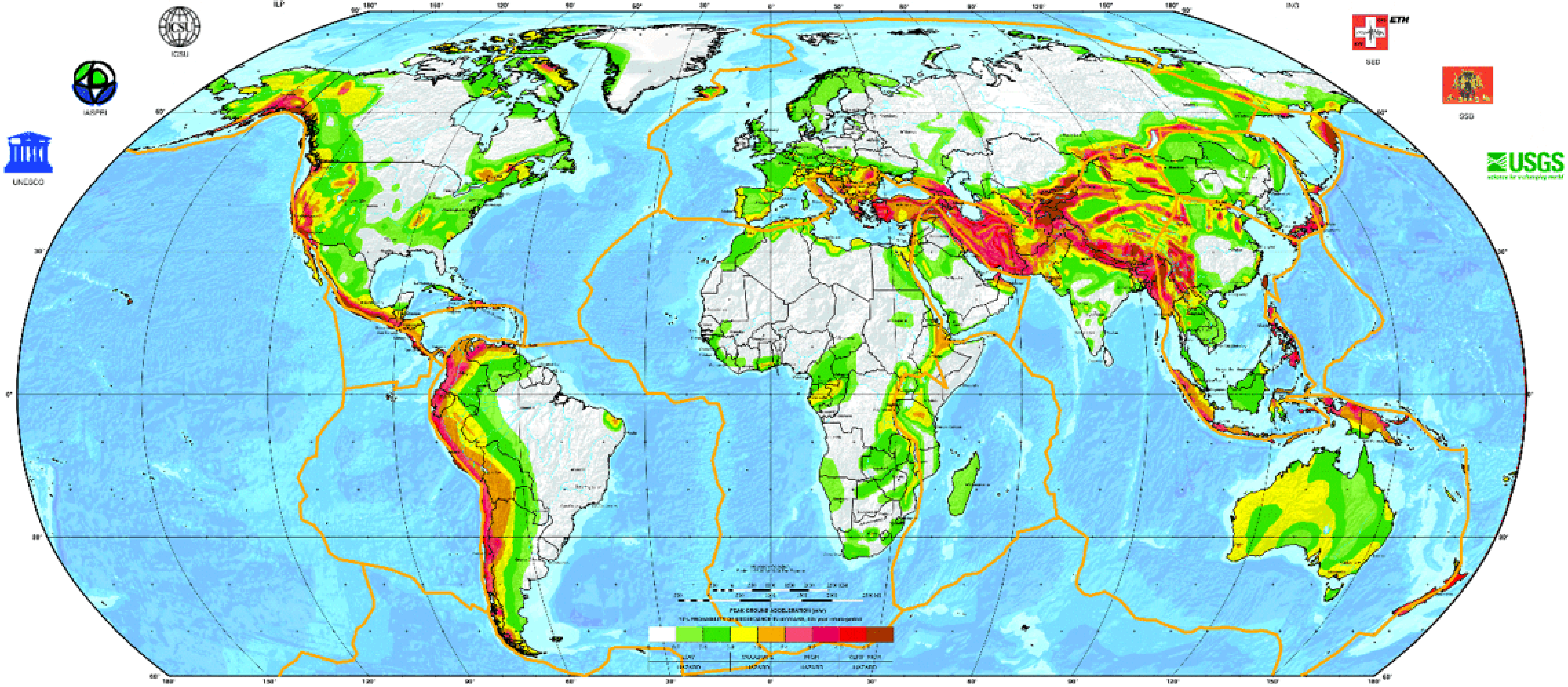
Khan *et al.*, 2018

Apel *et al.*, 2006

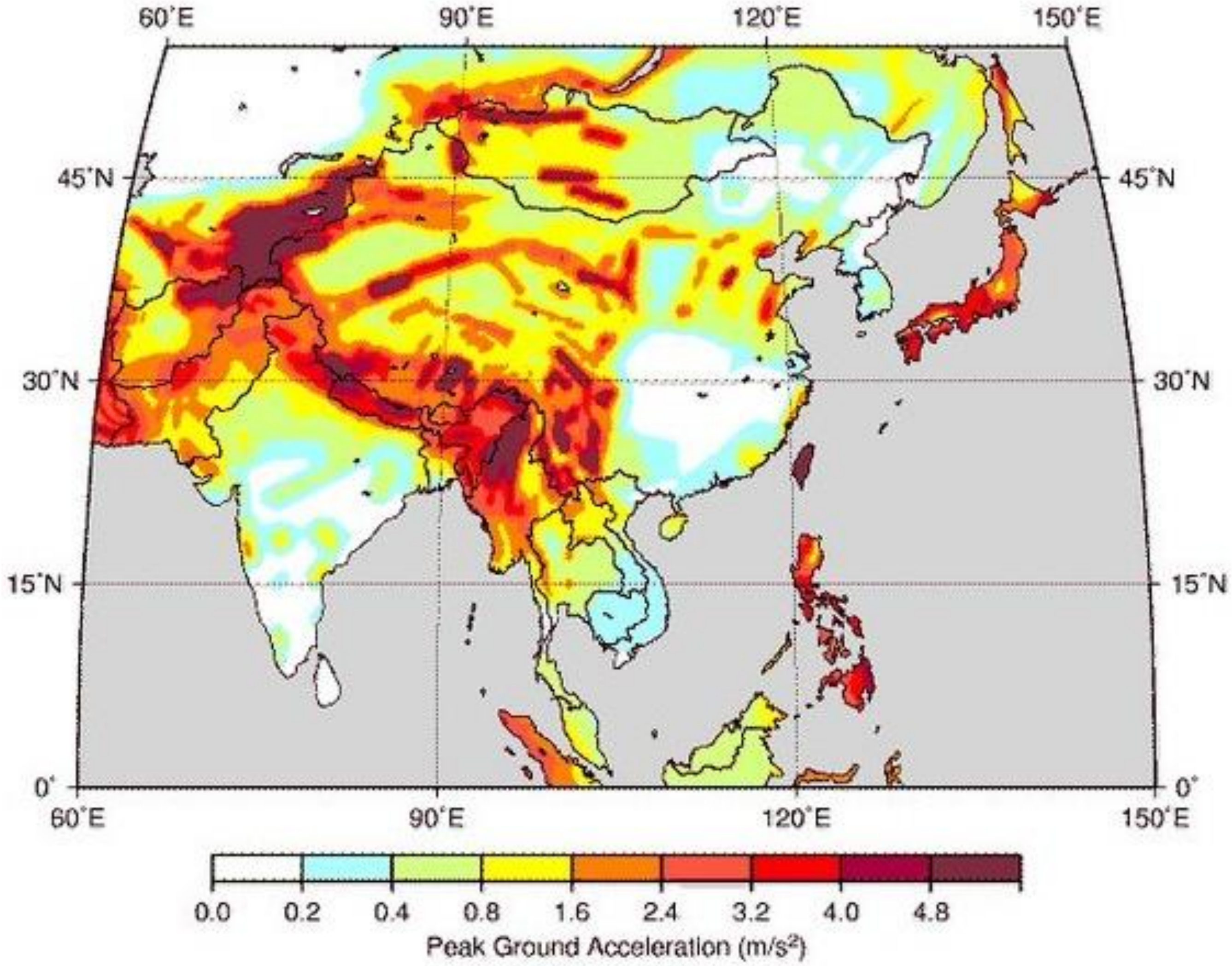
GLOBAL SEISMIC HAZARD MAP

Produced by the Global Seismic Hazard Assessment Program (GSHAP),
a demonstration project of the UN/International Decade of Natural Disaster Reduction, conducted by the
International Lithosphere Program.

Global map assembled by D. Giardini, G. Grünthal, K. Shedlock, and P. Zhang
1999

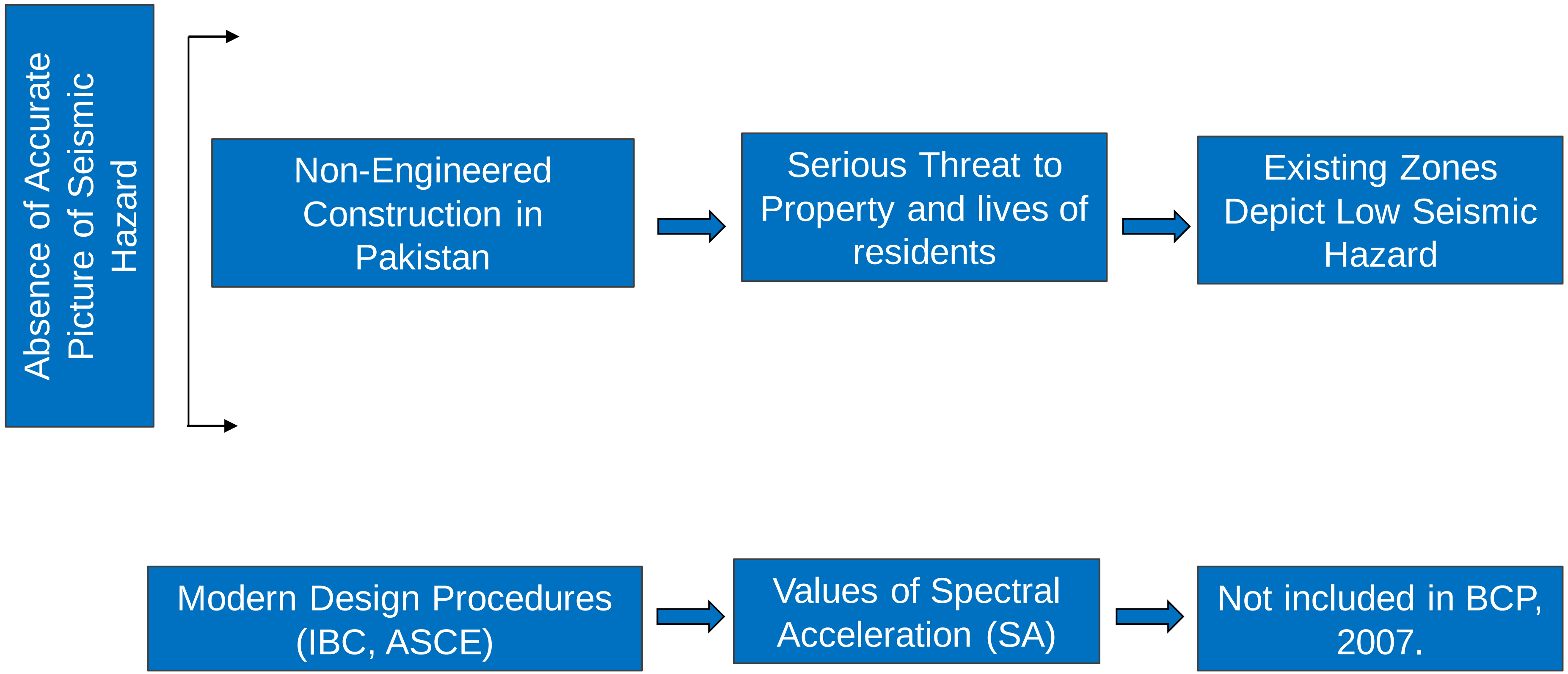


Seismic Hazard of South and Southeast Asia



(GSHAP, 1999)

Why Seismic Hazard Assessment of Pakistan?



Absence of Accurate Picture of Seismic Hazard

Non-Engineered Construction in Pakistan → Serious Threat to Property and lives of residents → Existing Zones Depict Low Seismic Hazard

Modern Design Procedures (IBC, ASCE) → Values of Spectral Acceleration (SA) → Not included in BCP, 2007.


Balakot, October 2005

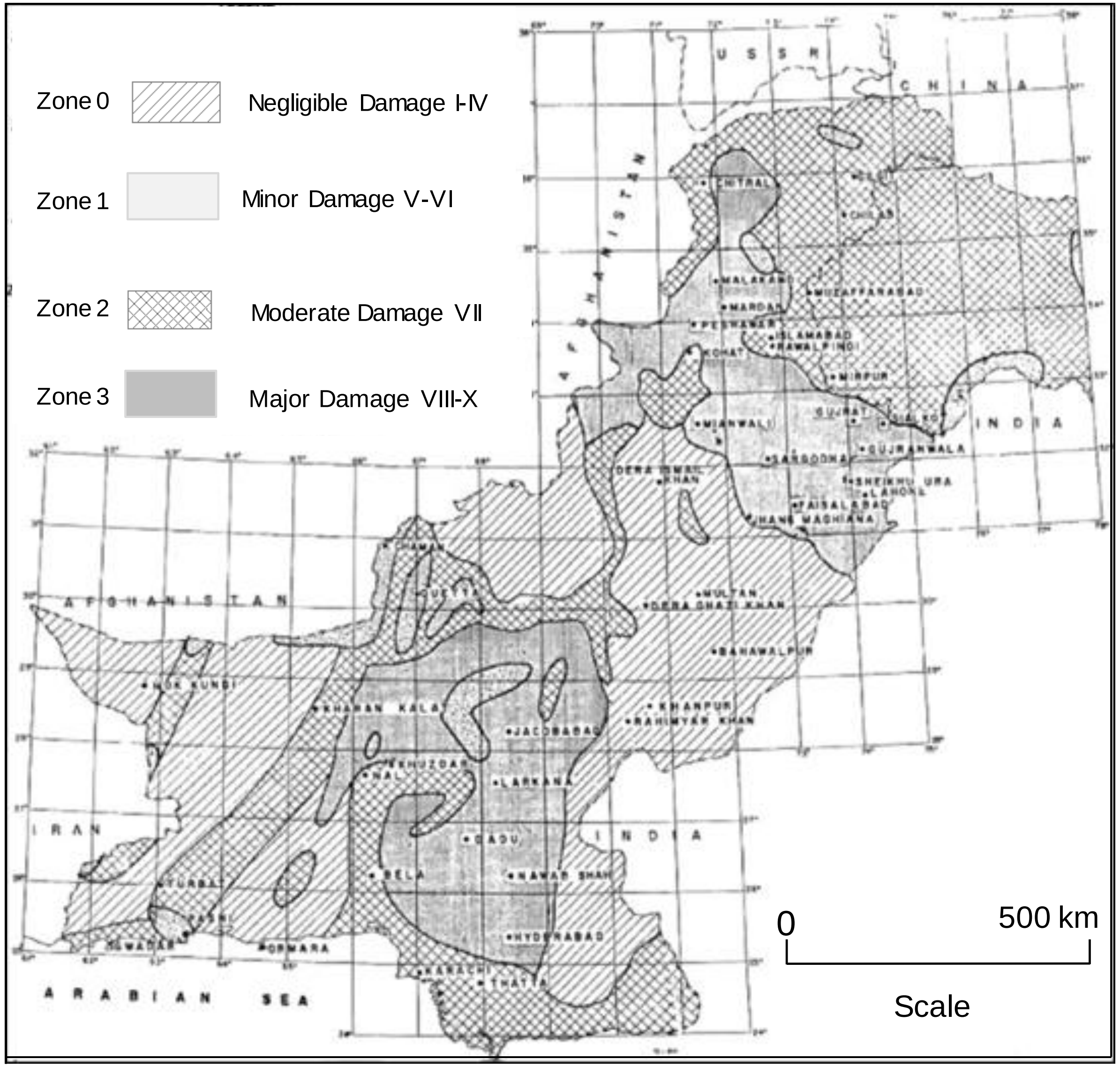
Are We Prepared Enough to Handle the Next “Big One”?

How safe are our buildings and structures against future earthquakes?

Seismic Hazard Assessment of Pakistan

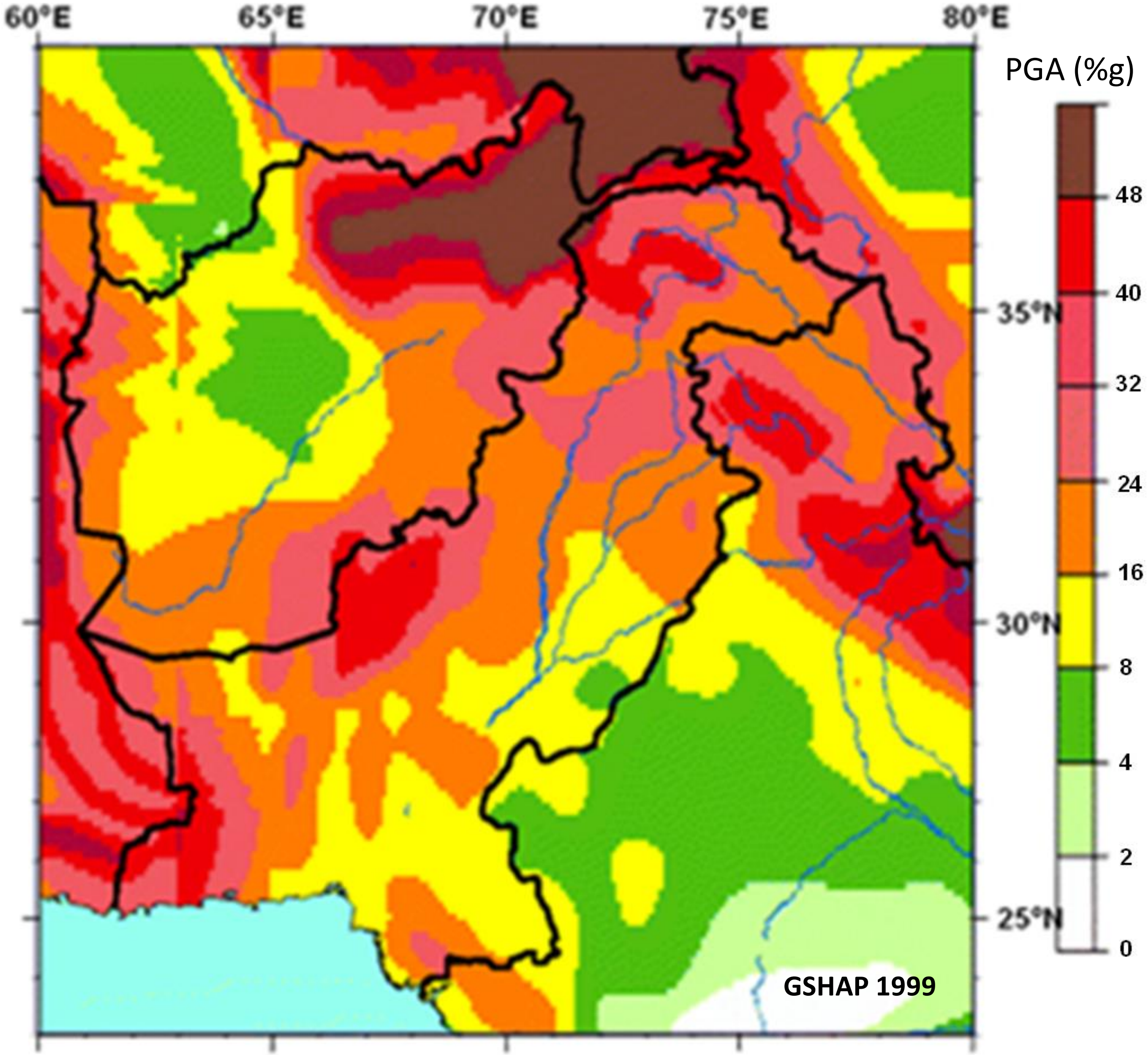
1) 1974 → Very first study by the Geological Survey of Pakistan. (Zaman, 2016)

2) 1986 → Federal Ministry of Housing and Works formulated Pakistan Building Code (PBC). (Federal Ministry of Housing and Works, GOP, 1986)



Seismic Hazard Assessment of Pakistan

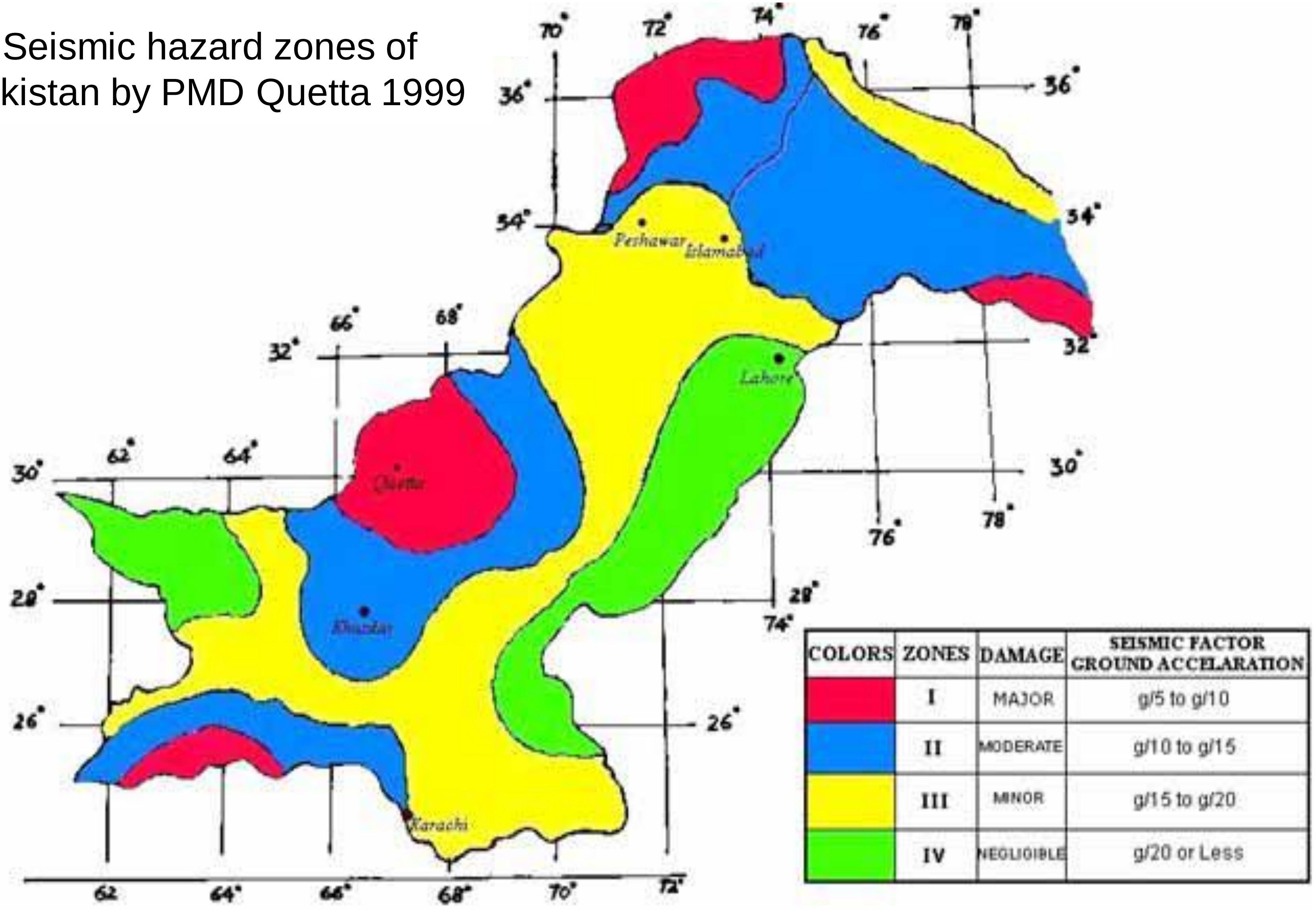
3) 1999 → Global Seismic Hazard Assessment Program (GSHAP). (Zhang et.al, 1999)



PGA: Peak Ground Acceleration
(10% Probability of Exceedance in 50 yrs)

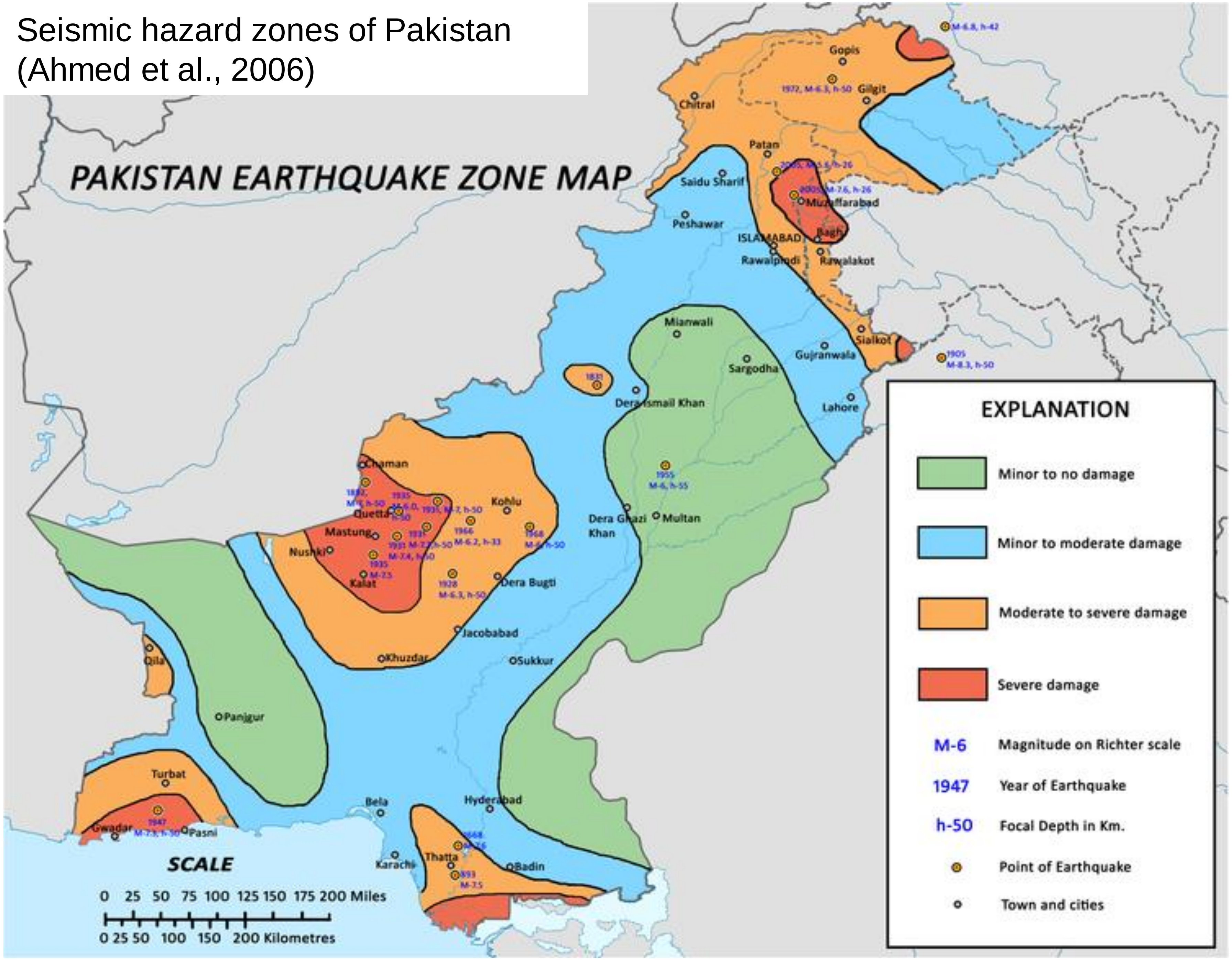
Seismic Hazard Assessment of Pakistan

Seismic hazard zones of
Pakistan by PMD Quetta 1999



COLORS	ZONES	DAMAGE	SEISMIC FACTOR GROUND ACCELARATION
🟥	I	MAJOR	g/5 to g/10
🟦	II	MODERATE	g/10 to g/15
🟨	III	MINOR	g/15 to g/20
🟩	IV	NEGLIGIBLE	g/20 or Less

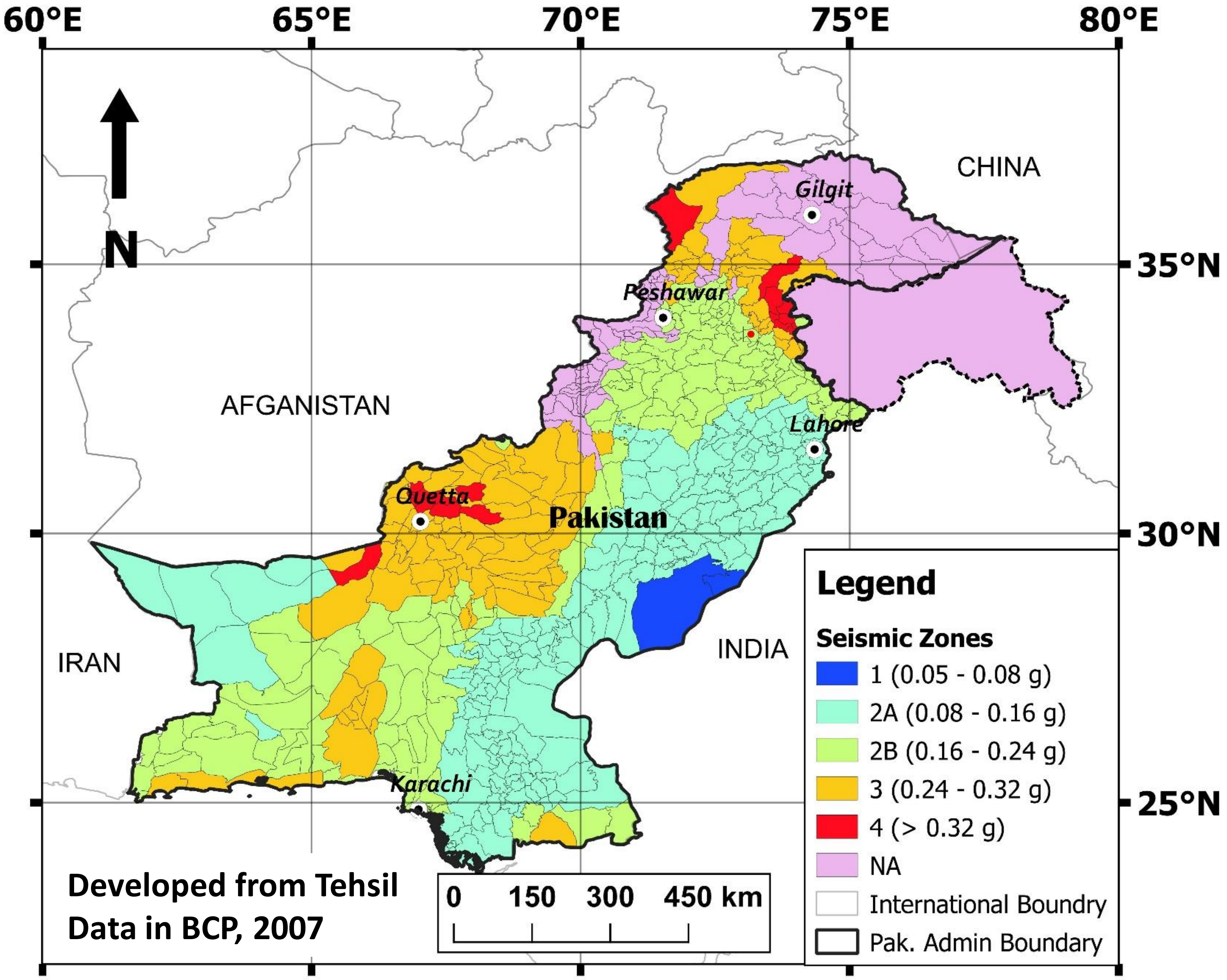
Seismic hazard zones of Pakistan (Ahmed et al., 2006)



Seismic Hazard Assessment of Pakistan

4) 2007 → NESPAK updated the Building Code of Pakistan. (BCP, 2007)

PGA: Peak Ground Acceleration
(10% Probability of Exceedance in 50 yrs)

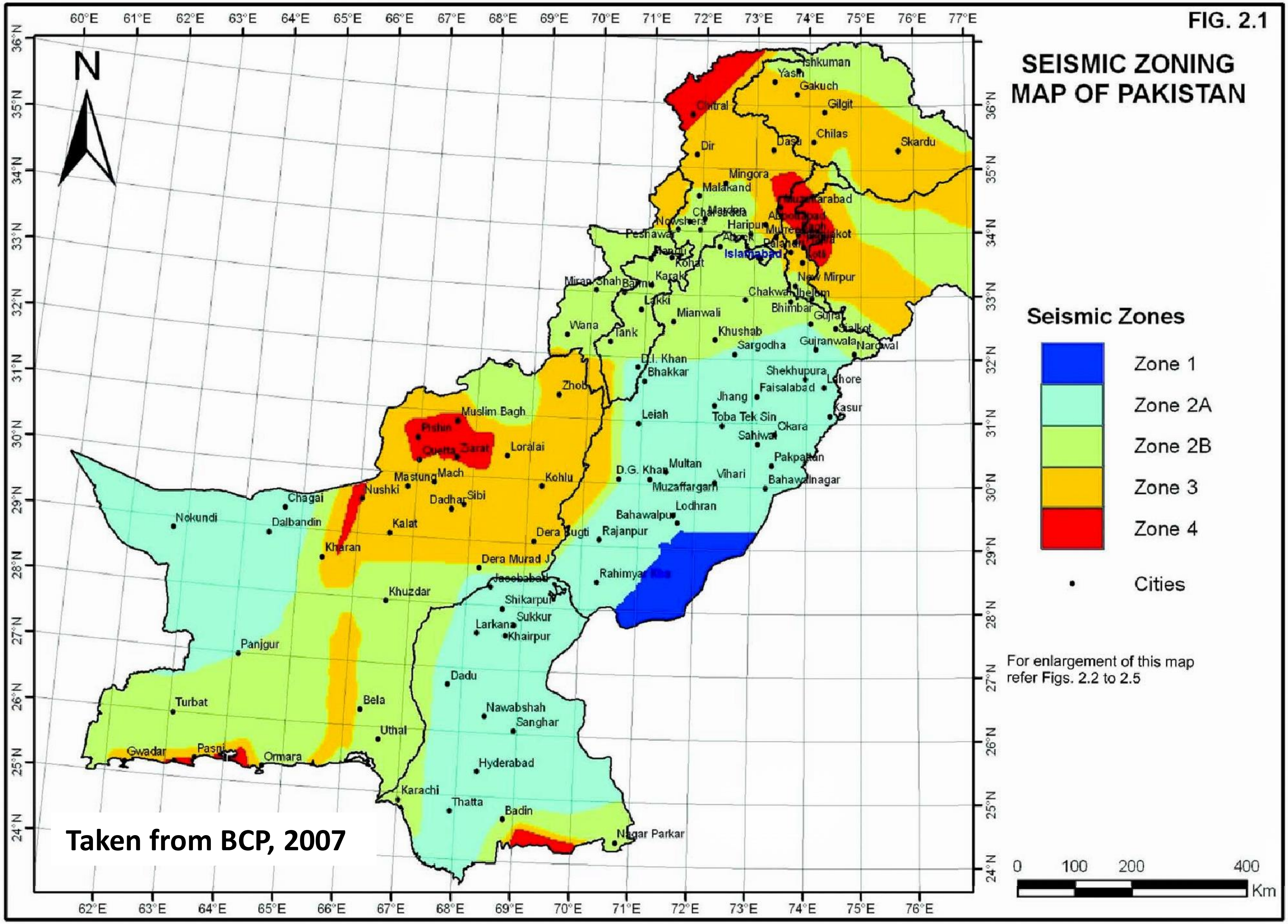


Developed from Tehsil Data in BCP, 2007

Seismic Hazard Assessment of Pakistan

4) 2007 → NESPAK updated the Building Code of Pakistan. (BCP, 2007)

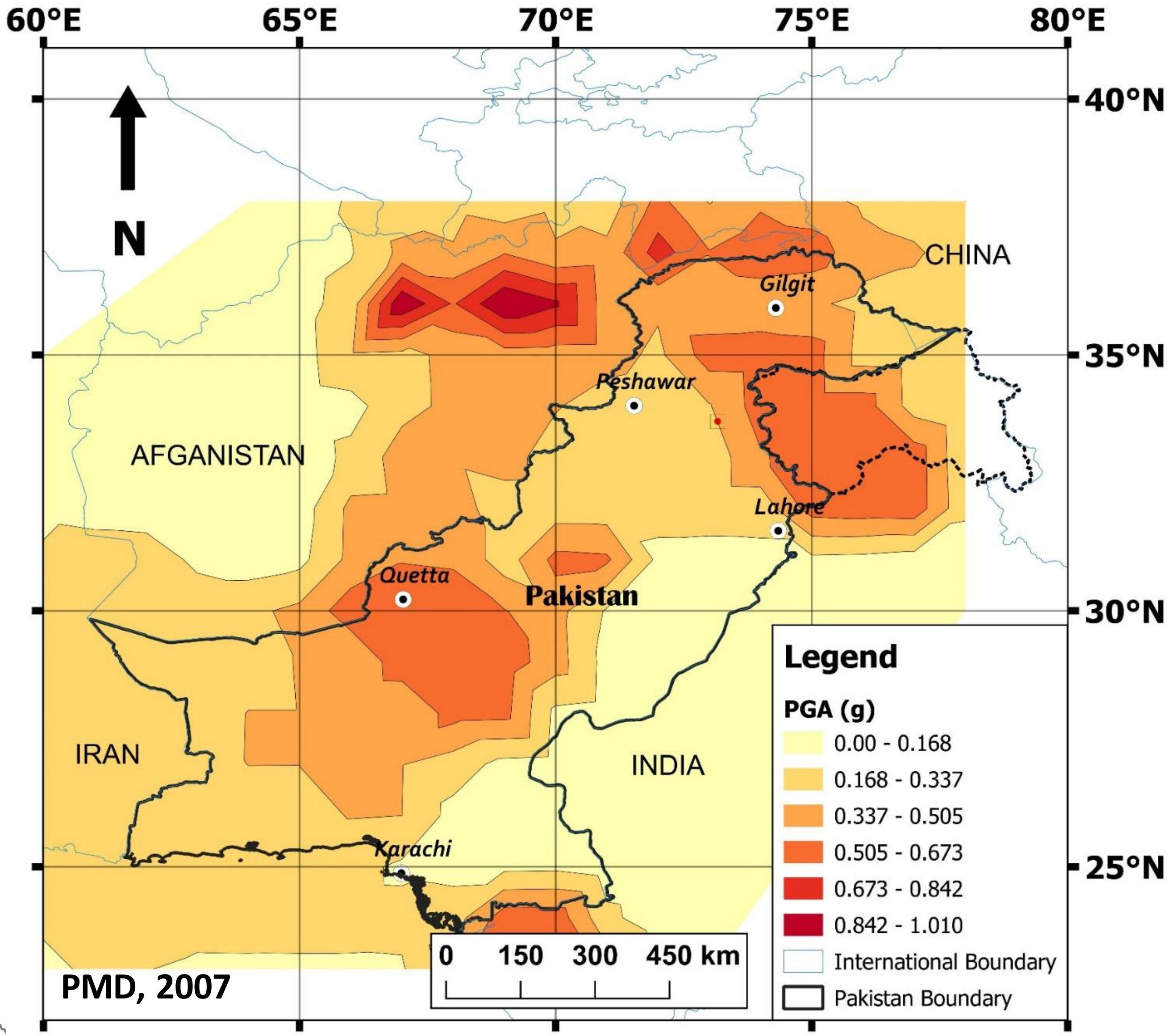
PGA: Peak Ground Acceleration
(10% Probability of Exceedance in 50 yrs)



Taken from BCP, 2007

Seismic Hazard Assessment of Pakistan

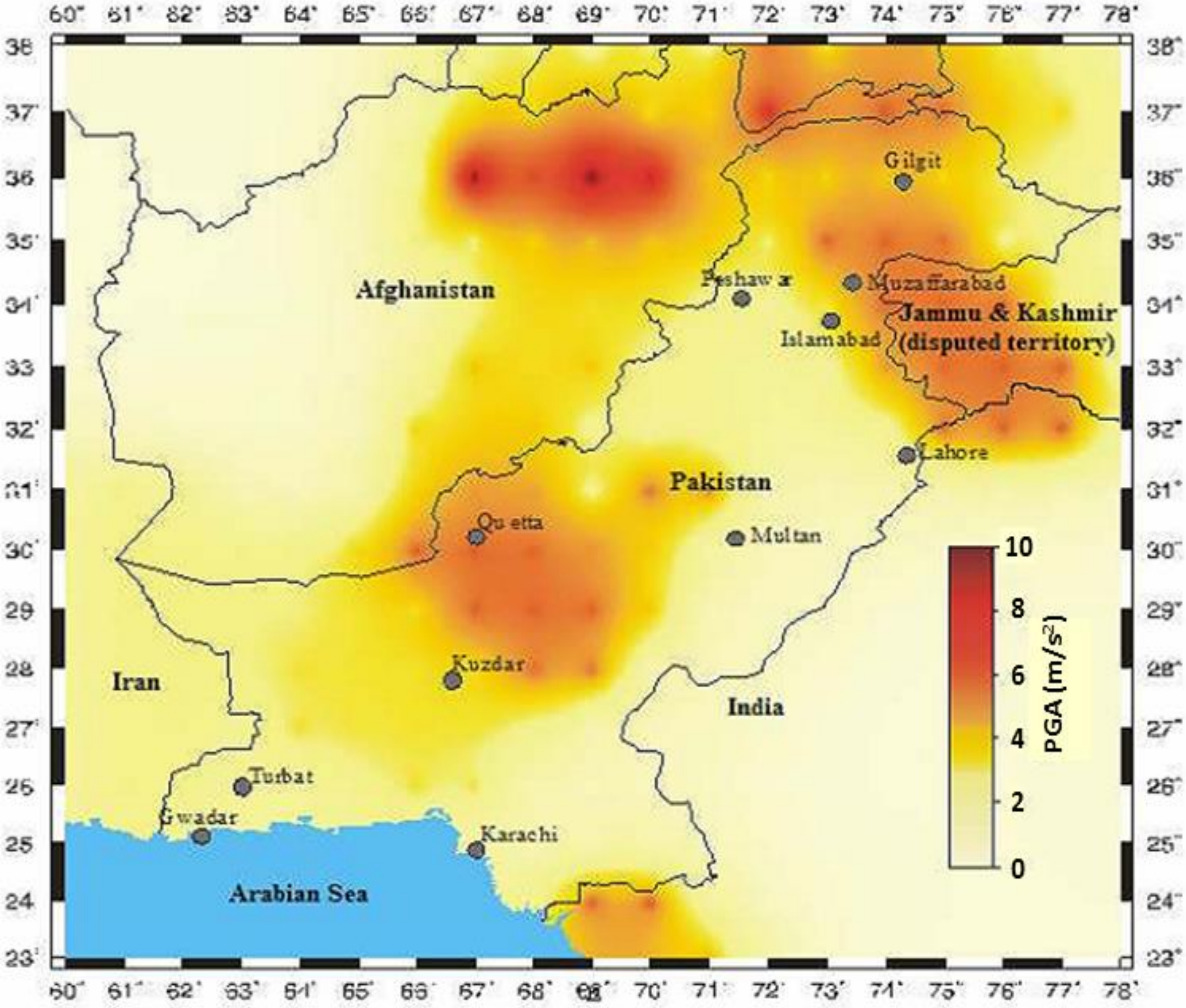
5) 2007 → Pakistan Meteorological Department (PMD) and Norwegian Seismic Array (NORSAR). (PMD & NORSAR, 2007)



PMD, 2007

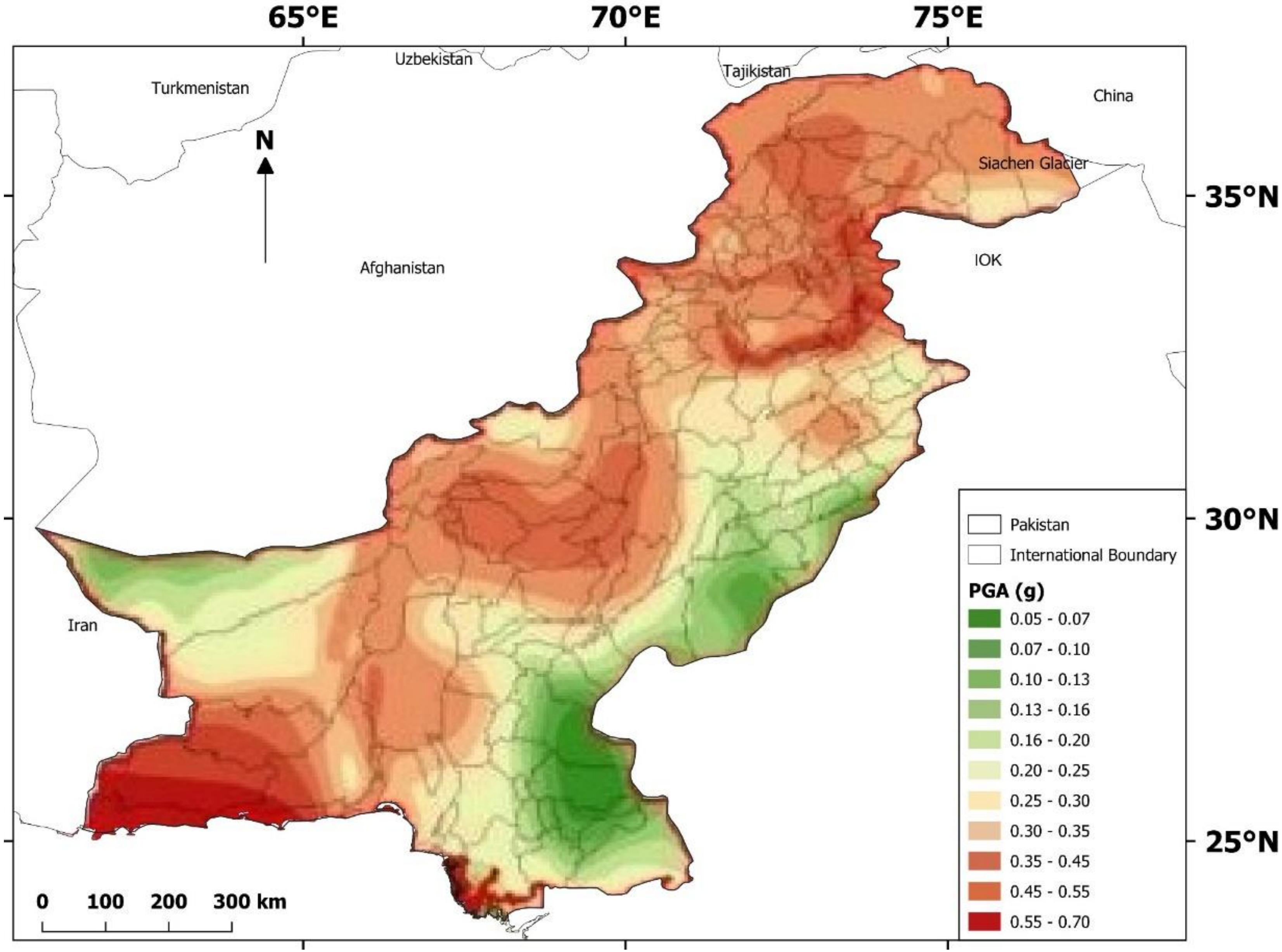
PGA: Peak Ground Acceleration
(10% Probability of Exceedance in 50 yrs)

Seismic hazard map of Pakistan for PGA for 475 years return period (Modified from PMD-NORSAR 2007)



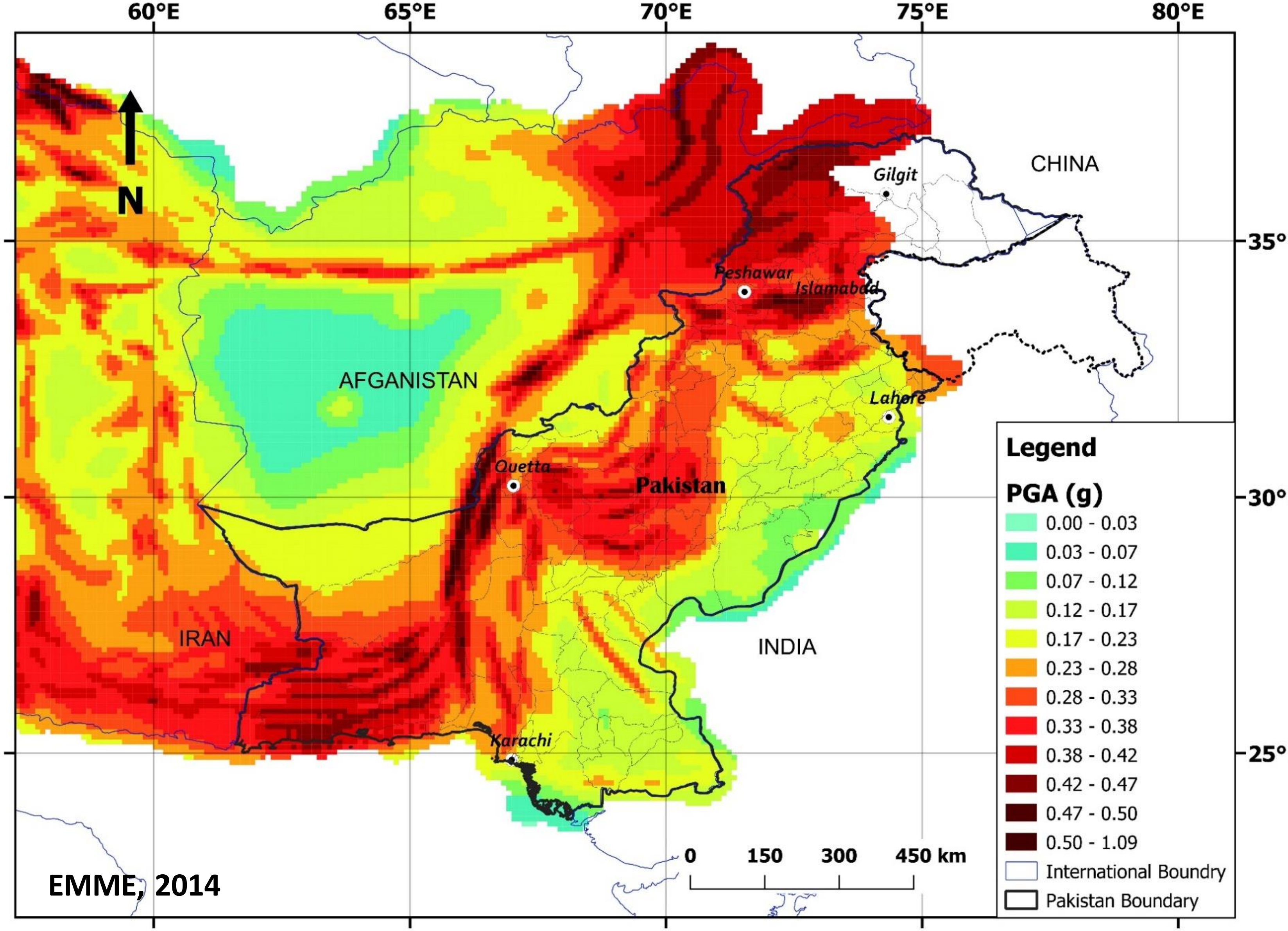
Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan

6) 2012 → Probabilistic seismic hazard assessment of Pakistan.
Zaman et al. (2012)



Seismic Hazard Assessment of Pakistan

7) 2014 → Earthquake Model of Middle East (EMME 2014). (Sesetyan et.al, 2014)



EMME, 2014

PGA: Peak Ground Acceleration
(10% Probability of Exceedance in 50 yrs)

Study 1:

PSHA for BCP (NESPAK, 2007)

A.2.2 *Major Faults of Pakistan*

Pakistan is characterized by extensive zones of moderate to high seismicity, induced by the regional collisional tectonics associated with Indian and Eurasian plates and resulting in manifestation of great Himalayan and associated mountain ranges. The geographic domain of Pakistan comprises a network of active seismotectonic features of regional extent, generally associated with collisional mountain ranges. These define four broad seismotectonic zones including 1) the Himalayan seismotectonic zone in the north, 2) Suleiman-Kirthar thrust-fold belt, 3) Chaman-Ornach Nal Transform Fault Zone, and 3) Makran Subduction Zone in the west, and 4) Rann of Kutch Seismotectonic Zone in the southeast. The Pamir-Hindukush Seismic Zone straddles across Afghanistan and Tajikistan outside Pakistan but in close vicinity of the NW Pakistan comprising District Chitral.

Major Faults of Pakistan

Major active faults of Pakistan and surrounding areas that strongly influence the seismic hazard are listed below:

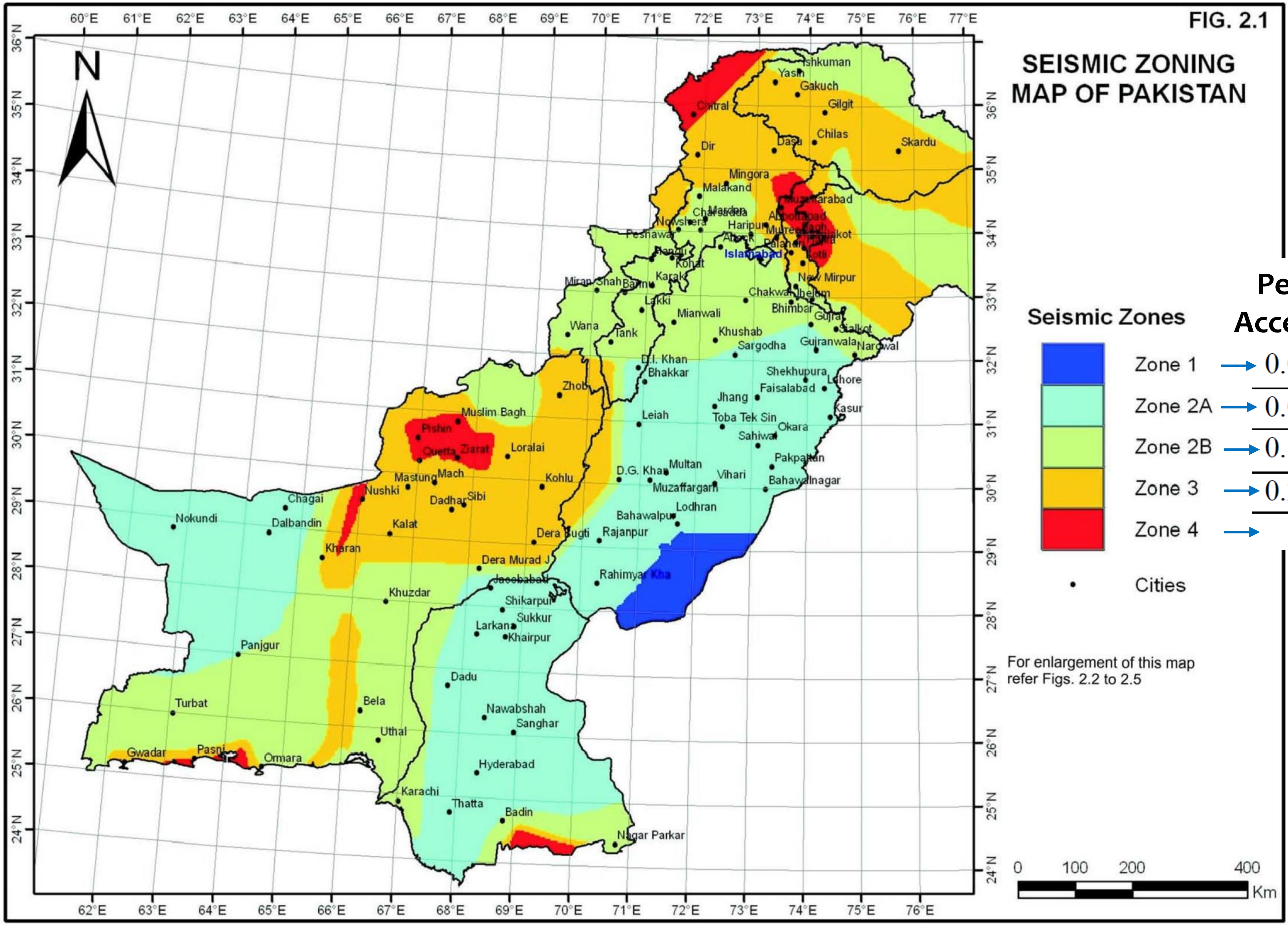
- Main Karakoram Thrust
- Main Mantle Thrust
- Raikot Fault
- Main Boundary Thrust
- Panjal-Khairabad Thrust
- Himalayan Frontal Thrust
- Riasi Thrust
- Jhelum Fault
- Salt Range Thrust
- Kalabagh Fault
- Bannu Fault
- Kurram Fault
- Chaman Transform Fault
- Ornach-Nal Transform Fault
- Quetta-Chiltan Fault
- Kirthar Fault
- Pab Fault
- Kutch Mainland Fault
- Allah Bund Fault
- Nagar Parkar Fault
- Hoshab Fault
- Nai Rud Fault
- Makran Coastal Fault

On the basis of PGA values obtained through PSHA, Pakistan was divided into five seismic zones in line with UBC (1997). The boundaries of these zones are defined on the following basis:

Zone 1	0.05 to 0.08g
Zone 2A	0.08 to 0.16g
Zone 2B	0.16 to 0.24g
Zone 3	0.24 to 0.32g
Zone 4	> 0.32g

FIG. 2.1

SEISMIC ZONING MAP OF PAKISTAN

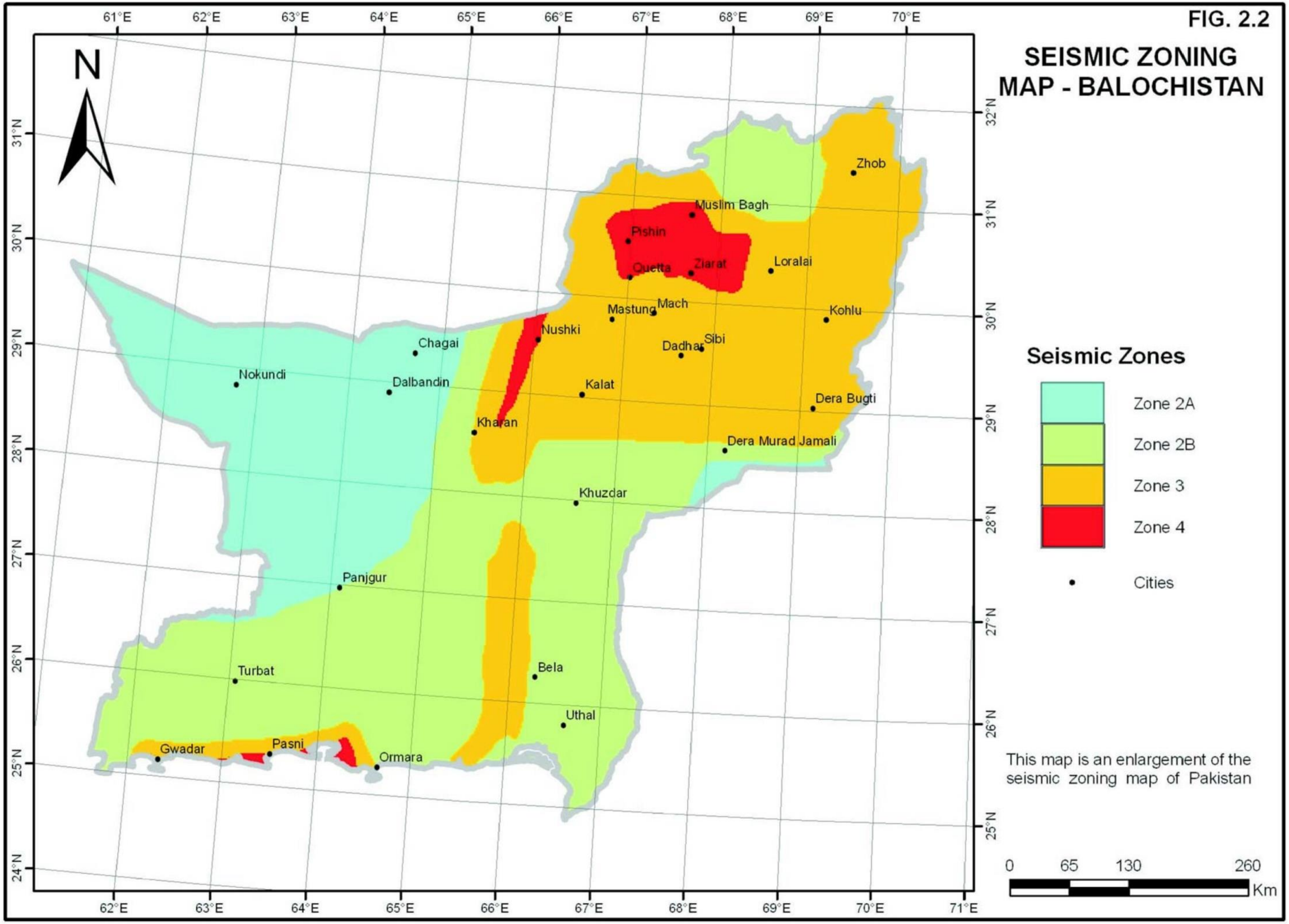


For enlargement of this map refer Figs. 2.2 to 2.5

Seismic Zones		Peak Ground Acceleration (g)
🟦	Zone 1 →	0.05 to 0.08g
🟦	Zone 2A →	0.08 to 0.16g
🟩	Zone 2B →	0.16 to 0.24g
🟧	Zone 3 →	0.24 to 0.32g
🟥	Zone 4 →	> 0.32g
•	Cities	

FIG. 2.2

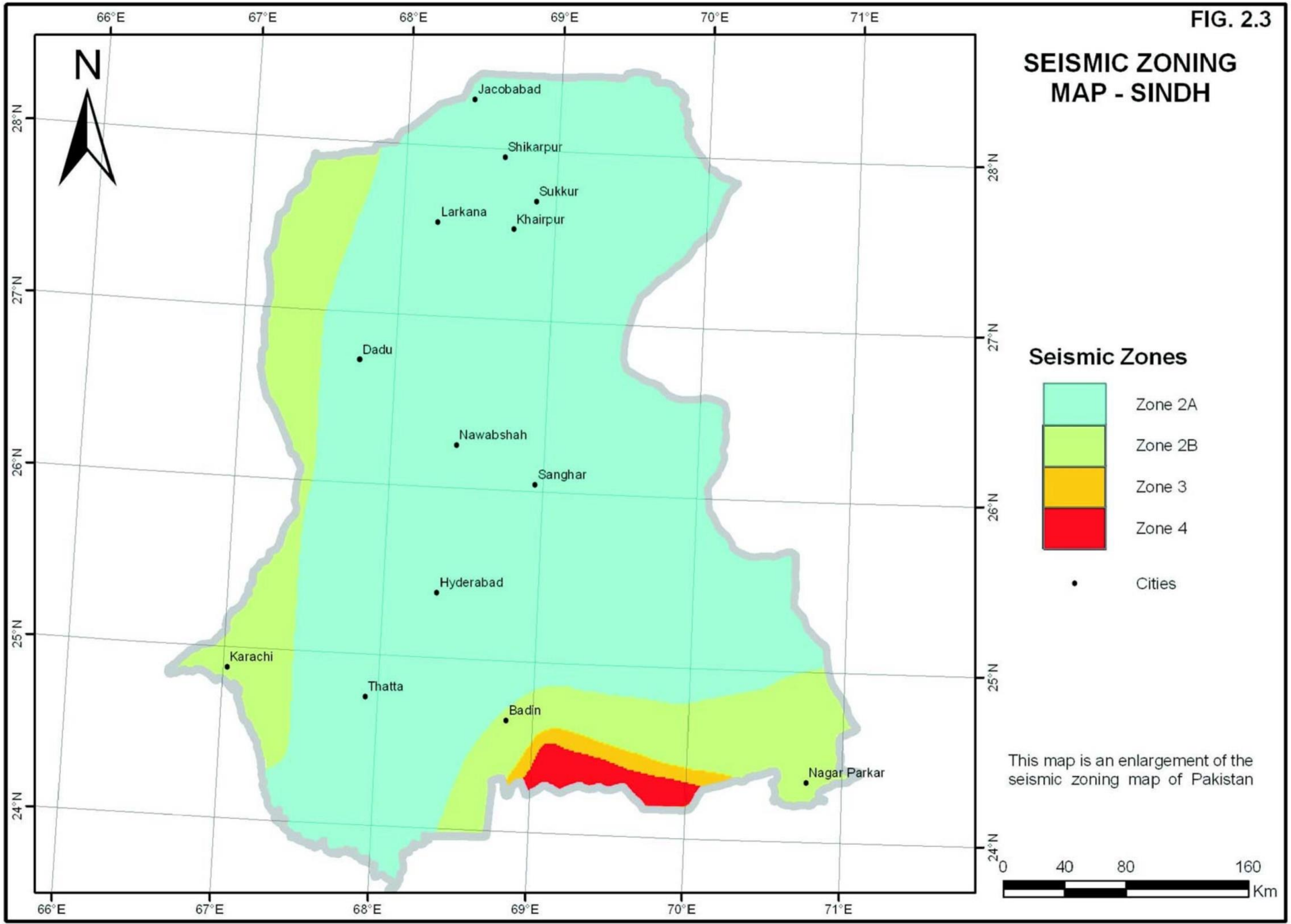
SEISMIC ZONING MAP - BALOCHISTAN



This map is an enlargement of the seismic zoning map of Pakistan

FIG. 2.3

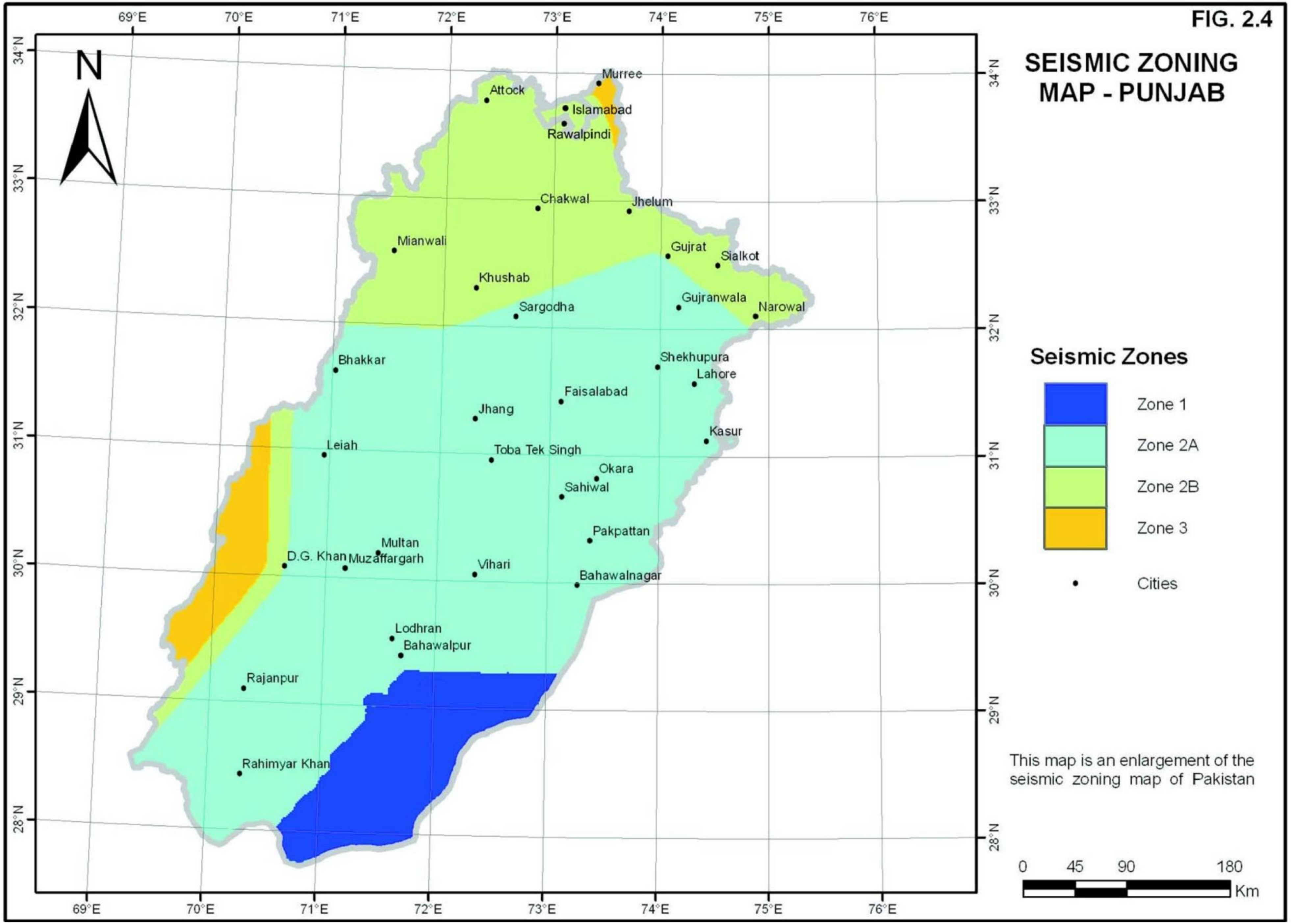
SEISMIC ZONING MAP - SINDH



This map is an enlargement of the seismic zoning map of Pakistan

FIG. 2.4

SEISMIC ZONING MAP - PUNJAB



This map is an enlargement of the seismic zoning map of Pakistan

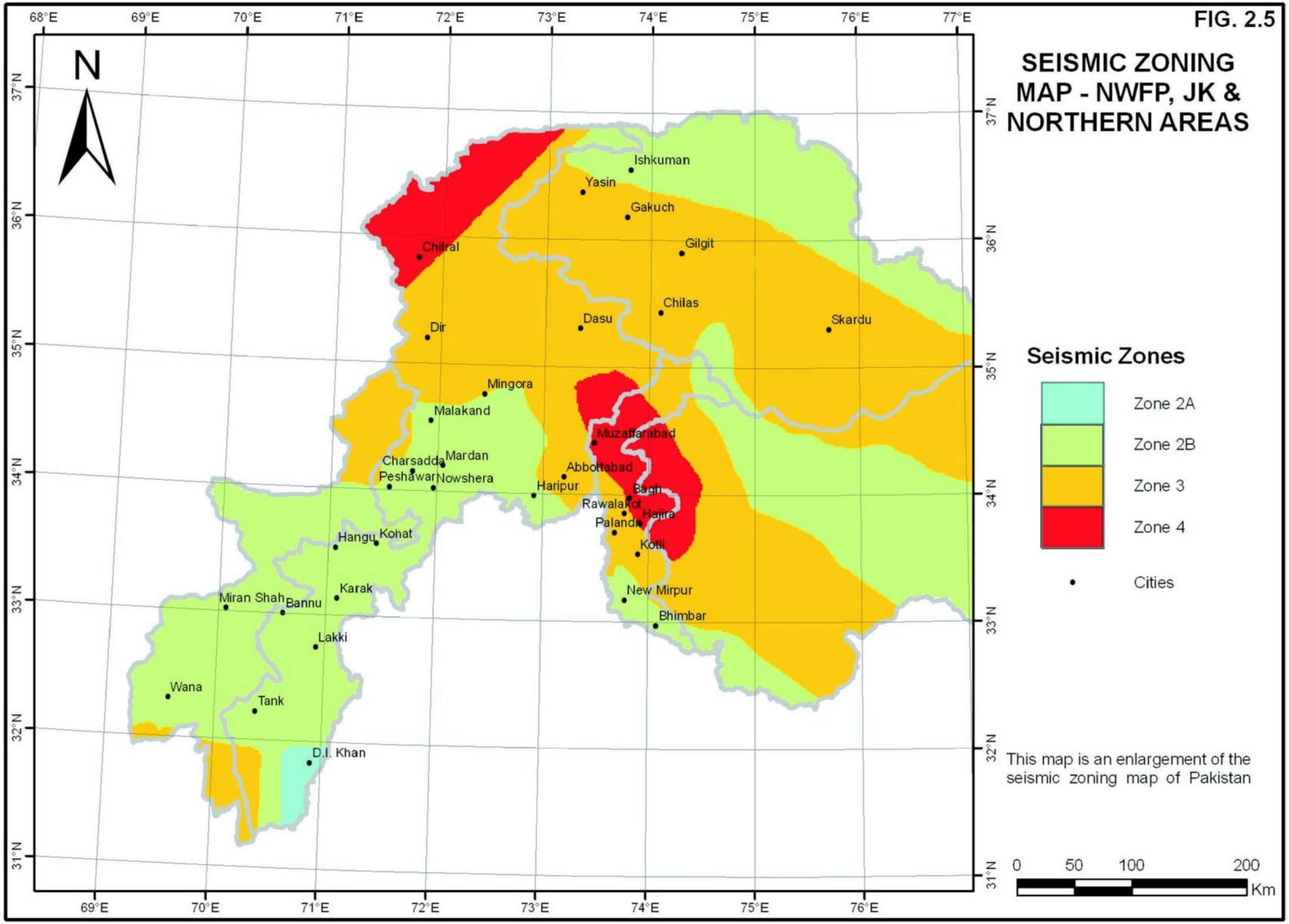
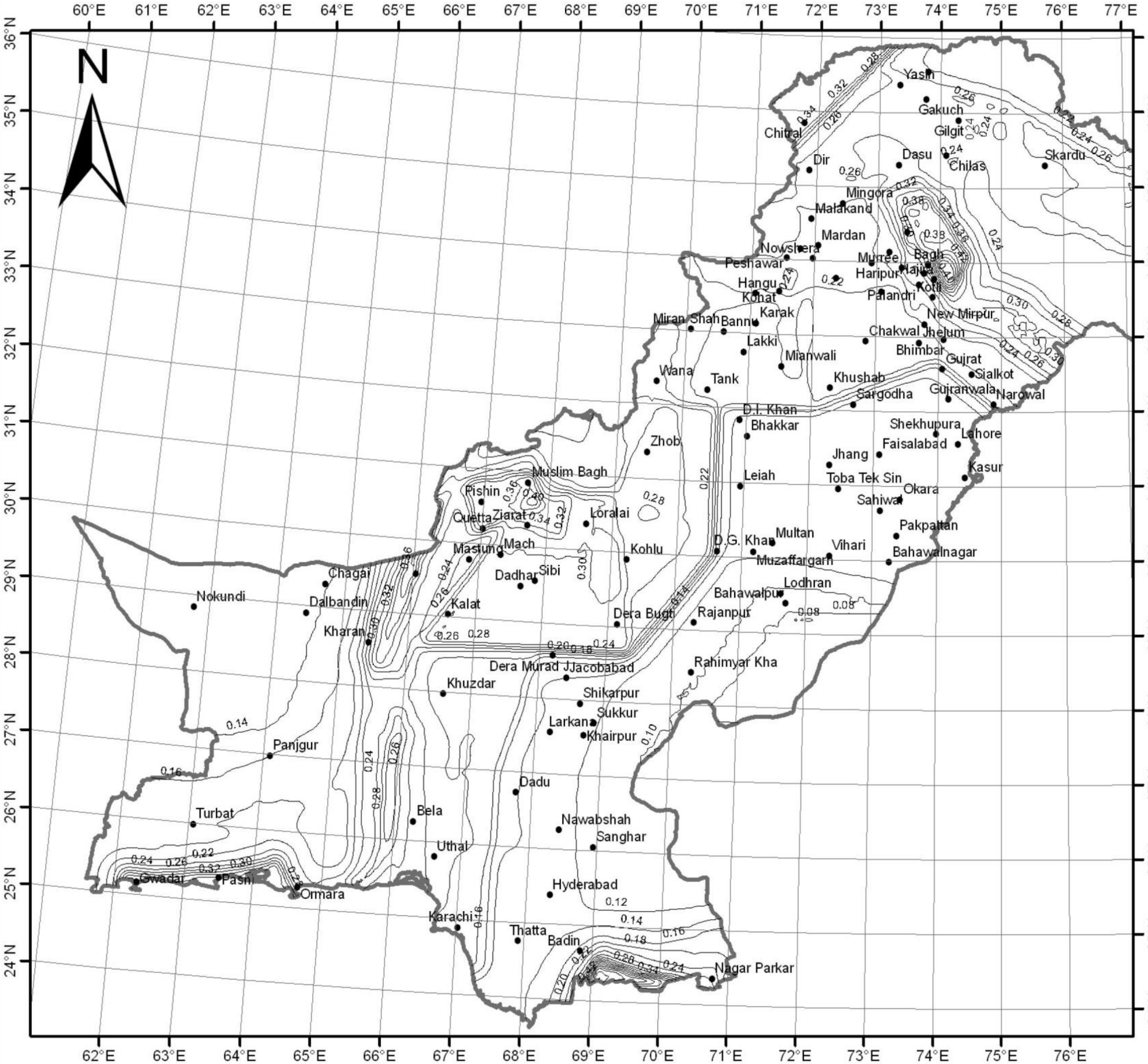


FIG. 2.5

SEISMIC ZONING MAP - NWFP, JK & NORTHERN AREAS

This map is an enlargement of the seismic zoning map of Pakistan

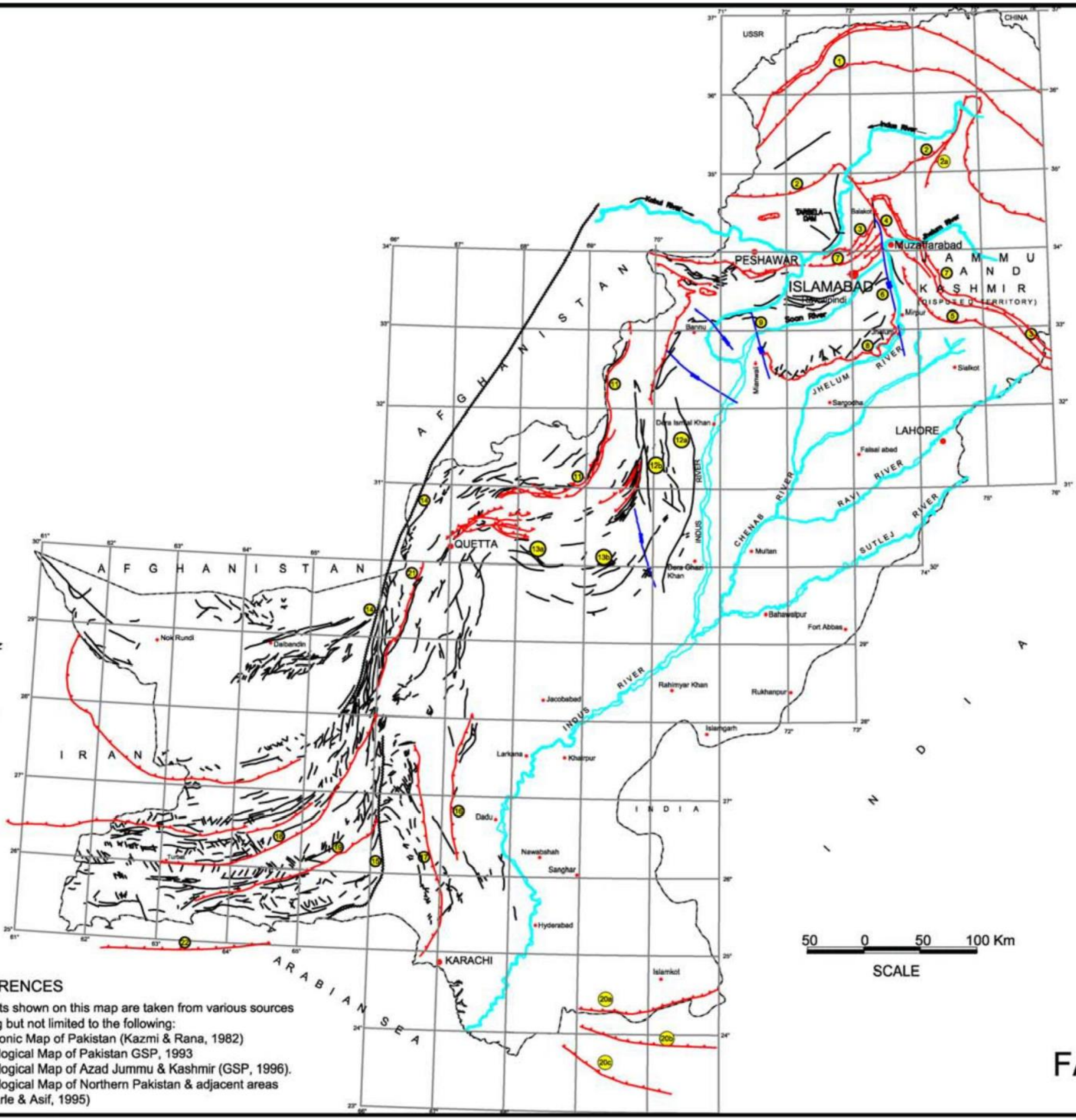
FIG. A-1



Peak Ground Acceleration (g) with 10% Probability of Exceedance in 50 years

PGA Contour Interval = 0.02g

FIG. A-2



MAJOR FAULTS

Code No.	Fault Name
1	Main Karakuram Thrust (MKT)
2	Main Mantle Thrust (MMT)
2a	Raikot Fault
3	Panjal Thrust (PT)
4	Himalayan Frontal Thrust (HFT)
5	Riasi Thrust (RT)
6	Jhelum Fault (JF)
7	Main Boundary Thrust (MBT)
8	Salt Range Thrust (SRT)
9	Kalabagh Fault (KF)
10	Bannu Fault (BF)
11	Kurram Thrust (KmT)
12a	Chaudhwan Fault (SFT N-1)
12b	Domanda Fault (SFT N-2)
13a	Harnai Fault (SFT S-1)
13b	Kohlu Fault (SFT S-2)
14	Chaman Fault (CF)
15	Ornach-Nal Fault
16	Kirthar Fault (KRF)
17	Pab Fault (PF)
18	Hoshab Fault (HF)
19	Nai Rud Fault (NRF)
20a	Nagar Parkar Fault
20b	Allah Band Fault
20c	Kutch Mainland Fault
21	Chiltan-Ghazaband Fault
22	Makran Coastal Fault

LEGEND

—	Faults unclassified
—	Strike-Slip Fault
▲	Thrust Faults
⇄	Wrench faults
▬	Transform faults

REFERENCES

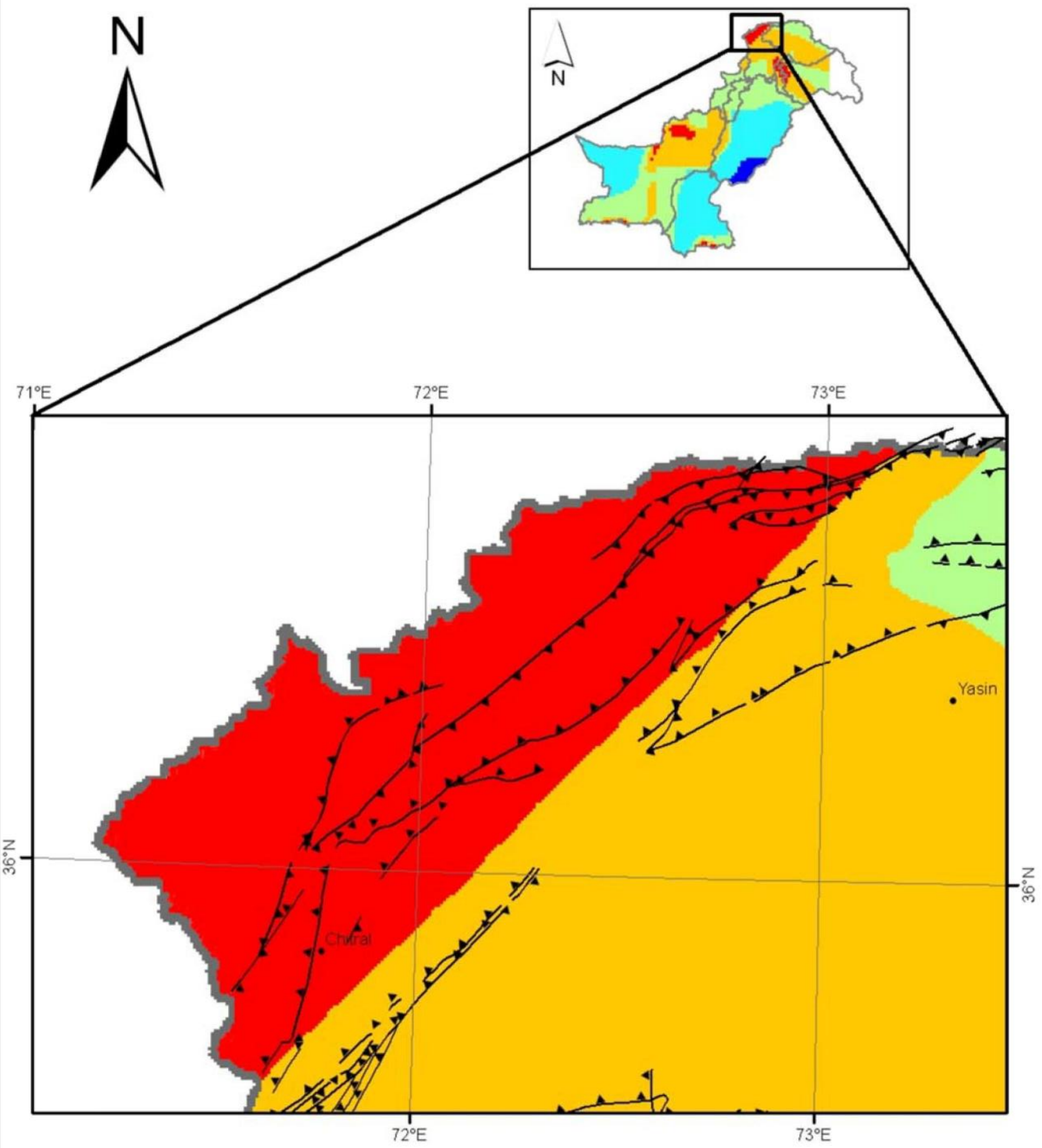
The faults shown on this map are taken from various sources including but not limited to the following:

1. Tectonic Map of Pakistan (Kazmi & Rana, 1982)
2. Geological Map of Pakistan GSP, 1993
3. Geological Map of Azad Jummu & Kashmir (GSP, 1996).
4. Geological Map of Northern Pakistan & adjacent areas (Searle & Asif, 1995)

FAULT MAP OF PAKISTAN

FIG. A-3a

DETAILS OF FAULTS IN ZONE 4

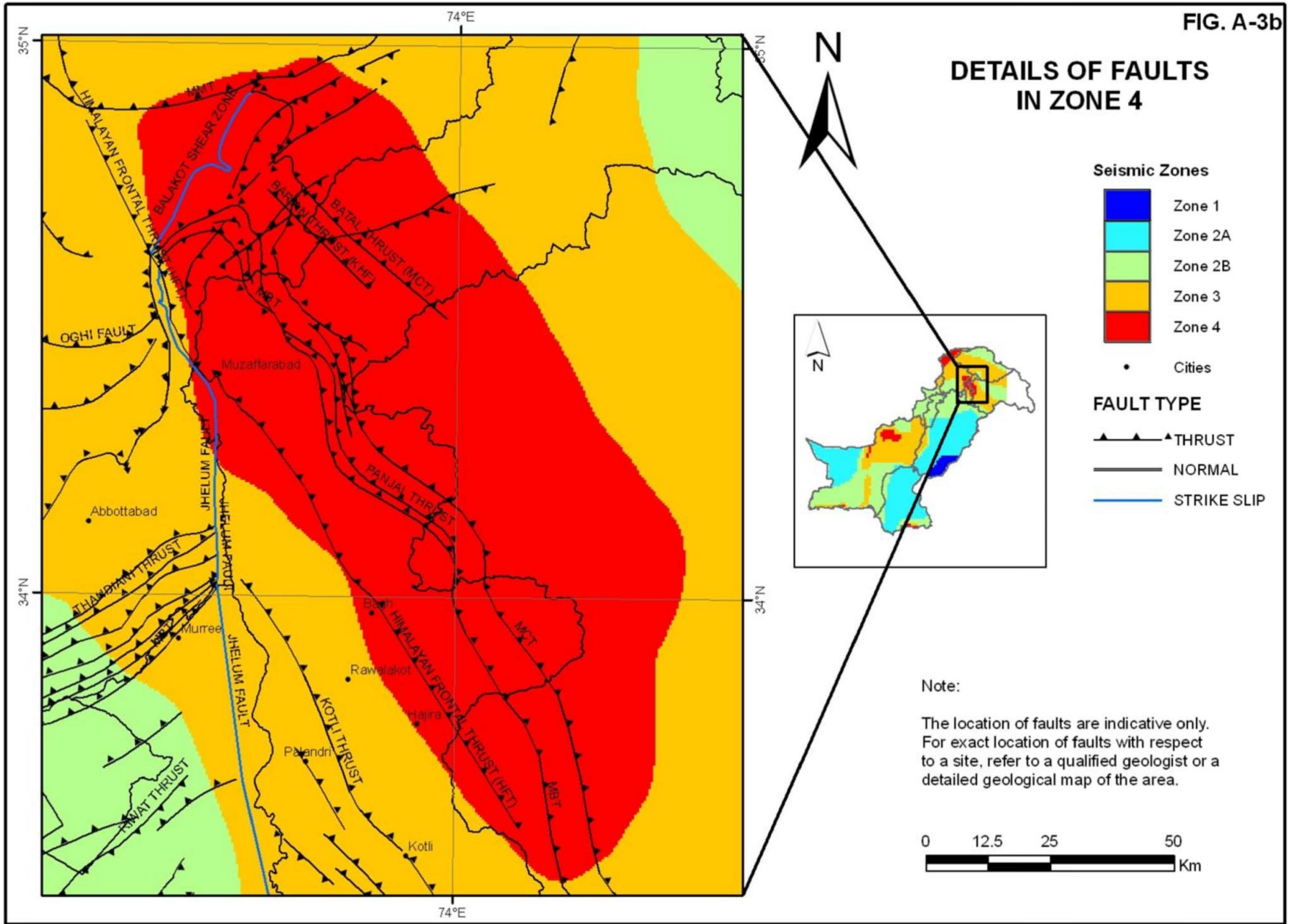


Note:

The location of faults are indicative only. For exact location of faults with respect to a site, refer to a qualified geologist or a detailed geological map of the area.

FIG. A-3b

DETAILS OF FAULTS IN ZONE 4



Note:

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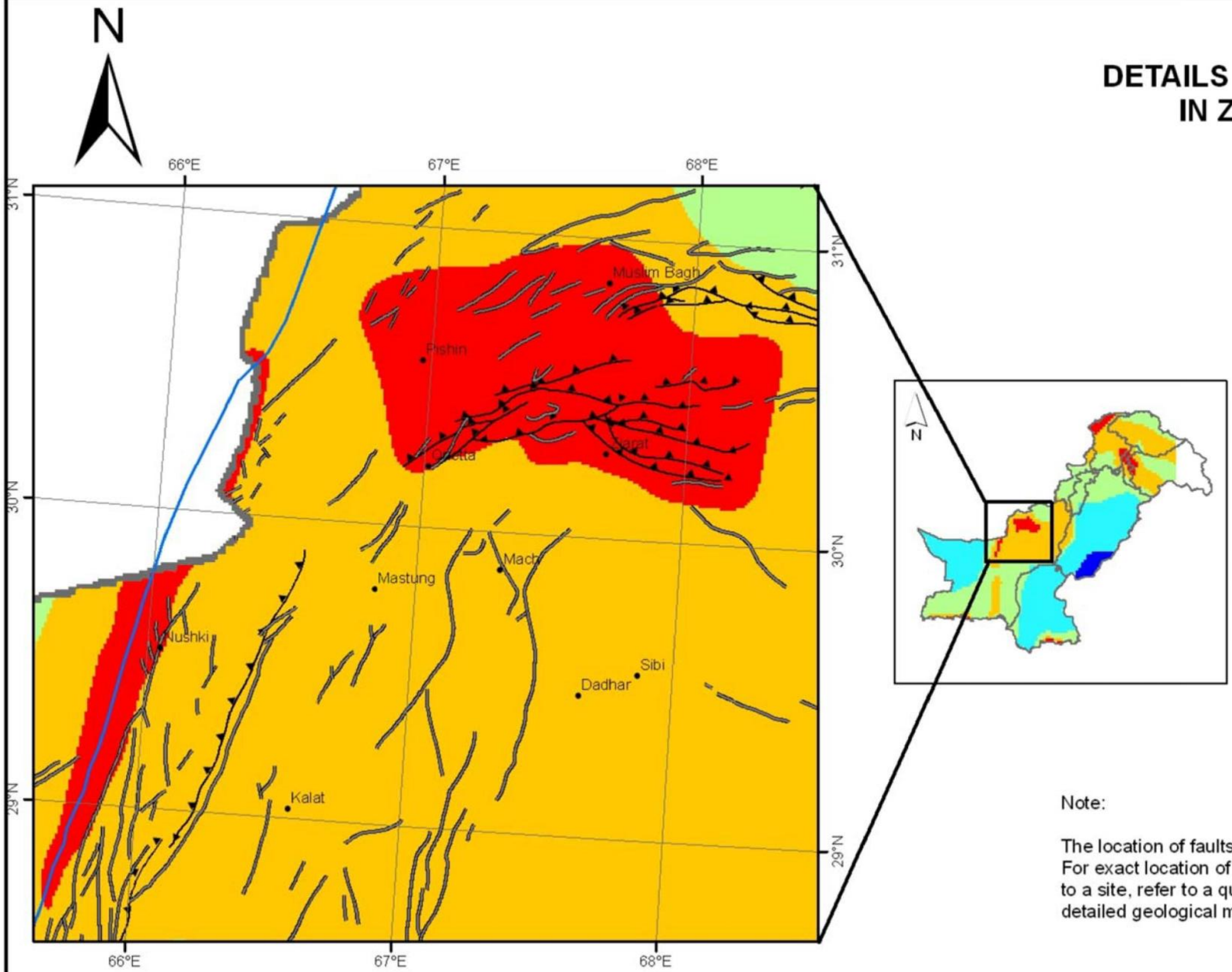
FIG. A-3c

DETAILS OF FAULTS IN ZONE 4



Seismic Zones

- 🟦 Zone 1
- 🟦 Zone 2A
- 🟩 Zone 2B
- 🟧 Zone 3
- 🟥 Zone 4
- • Cities

FAULT TYPE

- THRUST
- NORMAL
- STRIKE SLIP

Note:

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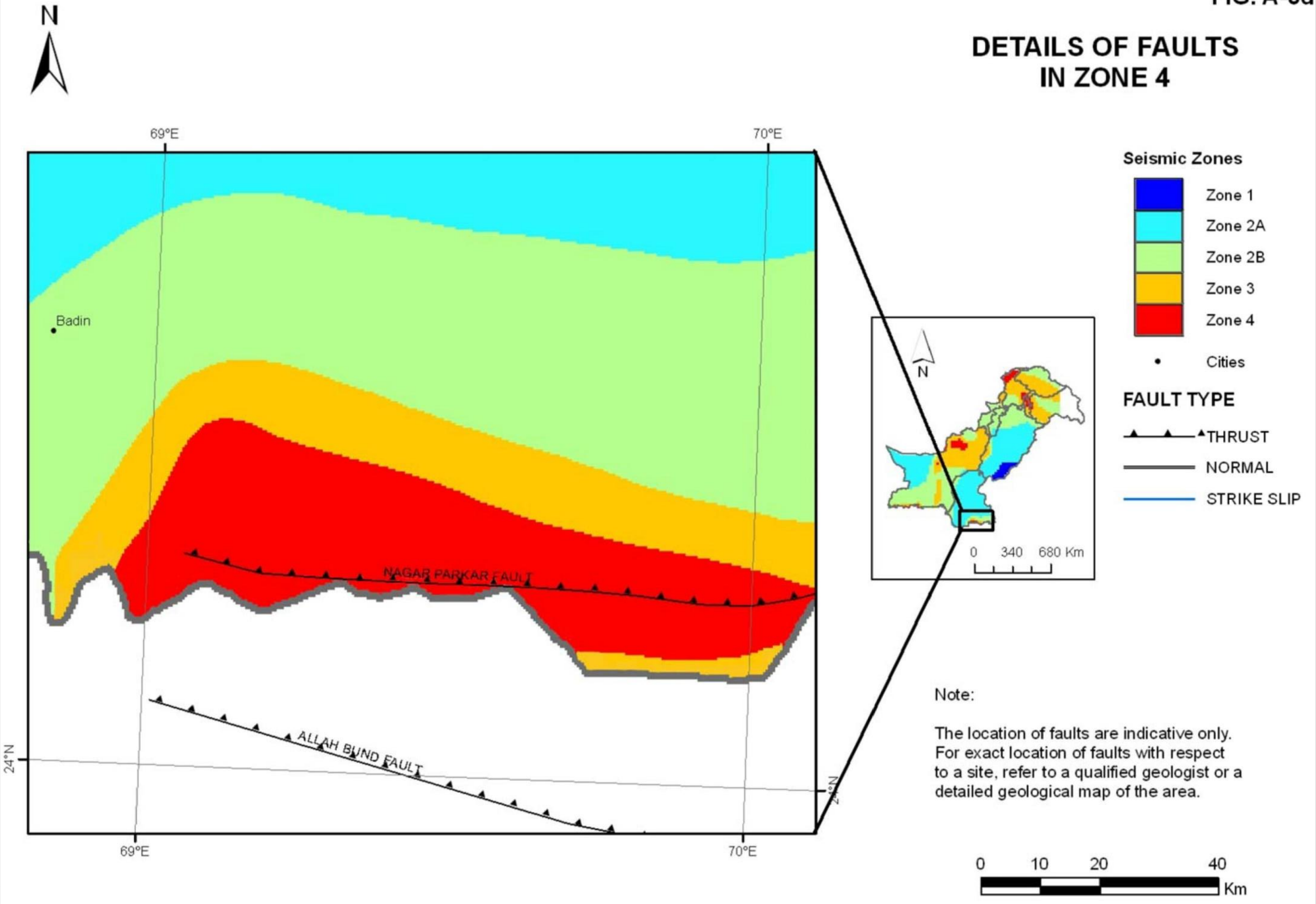
FIG. A-3d

DETAILS OF FAULTS IN ZONE 4



Note:

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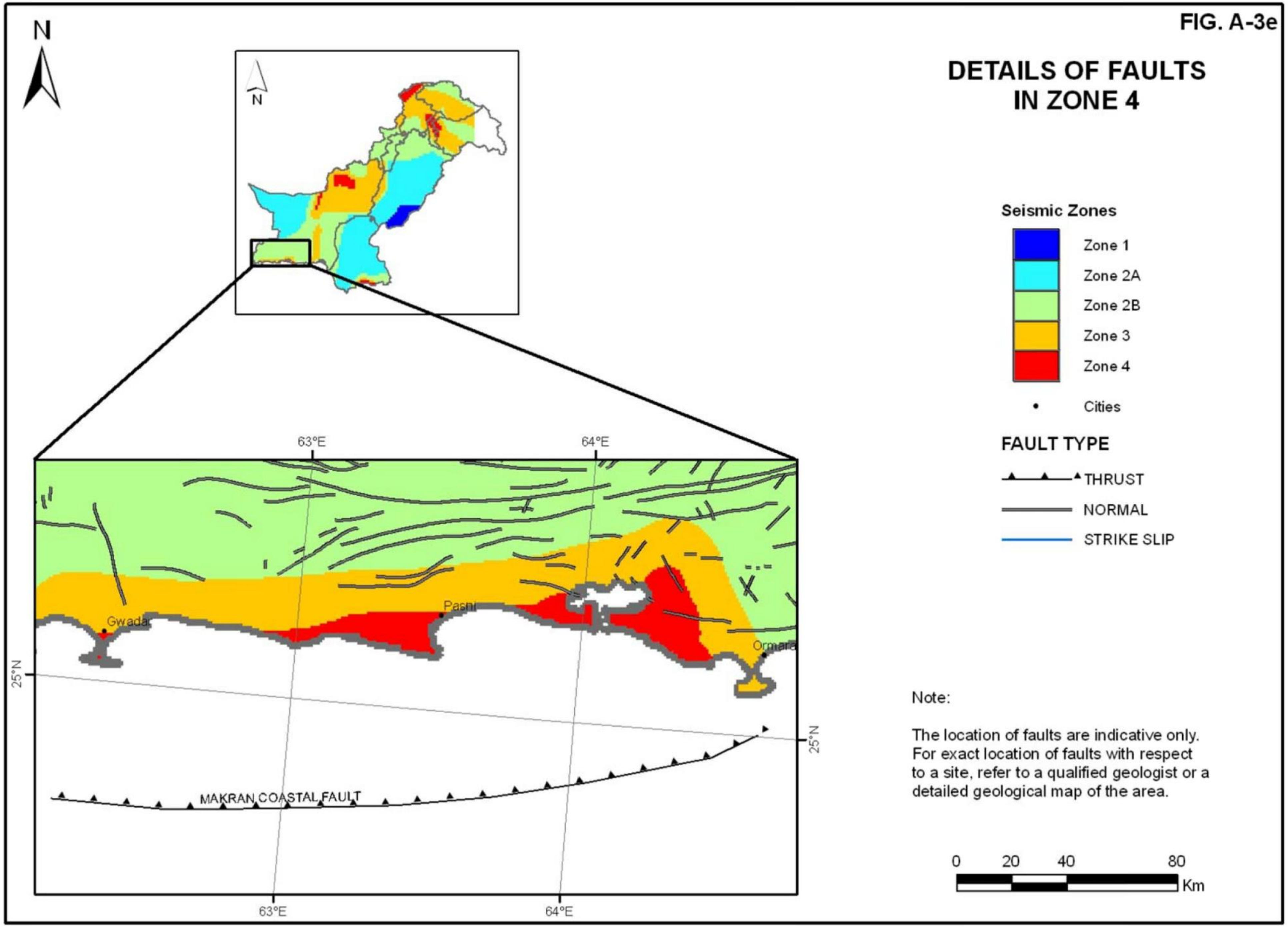
FIG. A-3e

DETAILS OF FAULTS IN ZONE 4



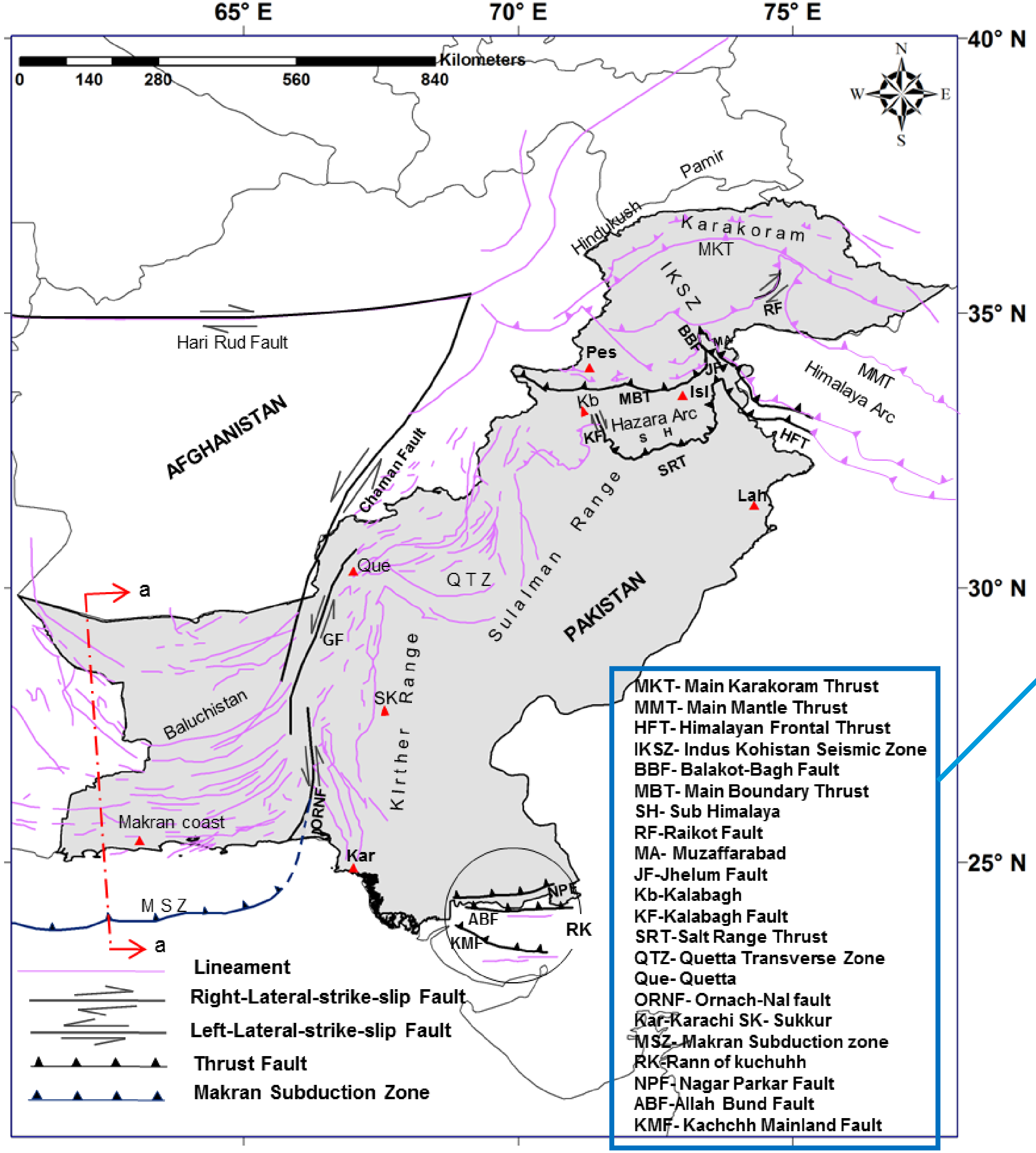
Note:

The location of faults are indicative only. For exact location of faults with respect to a site, refer to a qualified geologist or a detailed geological map of the area.

Study 2:

PSHA of Pakistan using Spatially Smoothed Background Seismicity and Crustal Faults Model (Zaman and Warnitchai, 2016)

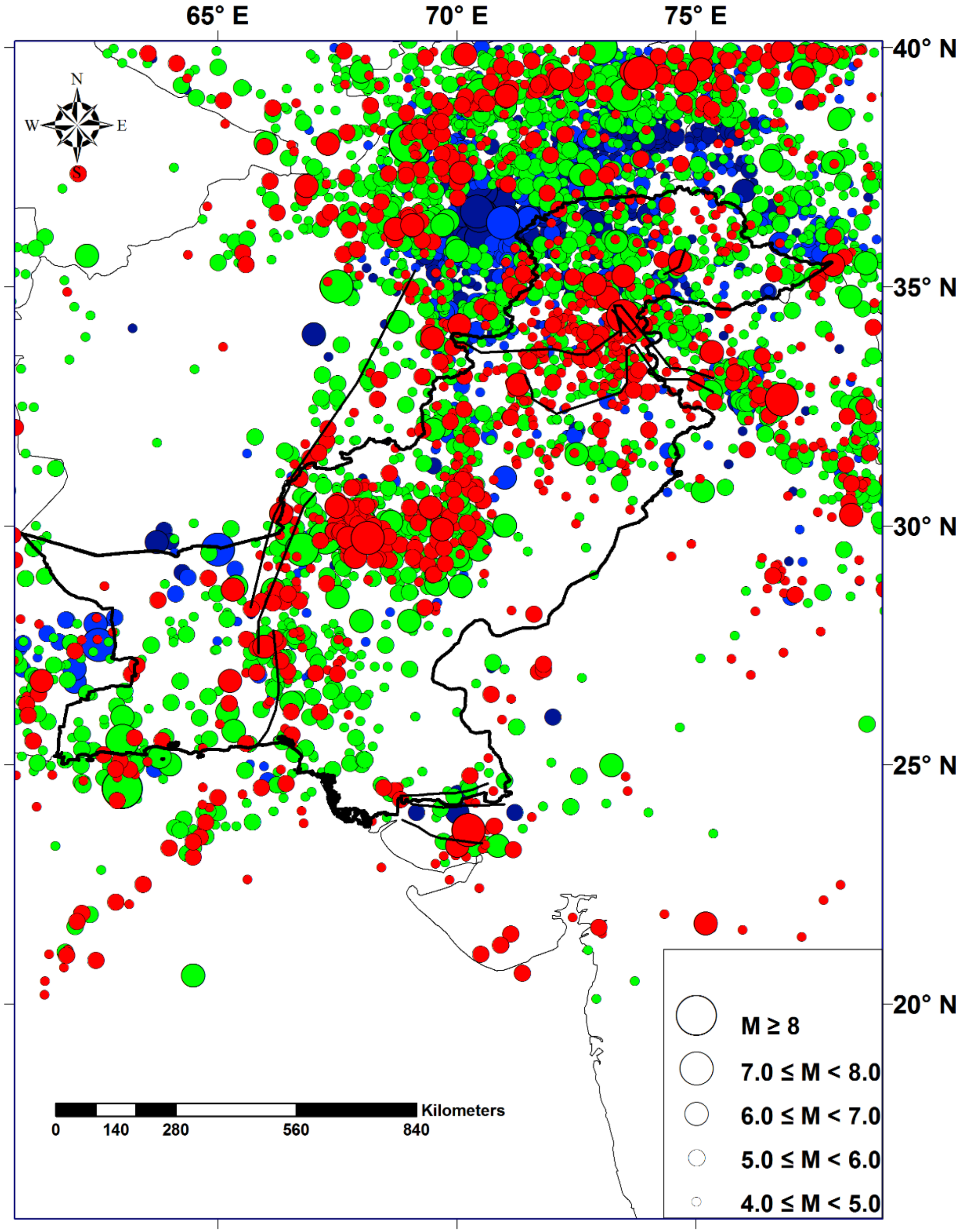
Regional tectonic setting of Pakistan



MKT- Main Karakoram Thrust
MMT- Main Mantle Thrust
HFT- Himalayan Frontal Thrust
IKSZ- Indus Kohistan Seismic Zo
BBF- Balakot-Bagh Fault
MBT- Main Boundary Thrust
SH- Sub Himalaya
RF-Raikot Fault
MA- Muzaffarabad
JF-Jhelum Fault
Kb-Kalabagh
KF-Kalabagh Fault
SRT-Salt Range Thrust
QTZ- Quetta Transverse Zone
Que- Quetta
ORNF- Ornach-Nal fault
Kar-Karachi SK- Sukkur
MSZ- Makran Subduction zone
RK-Rann of kuchuhh
NPF- Nagar Parkar Fault
ABF- Allah Bund Fault
KMF- Kachchh Mainland Fault

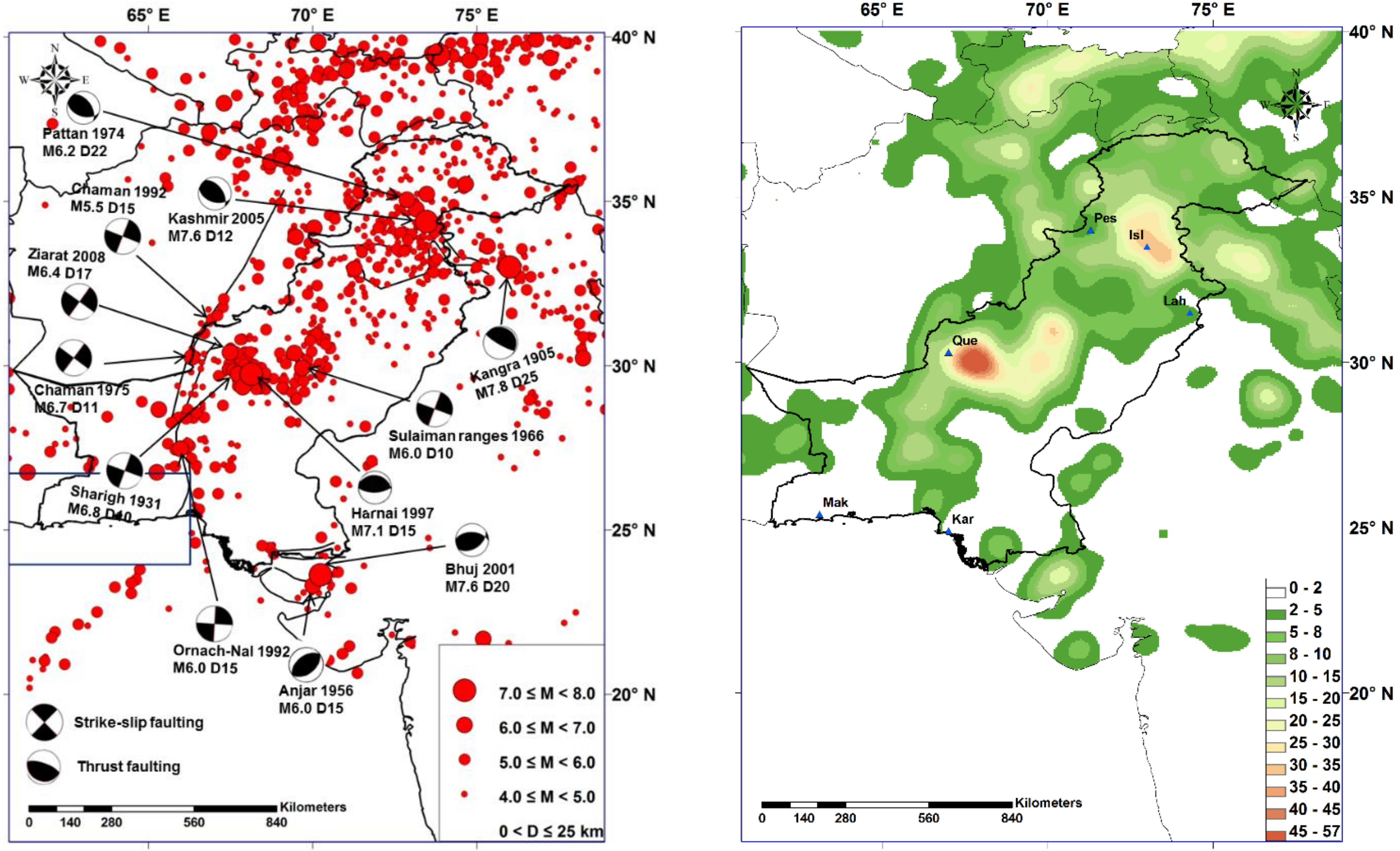
(Modified from Sarwar et al., 1979)

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



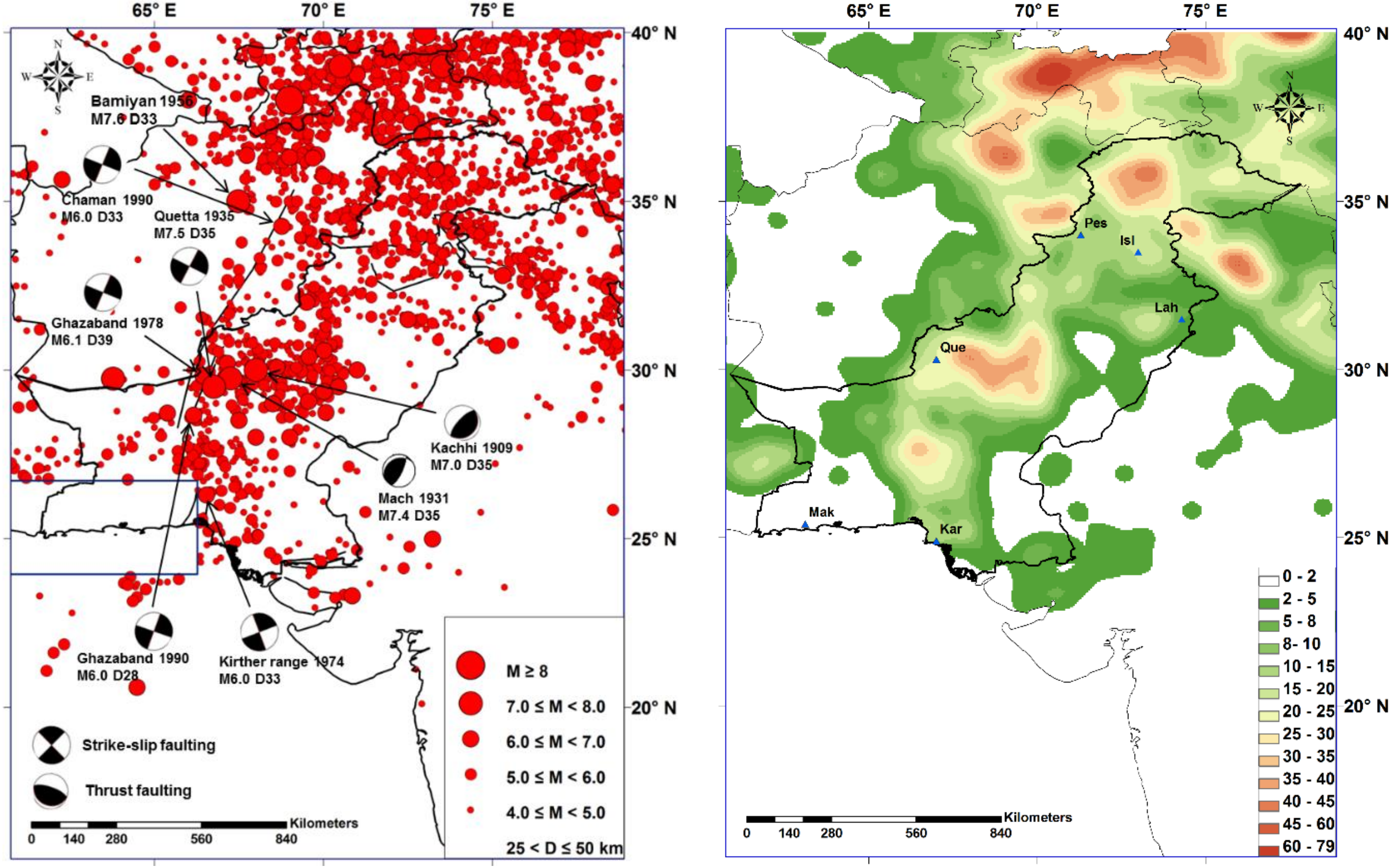
Pakistan and its surrounding seismicity from 1902 to 2009; red: 0-25 km depth, green: 25-50 km depth, blue: 50-100 km depth, and dark blue: 100-250 km depth

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



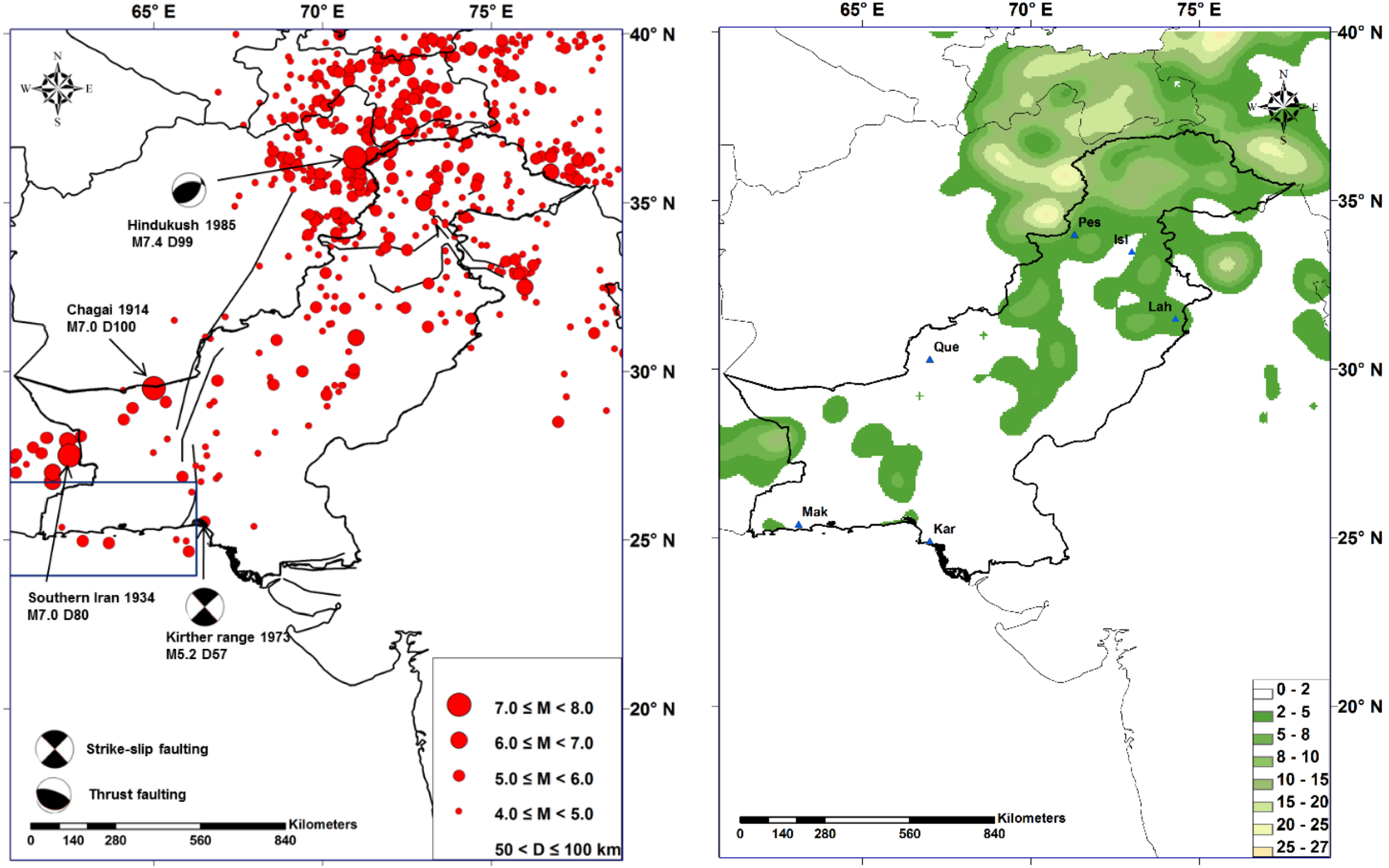
(a) Seismicity and (b) smoothed activity rate 10^a value derived for seismicity from 0-25 km depth

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



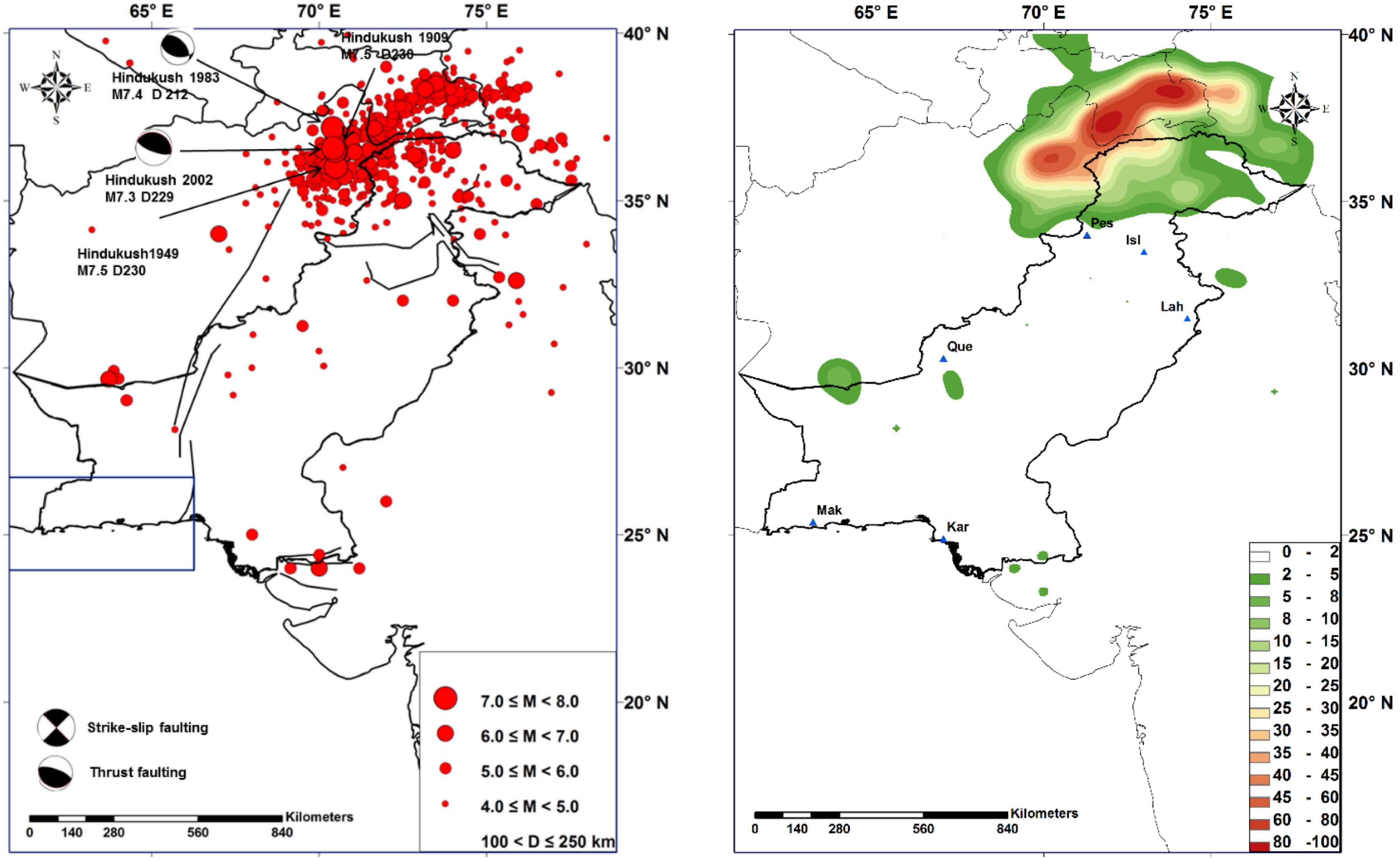
(a) Seismicity and (b) smoothed activity rate 10^a value derived for seismicity from 25-50 km depth

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



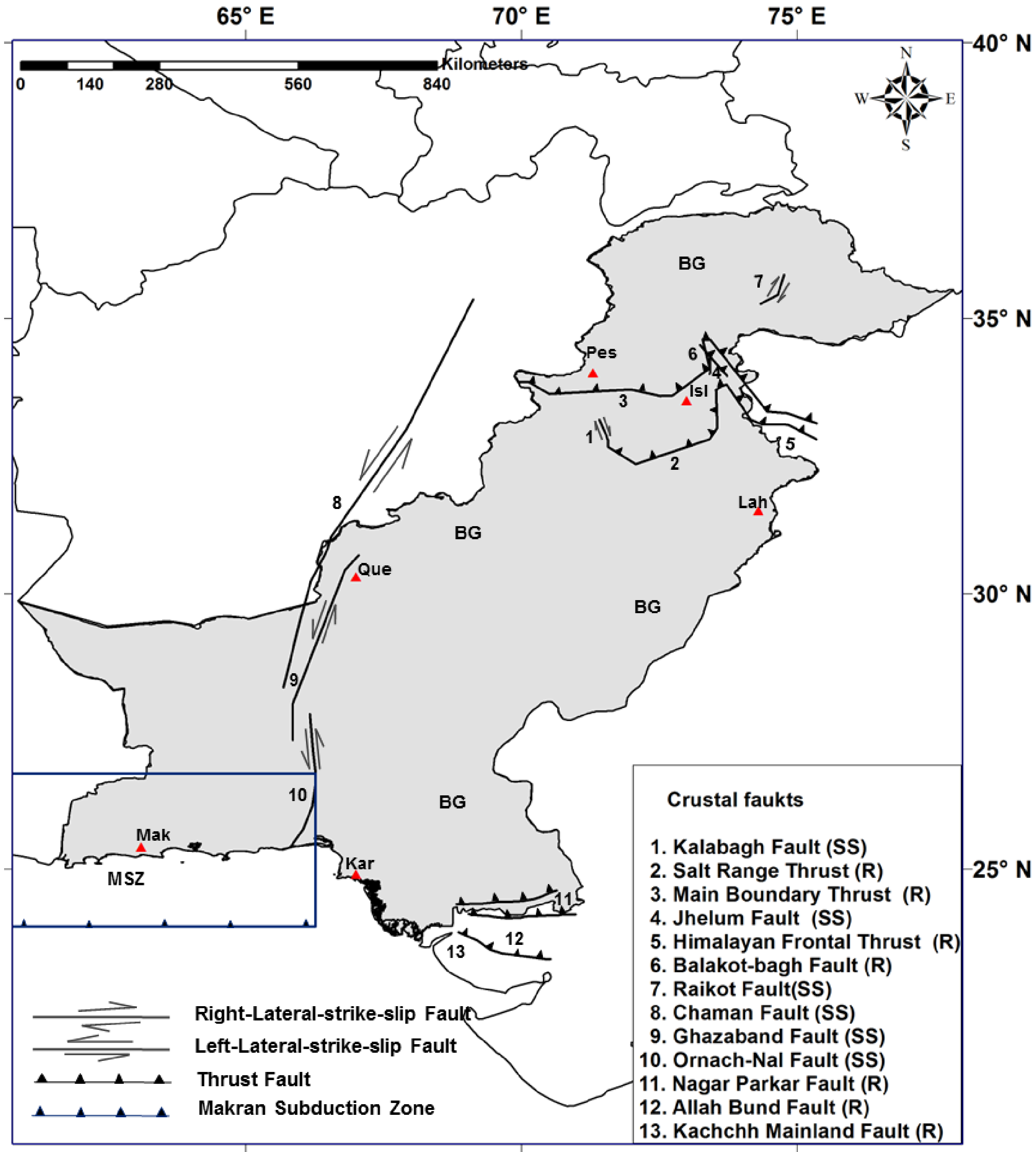
(a) Seismicity and (b) smoothed activity rate 10^a value derived for seismicity from 50-100 km depth

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



(a) Seismicity and (b) smoothed activity rate 10ª value derived for seismicity from 100-250 km depth.

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



Earthquake sources of the study area:

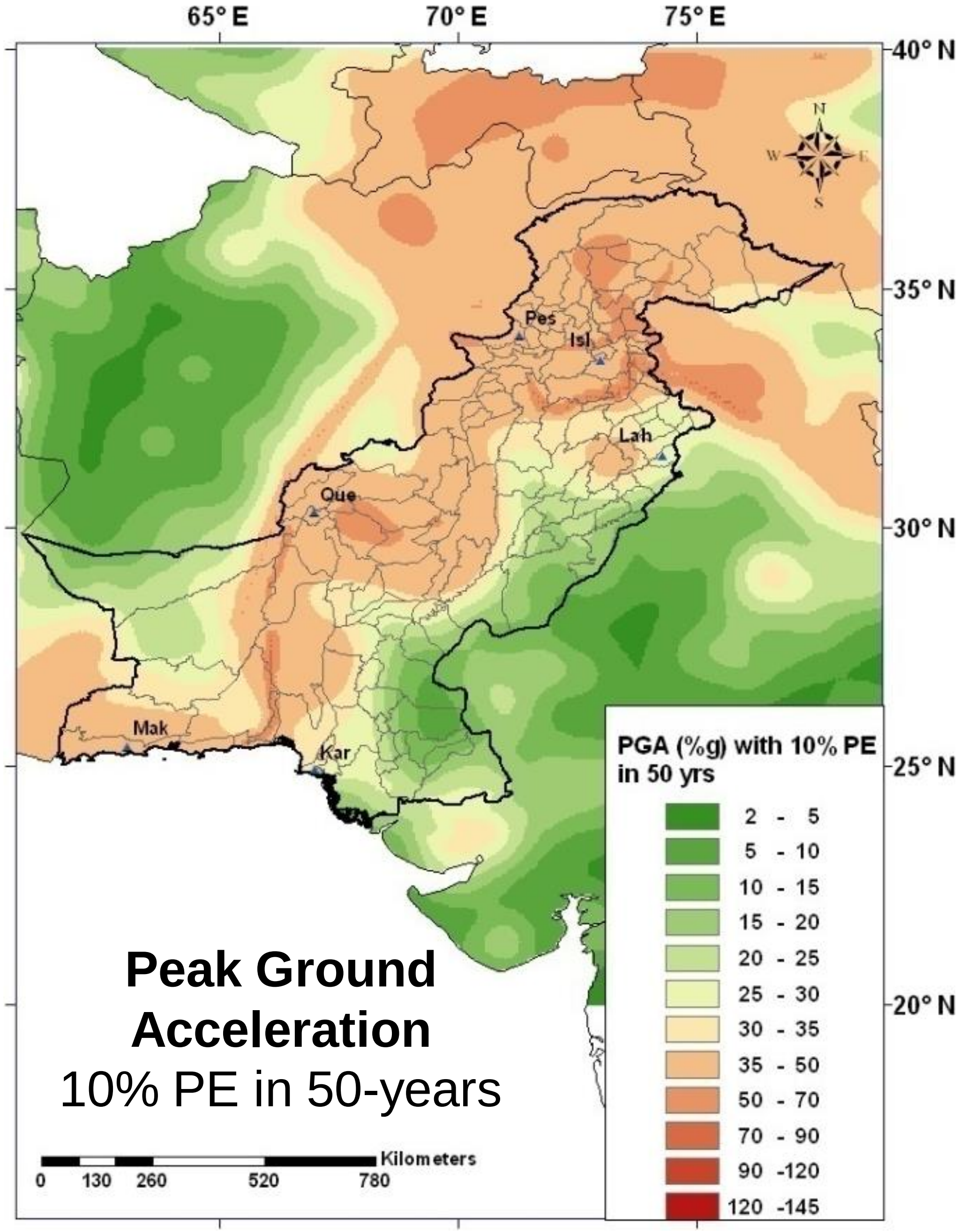
a) Background seismicity zone (BG)

b) Crustal faults (1-13) SS: Strike-Slip fault, R: Reverse fault), and

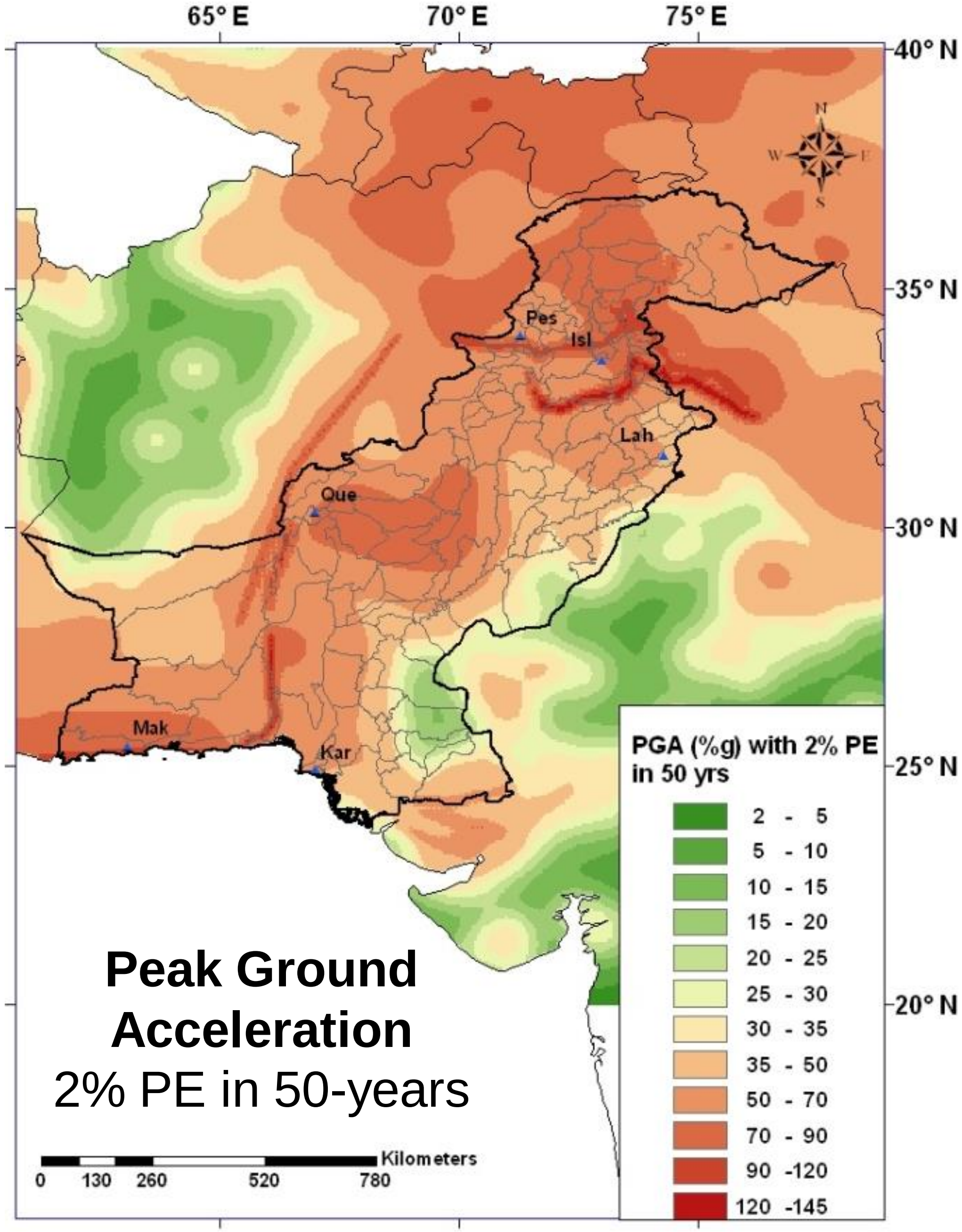
c) Makran subduction zone (MSZ)

Red Triangle shows major cities of Pakistan that is Peshawar (Pes), Islamabad (Isl), Lahore (Lah), Quetta (Que), Karachi (Kar), and Makran (Mak)

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan

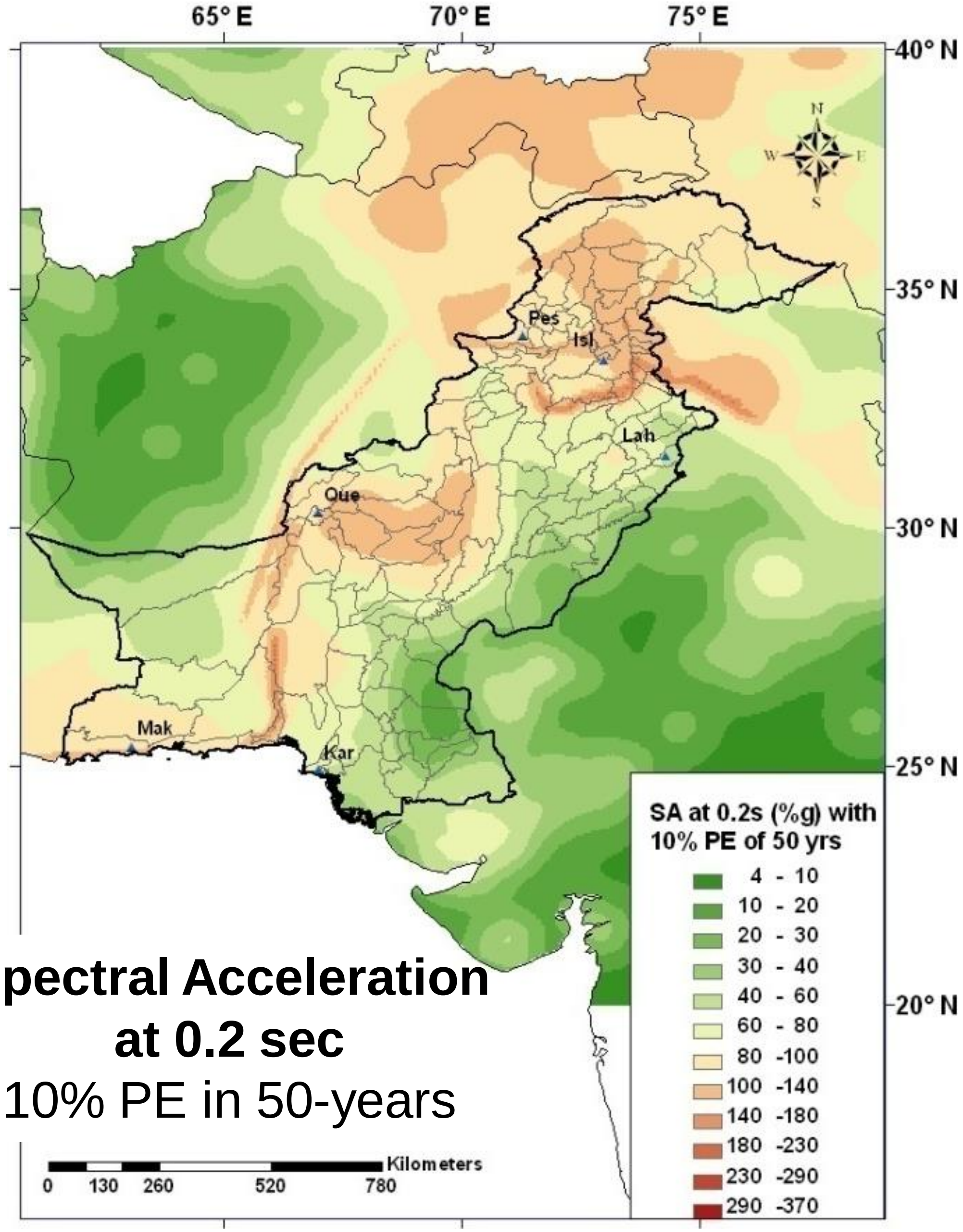


Peak Ground Acceleration
10% PE in 50-years



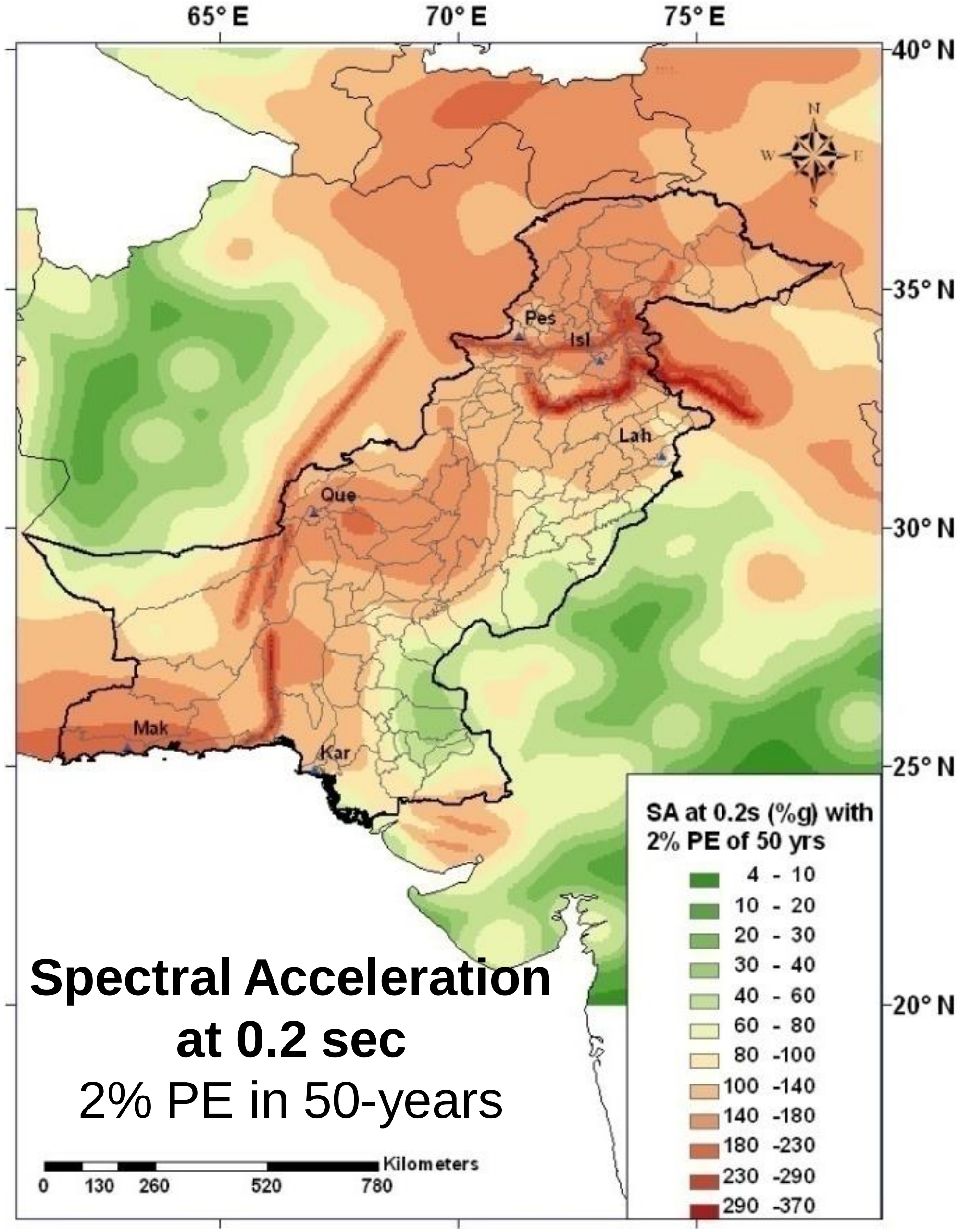
Peak Ground Acceleration
2% PE in 50-years

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



Spectral Acceleration at 0.2 sec

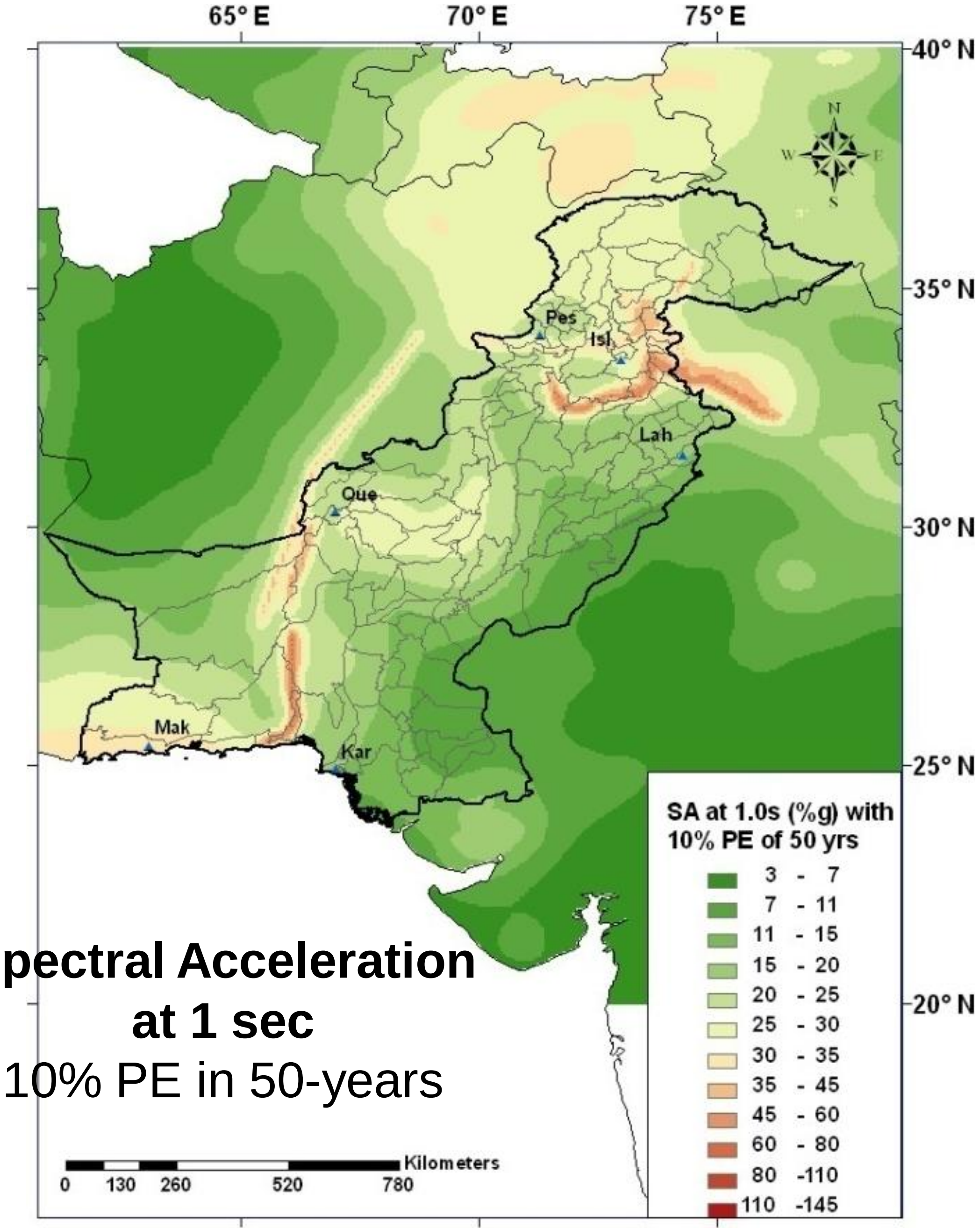
10% PE in 50-years



Spectral Acceleration at 0.2 sec

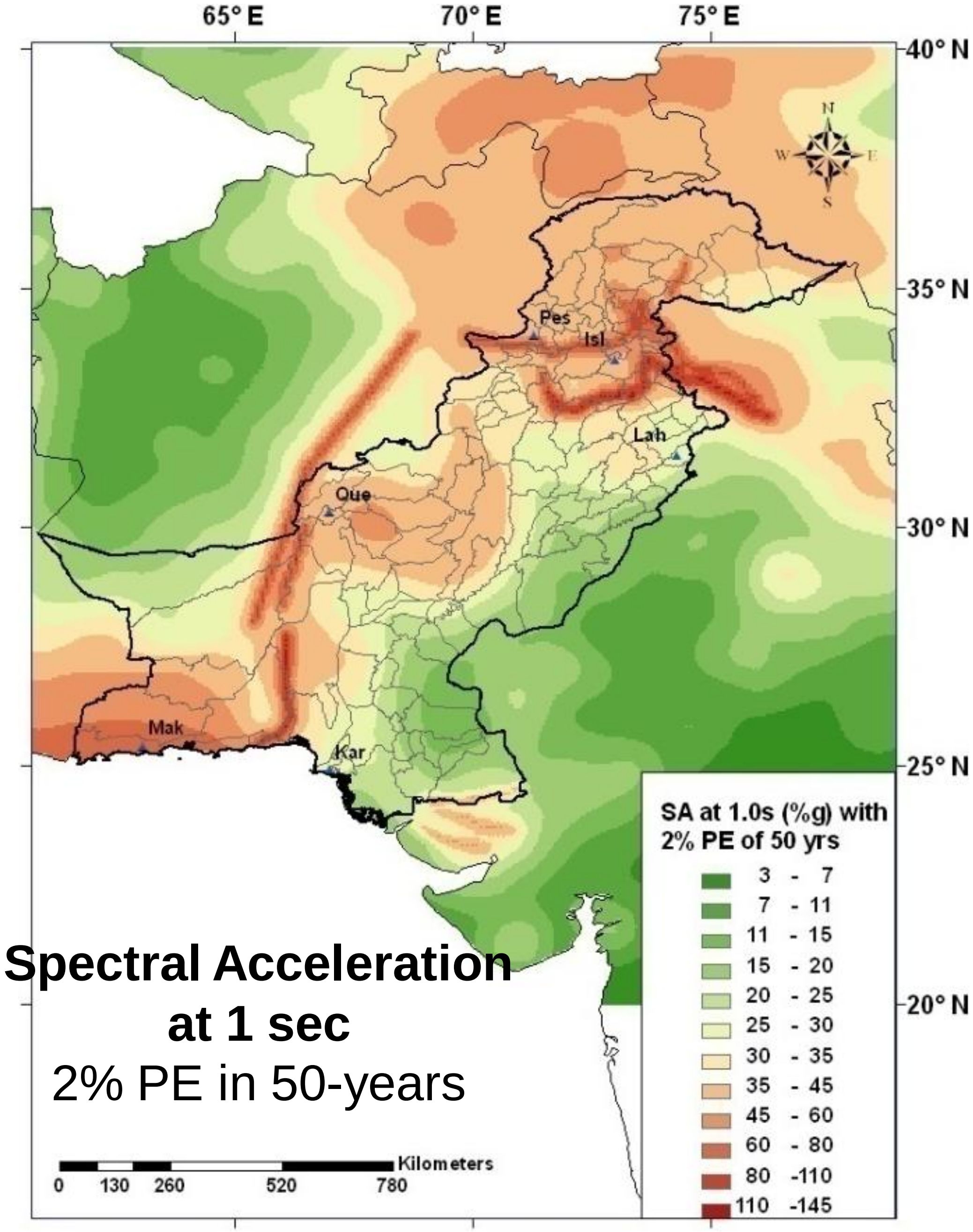
2% PE in 50-years

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



Spectral Acceleration at 1 sec

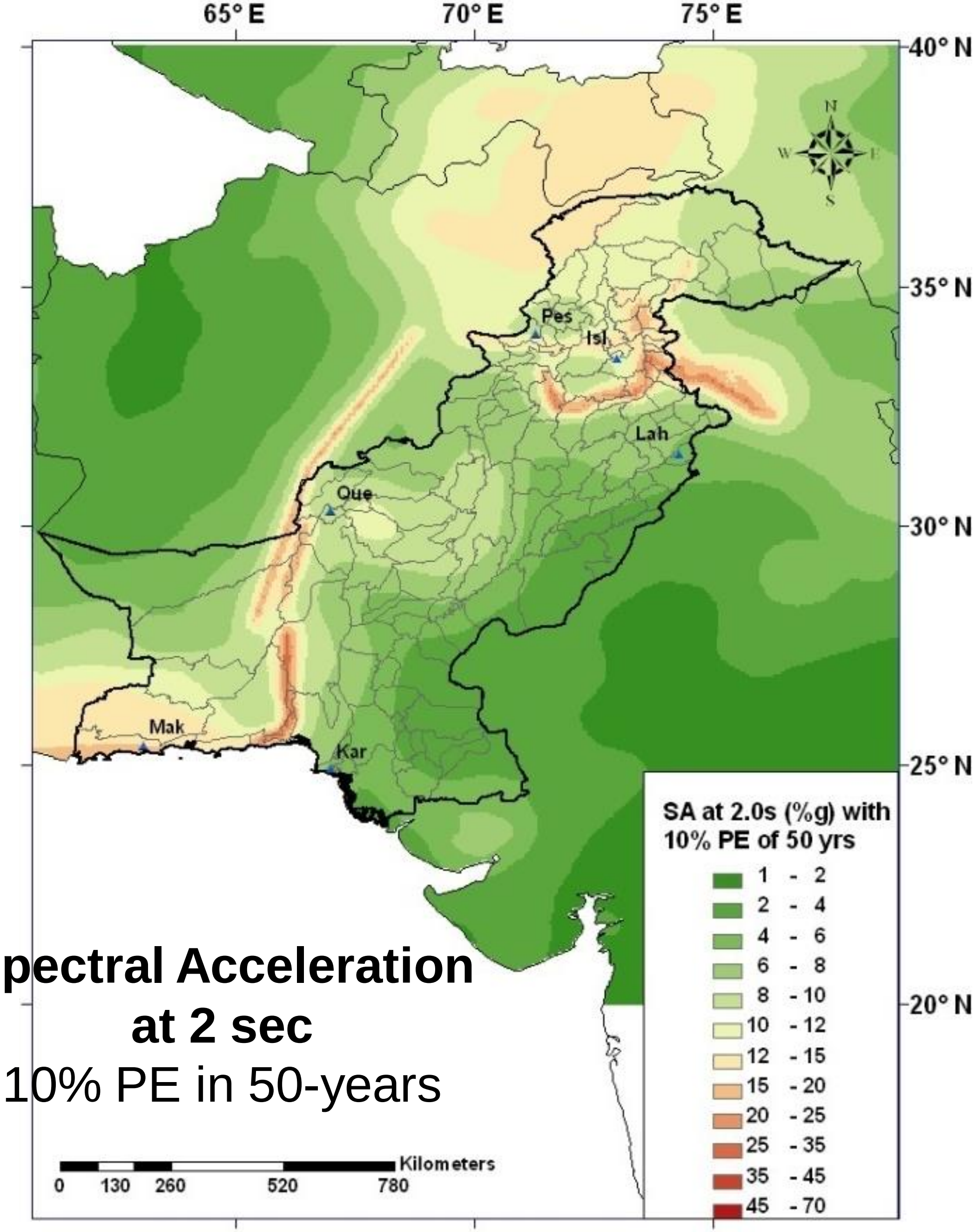
10% PE in 50-years



Spectral Acceleration at 1 sec

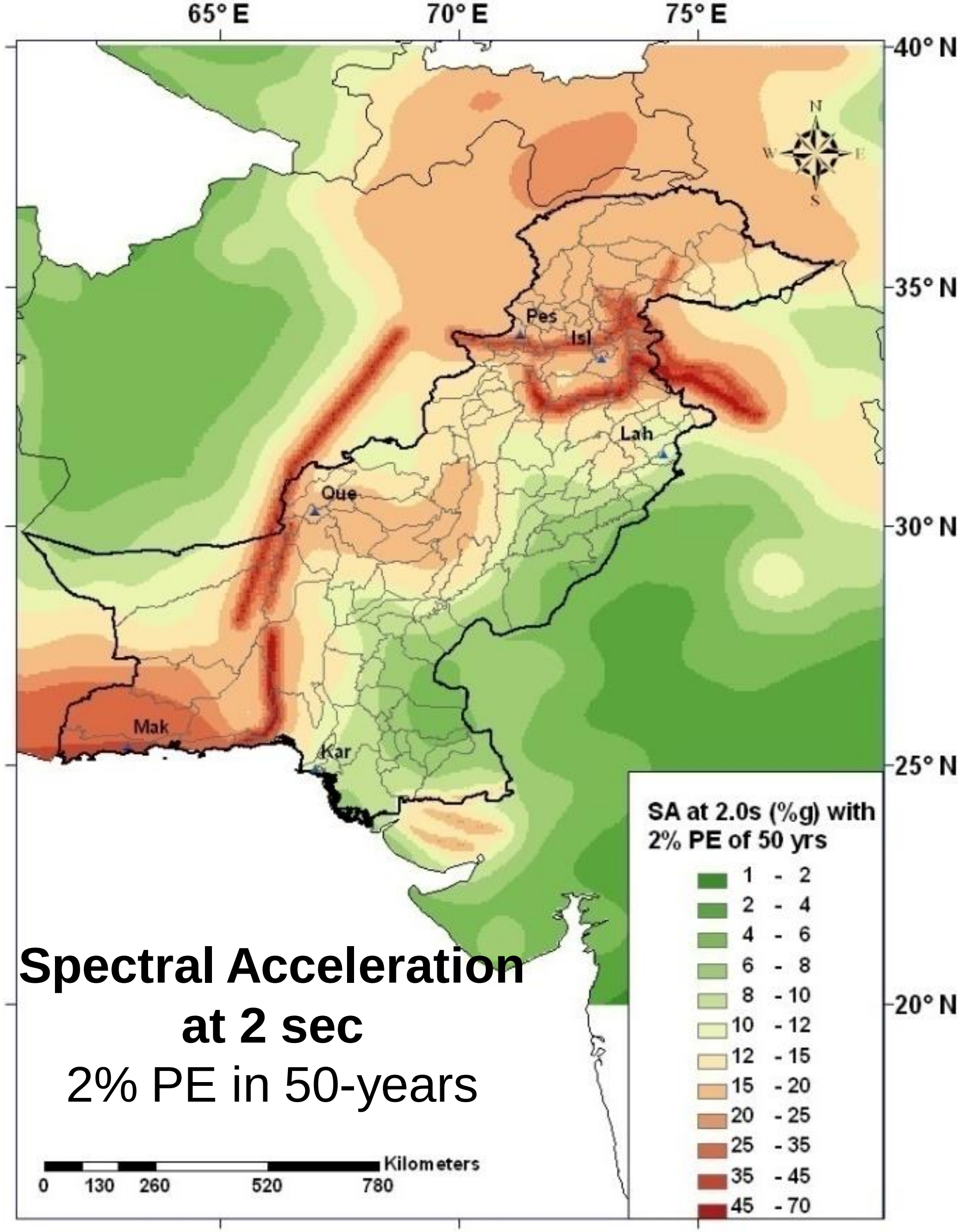
2% PE in 50-years

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan



Spectral Acceleration at 2 sec

10% PE in 50-years



Spectral Acceleration at 2 sec

2% PE in 50-years

Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan

Deaggregation of Seismic Hazard at Islamabad (Pakistan)

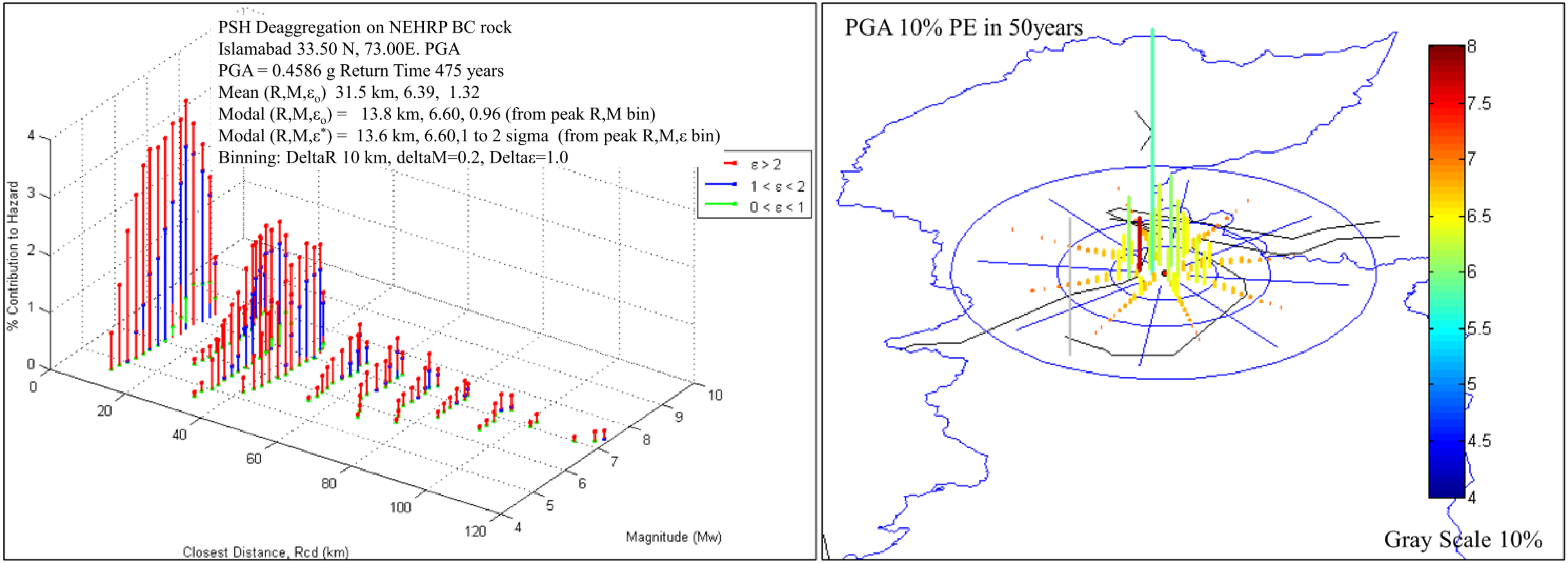


Figure 4.3 Deaggregation plots for Islamabad. PGA (10% PE in 50years): M-R-ε_o (left) and Geographic (right). The red dot and black line in Geographic Plot shows the location of Islamabad and crustal faults, respectively.

Source: Zaman (2016)

Mean and Modal values of M-R-ε for 10% PE in 50-years

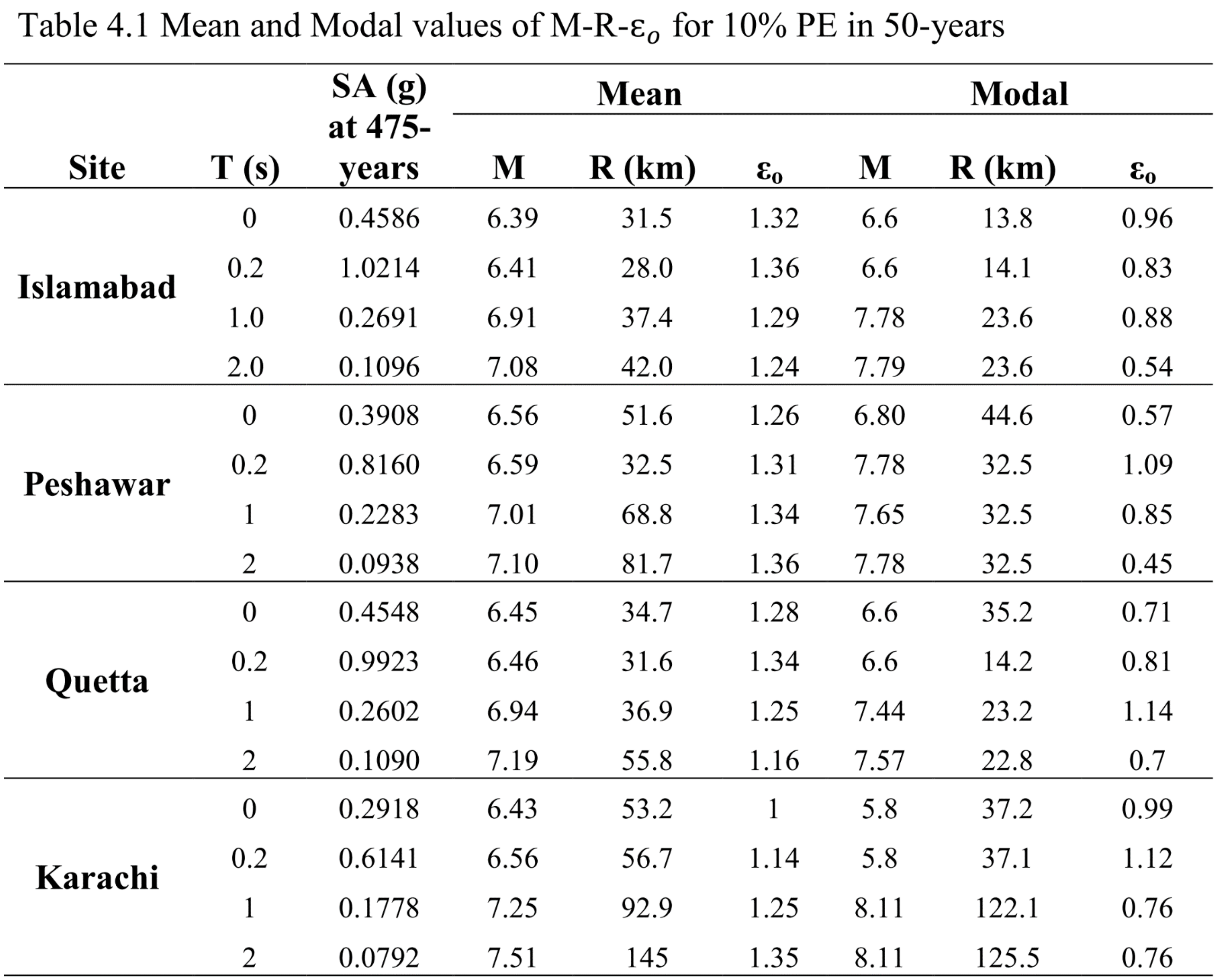


Table 4.1 Mean and Modal values of M-R-ε_o for 10% PE in 50-years

Site	T (s)	SA (g) at 475-years	Mean			Modal		
			M	R (km)	ε_o	M	R (km)	ε_o
Islamabad	0	0.4586	6.39	31.5	1.32	6.6	13.8	0.96
	0.2	1.0214	6.41	28.0	1.36	6.6	14.1	0.83
	1.0	0.2691	6.91	37.4	1.29	7.78	23.6	0.88
	2.0	0.1096	7.08	42.0	1.24	7.79	23.6	0.54
Peshawar	0	0.3908	6.56	51.6	1.26	6.80	44.6	0.57
	0.2	0.8160	6.59	32.5	1.31	7.78	32.5	1.09
	1	0.2283	7.01	68.8	1.34	7.65	32.5	0.85
	2	0.0938	7.10	81.7	1.36	7.78	32.5	0.45
Quetta	0	0.4548	6.45	34.7	1.28	6.6	35.2	0.71
	0.2	0.9923	6.46	31.6	1.34	6.6	14.2	0.81
	1	0.2602	6.94	36.9	1.25	7.44	23.2	1.14
	2	0.1090	7.19	55.8	1.16	7.57	22.8	0.7
Karachi	0	0.2918	6.43	53.2	1	5.8	37.2	0.99
	0.2	0.6141	6.56	56.7	1.14	5.8	37.1	1.12
	1	0.1778	7.25	92.9	1.25	8.11	122.1	0.76
	2	0.0792	7.51	145	1.35	8.11	125.5	0.76

Source: Zaman (2016)

Mean and Modal values of M-R-ε for 2% PE in 50-years

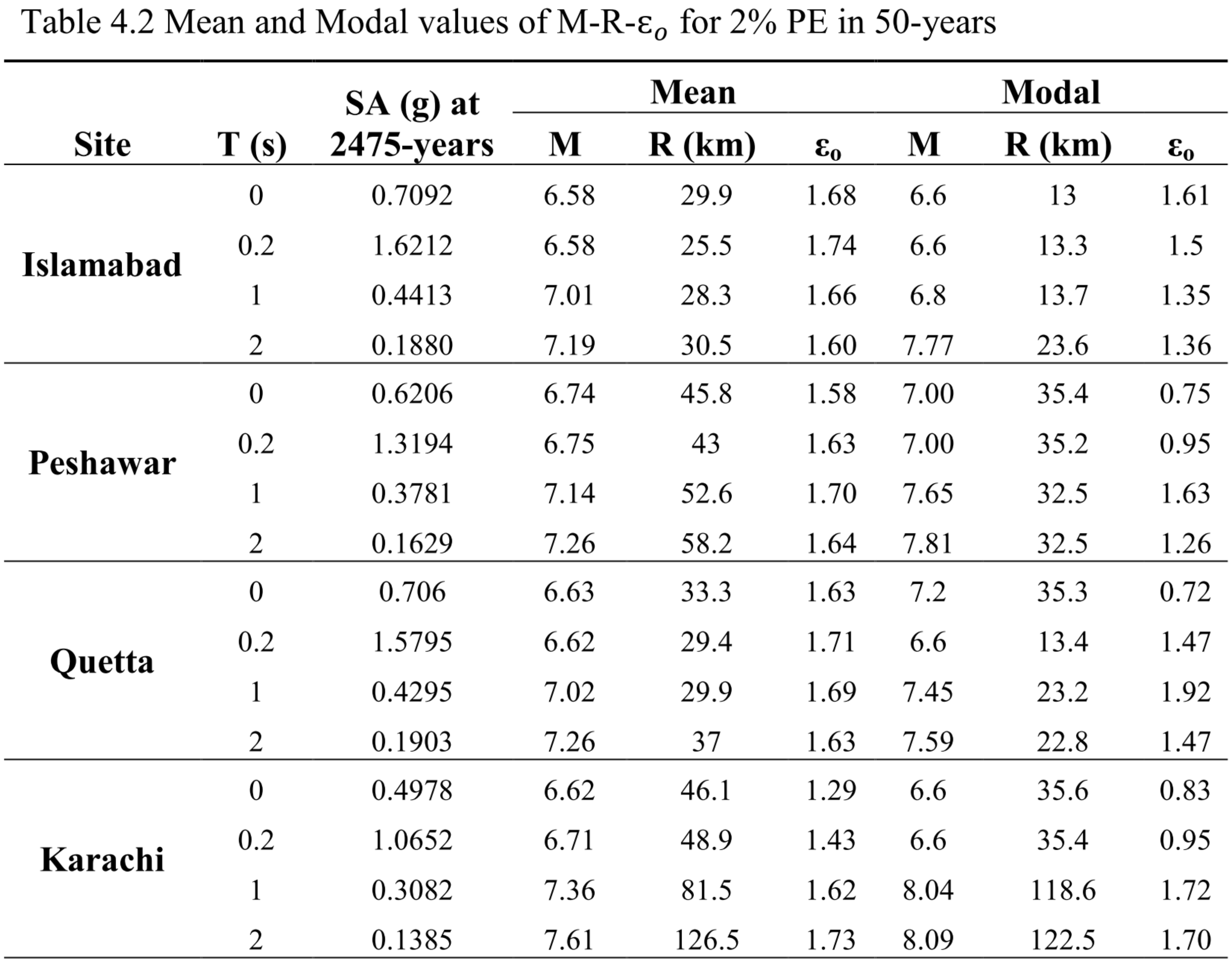


Table 4.2 Mean and Modal values of M-R-ε_o for 2% PE in 50-years

Site	**T (s)**	**SA (g) at 2475-years**	**Mean**			**Modal**		
			M	**R (km)**	**ε_o**	**M**	**R (km)**	**ε_o**
Islamabad	0	0.7092	6.58	29.9	1.68	6.6	13	1.61
	0.2	1.6212	6.58	25.5	1.74	6.6	13.3	1.5
	1	0.4413	7.01	28.3	1.66	6.8	13.7	1.35
	2	0.1880	7.19	30.5	1.60	7.77	23.6	1.36
Peshawar	0	0.6206	6.74	45.8	1.58	7.00	35.4	0.75
	0.2	1.3194	6.75	43	1.63	7.00	35.2	0.95
	1	0.3781	7.14	52.6	1.70	7.65	32.5	1.63
	2	0.1629	7.26	58.2	1.64	7.81	32.5	1.26
Quetta	0	0.706	6.63	33.3	1.63	7.2	35.3	0.72
	0.2	1.5795	6.62	29.4	1.71	6.6	13.4	1.47
	1	0.4295	7.02	29.9	1.69	7.45	23.2	1.92
	2	0.1903	7.26	37	1.63	7.59	22.8	1.47
Karachi	0	0.4978	6.62	46.1	1.29	6.6	35.6	0.83
	0.2	1.0652	6.71	48.9	1.43	6.6	35.4	0.95
	1	0.3082	7.36	81.5	1.62	8.04	118.6	1.72
	2	0.1385	7.61	126.5	1.73	8.09	122.5	1.70

Source: Zaman (2016)

Contribution from individual seismic sources to Islamabad (10% PE in 50-years)

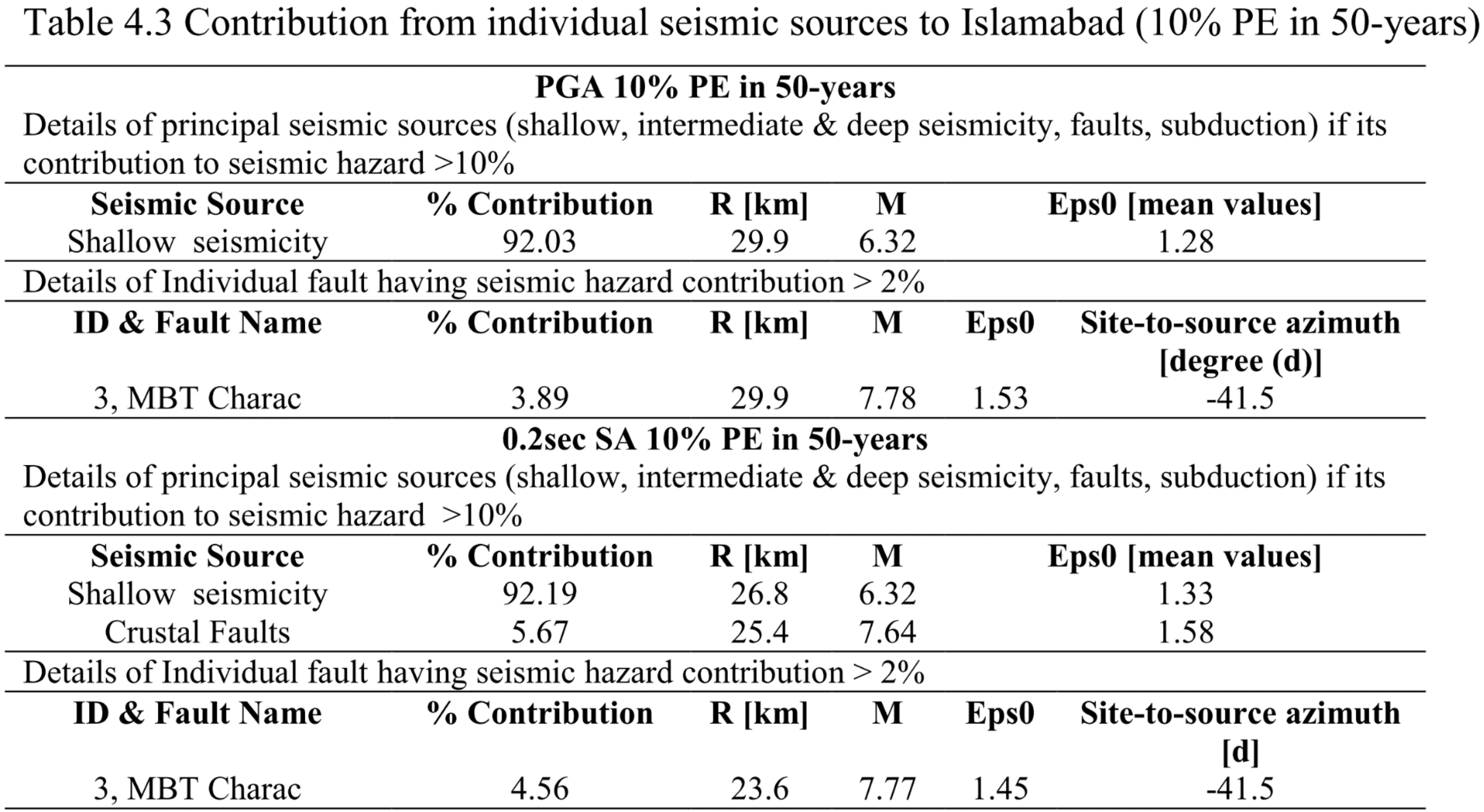


Table 4.3 Contribution from individual seismic sources to Islamabad (10% PE in 50-years)

PGA 10% PE in 50-years					
Details of principal seismic sources (shallow, intermediate & deep seismicity, faults, subduction) if its contribution to seismic hazard >10%					
Seismic Source	**% Contribution**	**R [km]**	**M**	**Eps0 [mean values]**	
Shallow seismicity	92.03	29.9	6.32	1.28	
Details of Individual fault having seismic hazard contribution > 2%					
ID & Fault Name	**% Contribution**	**R [km]**	**M**	**Eps0**	**Site-to-source azimuth [degree (d)]**
3, MBT Charac	3.89	29.9	7.78	1.53	-41.5
0.2sec SA 10% PE in 50-years					
Details of principal seismic sources (shallow, intermediate & deep seismicity, faults, subduction) if its contribution to seismic hazard >10%					
Seismic Source	**% Contribution**	**R [km]**	**M**	**Eps0 [mean values]**	
Shallow seismicity	92.19	26.8	6.32	1.33	
Crustal Faults	5.67	25.4	7.64	1.58	
Details of Individual fault having seismic hazard contribution > 2%					
ID & Fault Name	**% Contribution**	**R [km]**	**M**	**Eps0**	**Site-to-source azimuth [d]**
3, MBT Charac	4.56	23.6	7.77	1.45	-41.5

Source: Zaman (2016)

Contribution from individual seismic sources to Islamabad (10% PE in 50-years)

1.0sec SA 10% PE in 50-years

Details of principal seismic sources (shallow, intermediate & deep seismicity, faults, subduction) if its contribution to seismic hazard >10%

Seismic Source	% Contribution	R [km]	M	Eps0 [mean values]
Shallow seismicity	73.59	33.4	6.72	1.25
Crustal Faults	20.61	33	7.60	1.28
Intermediate & Deep seismicity (50 to 200 km)	5.80	103.6	6.95	1.84

Details of Individual fault having seismic hazard contribution > 2%

ID & Fault Name	% Contribution	R (km)	M	Eps0	Site-to-source azimuth [d]
3, MBT Charac	13.37	23.6	7.79	0.89	-41.5

2.0sec SA 10% PE in 50-years

Details of principal seismic sources (shallow, intermediate & deep seismicity, faults, subduction) if its contribution to seismic hazard >10%

Seismic Source	% Contribution	R [km]	M	Eps0 [mean values]
Shallow seismicity	58.13	23.5	6.88	1.58
Crustal Faults	35.18	29.3	7.73	1.53
Intermediate & Deep seismicity (50 to 200 km)	6.69	97.7	7.07	2.13

Details of Individual fault having seismic hazard contribution > 2%

ID & Fault Name	% Contribution	R (km)	M	Eps0	Site-to-source azimuth [d]
3, MBT Charac	18.80	23.6	7.78	0.58	-41.5
MBT GR	2.58	31.2	7.25	1.36	-37.1
5, HFT Charac	2.50	74	7.81	1.62	64.8
2, Salt range Charac	2.11	48	7.11	1.92	88.5

Source: Zaman (2016)

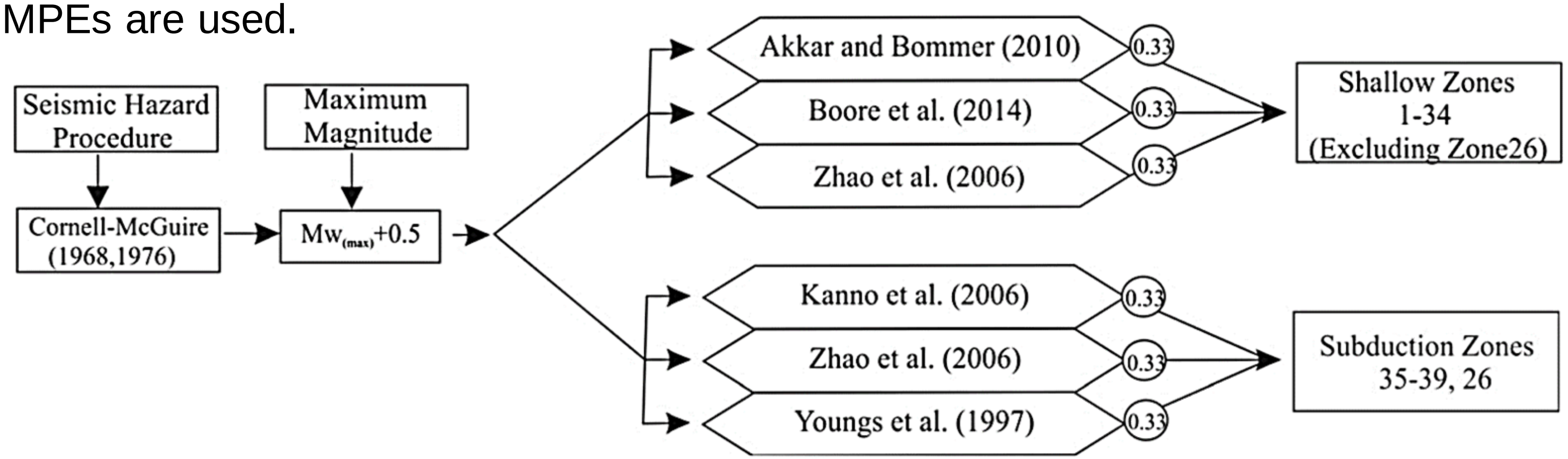
Study 3:

An Updated Probabilistic Seismic Hazard Analysis of Pakistan (Conventional Area Source Model)

Muhammad Waseem, Sarfraz Khan and M. Asif Khan – 2020

Summary of PSHA (Muhammad Waseem, Sarfraz Khan and M. Asif Khan – 2020)

- Standard Cornell–McGuire (1968–1976) approach is employed. The computations are made over a rectangular grid of 0.1 degree. Software: EZ-FRISK
- A recently compiled earthquake catalogue (Khan et al., 2018) is used.
- 34 shallow and 5 deep area sources modeled using the Gutenberg–Richter recurrence law.
- The following GMPEs are used.

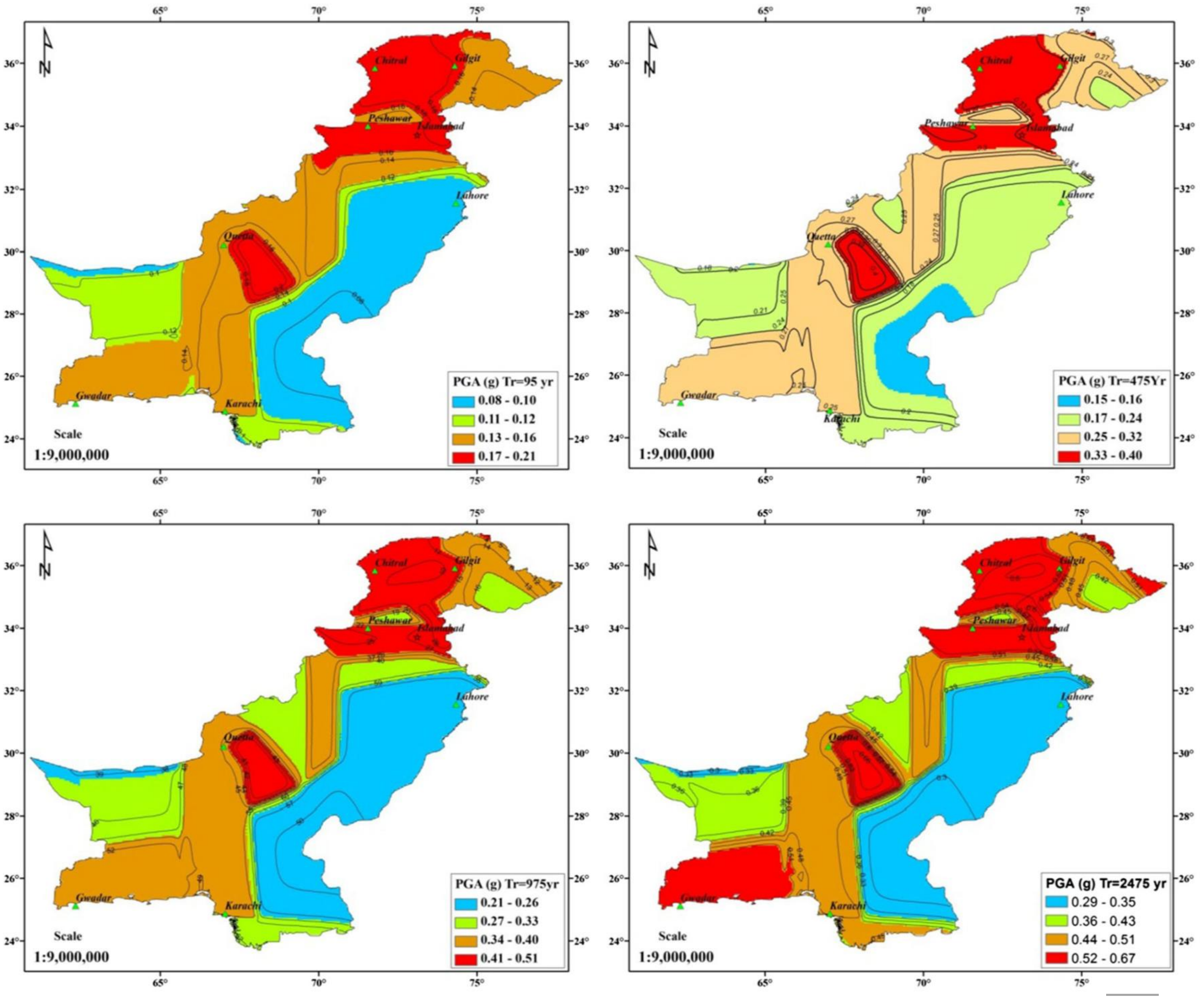


- Hazard maps for PGA and SA at T = 0.2 s and T = 1.0 s for 475-, 975- and 2475-year return periods (RPs) (flat rock site conditions).

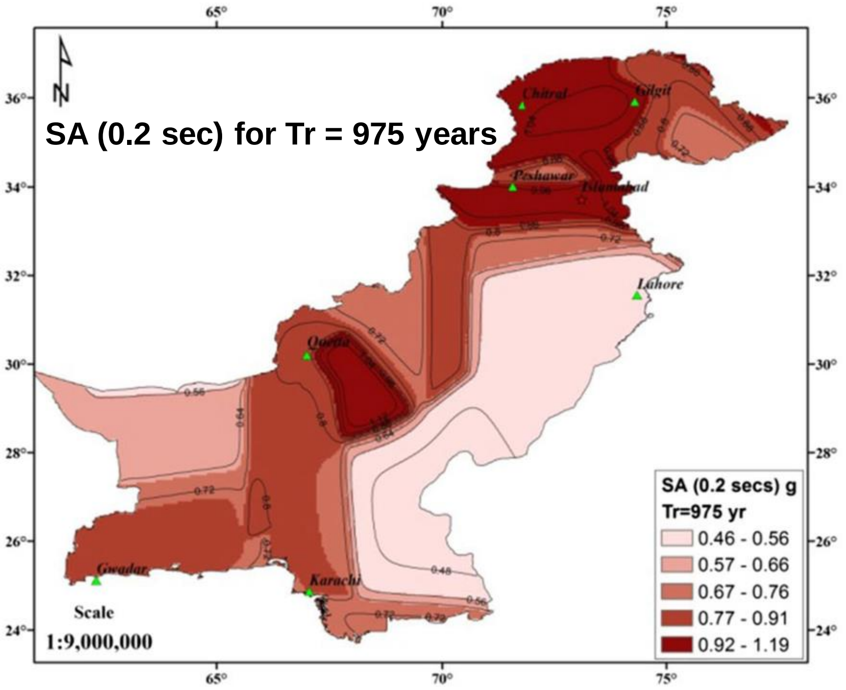
Waseem et al. (2020)

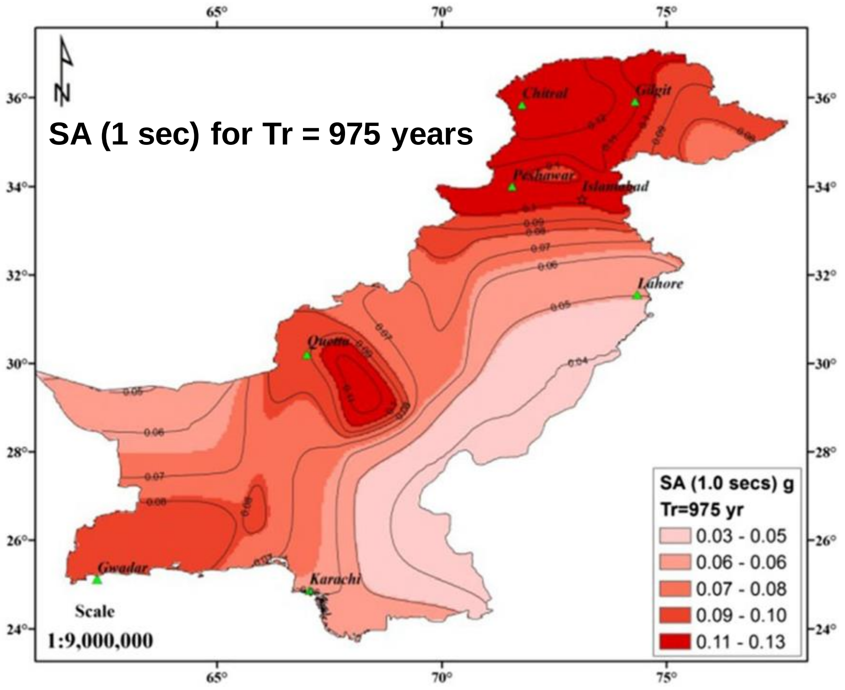
Classical PSHA Approach (Conventional Cornell- McGuire Methodology)

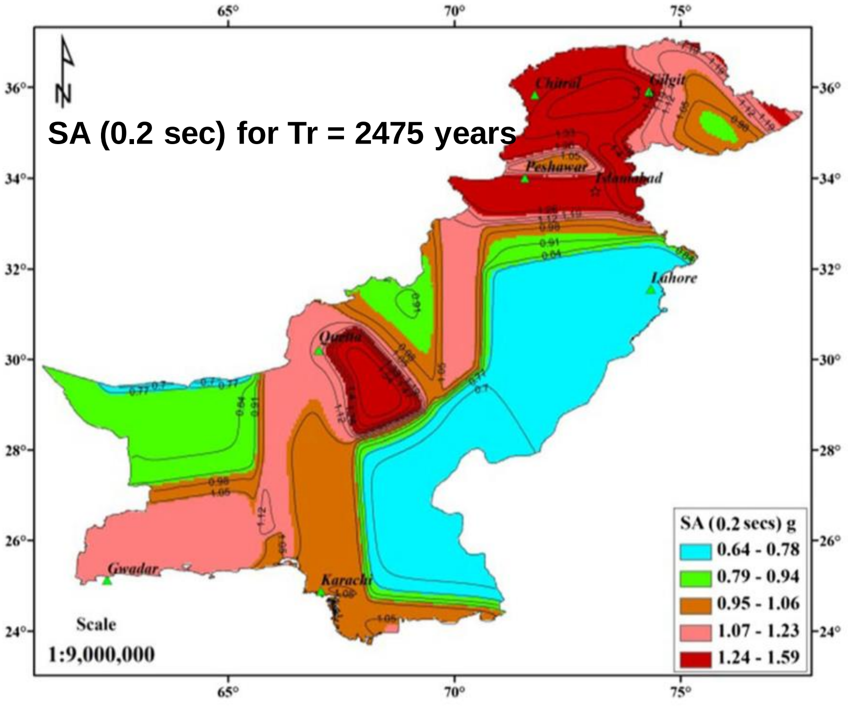
PGA for T_r = 95 years, 475 years, 975 years and 2475 years

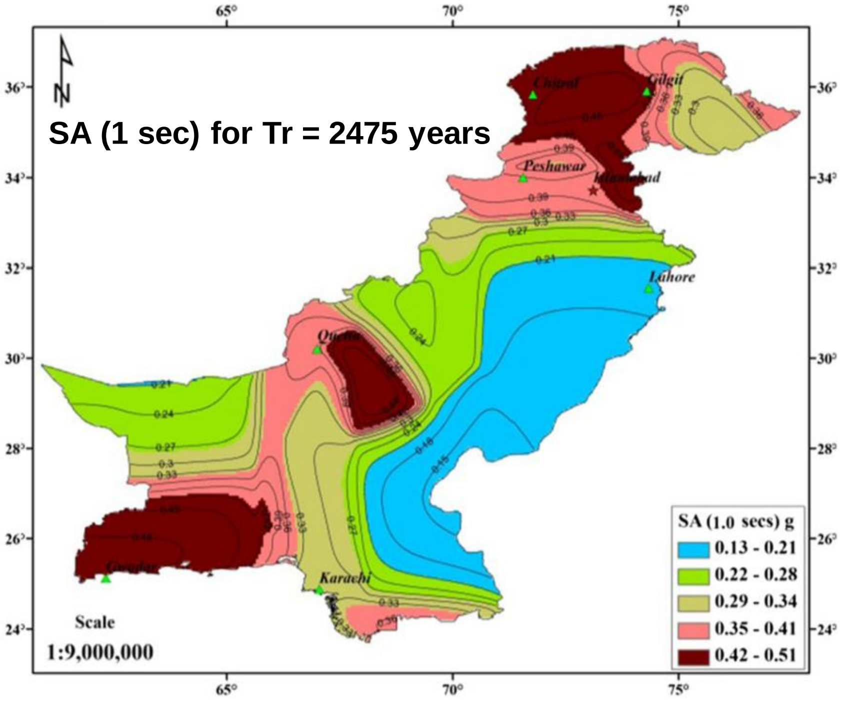


SA (0.2 sec and 1 sec) for Tr = 975 years and 2475 years

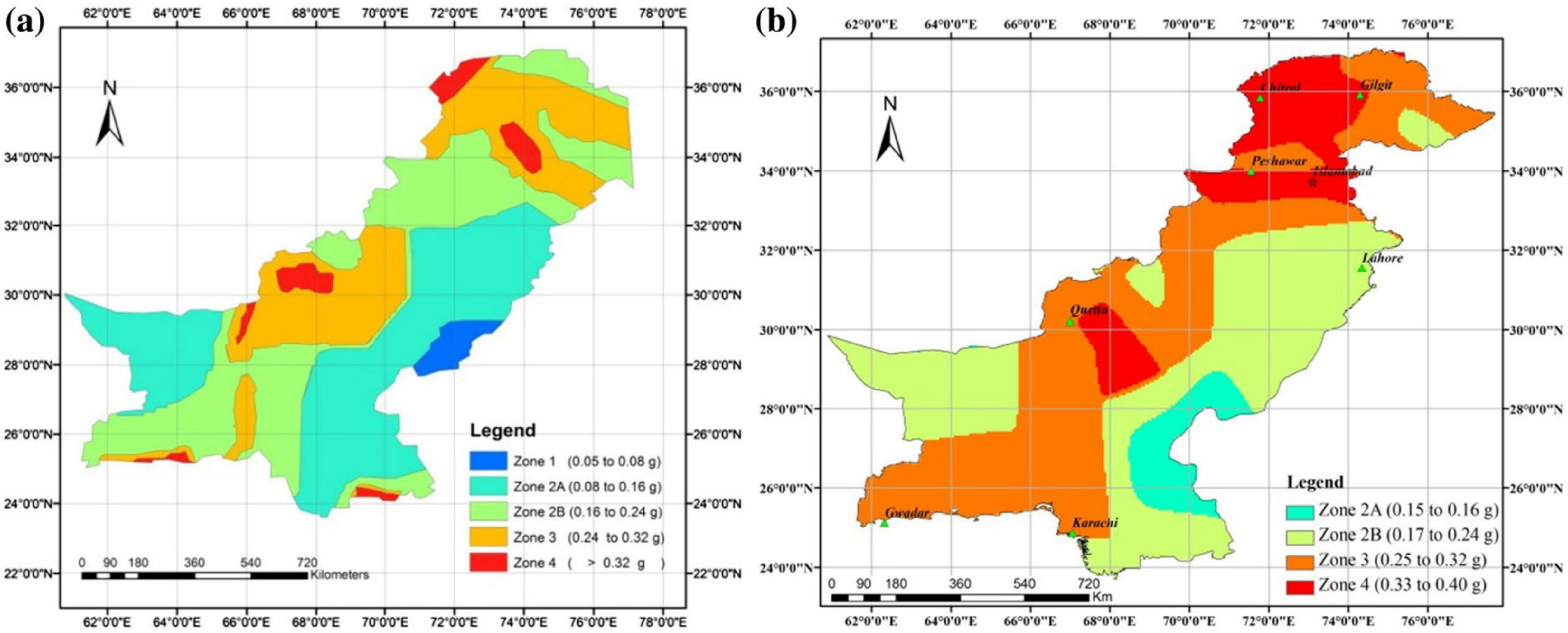








Comparison of BCP (2007) and Waseem et al. (2020)



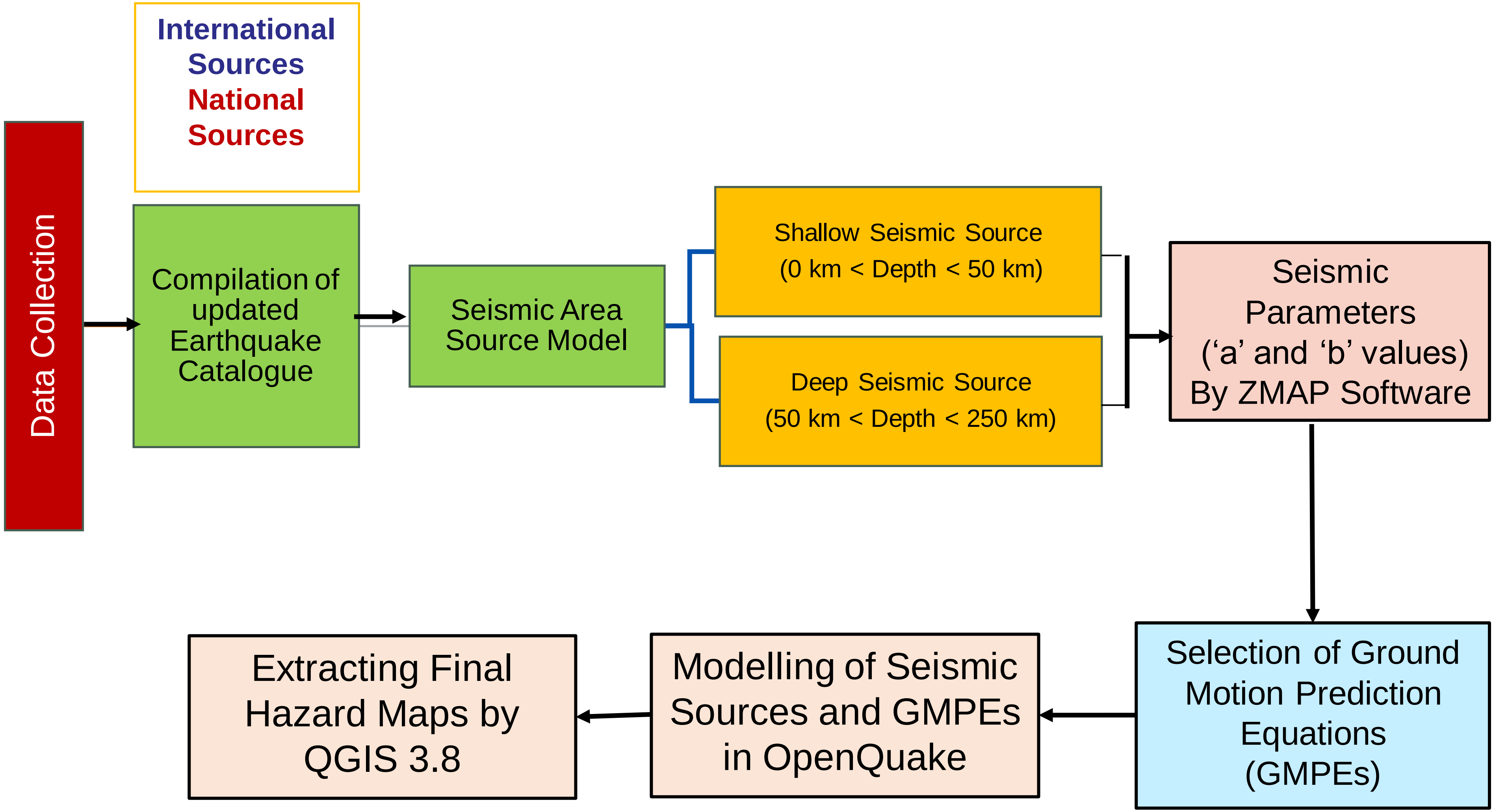
Study 4:

Probabilistic Seismic Hazard and Deaggregation Analysis of Pakistan using Conventional Area Source Model

Atif Rasheed

MS Structural Engineering (2017)

Methodology



Data Collection

International Sources

National Sources

Compilation of updated Earthquake Catalogue

Seismic Area Source Model

Shallow Seismic Source (0 km < Depth < 50 km)

Deep Seismic Source (50 km < Depth < 250 km)

Seismic Parameters (‘a’ and ‘b’ values) By ZMAP Software

Selection of Ground Motion Prediction Equations (GMPEs)

Modelling of Seismic Sources and GMPEs in OpenQuake

Extracting Final Hazard Maps by QGIS 3.8

Methodology - Compilation of Earthquake Catalogue (Data collection)

- Geographical Region $20° – 40°\ N$ and $58° – 83° E$
- Historically reported (AD 10 to 1900 CE) and Instrumentally recorded (1900 CE to December 2018 CE) earthquake events
- International sources
  - South Asian Catalogue (SACAT)
  - International Seismological Centre (ISC)
  - National Earthquake Information Centre (NEIC)
  - National Geophysical Data Centre (NGDC)
  - Advanced National Seismic Centre (ANSS)
  - Global Centroid Moment Tensor (GCMT)
- National Sources
  - Pakistan Meteorological Department (PMD)
  - Water & Power Development Authority (WAPDA)

☐ A total of **71,759** events are collected for period of AD 10 to 2018 CE

Methodology - Compilation of Earthquake Catalogue

➢ Magnitude Homogenization

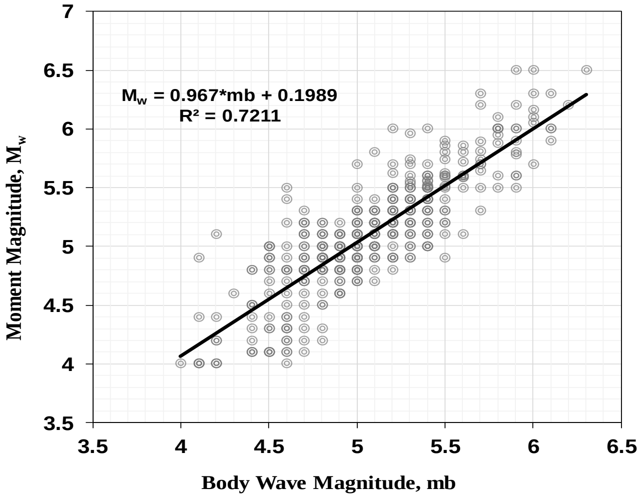
- Empirical Equations are developed
- Body wave magnitude

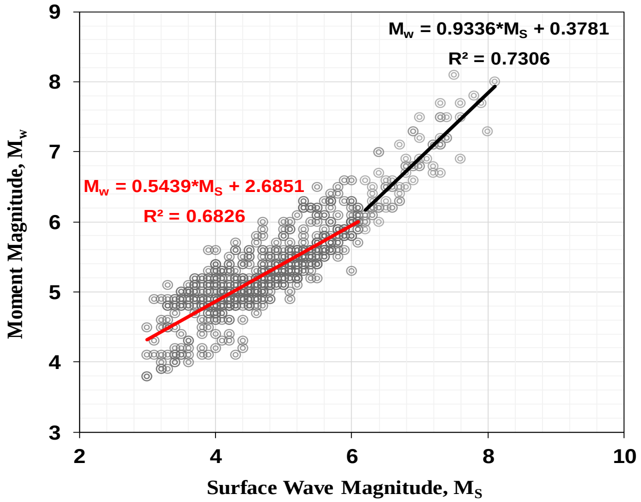
$$M_w = 0.967mb + 0.1989 \quad (4.0 \le mb \le 6.2)$$

- Surface wave magnitude

$$M_w = 0.5396 * M_S + 2.7051 \qquad 3.0 \le M_S \le 6.1$$

$$M_w = 0.9336 * M_S + 0.3781 \qquad 6.2 \le M_S \le 8.2$$

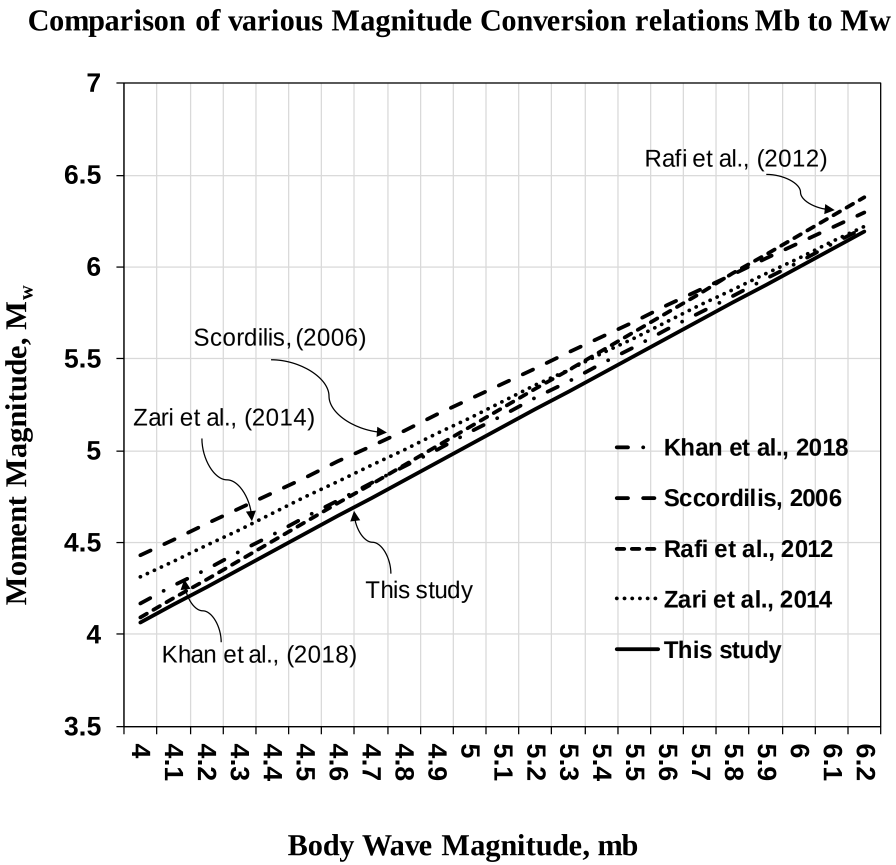

Magnitude Conversion relation Mb to Mw

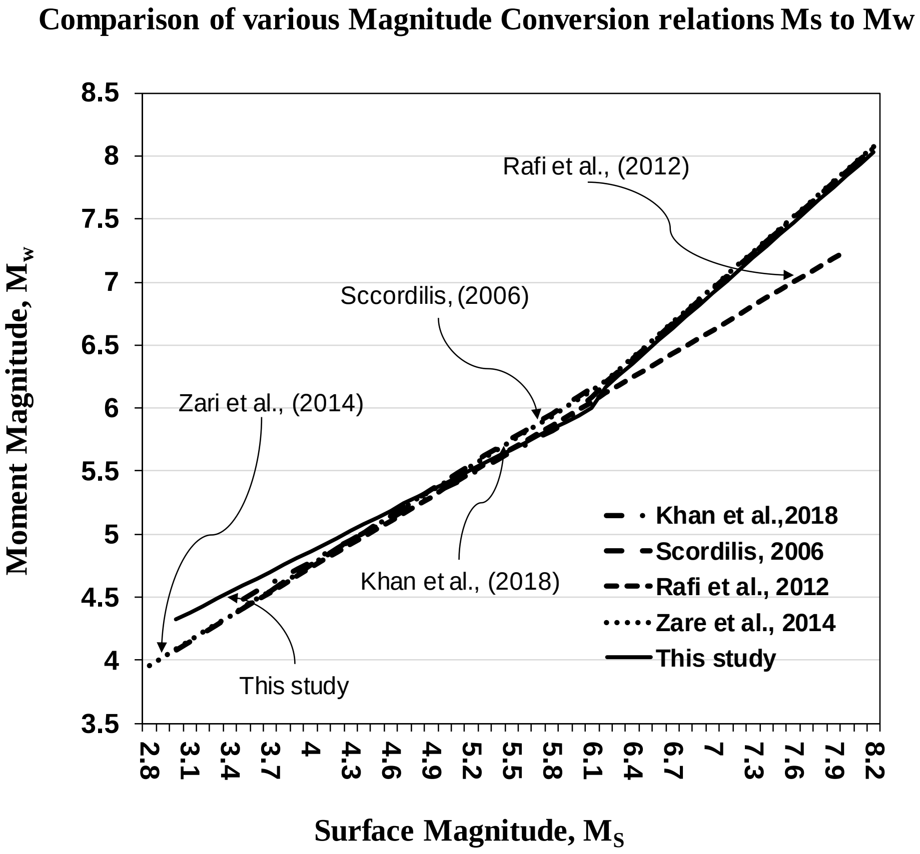

Magnitude Conversion relation Ms to Mw

Methodology - Compilation of Earthquake Catalogue

Magnitude Homogenization

Comparison of developed empirical relations with previous studies





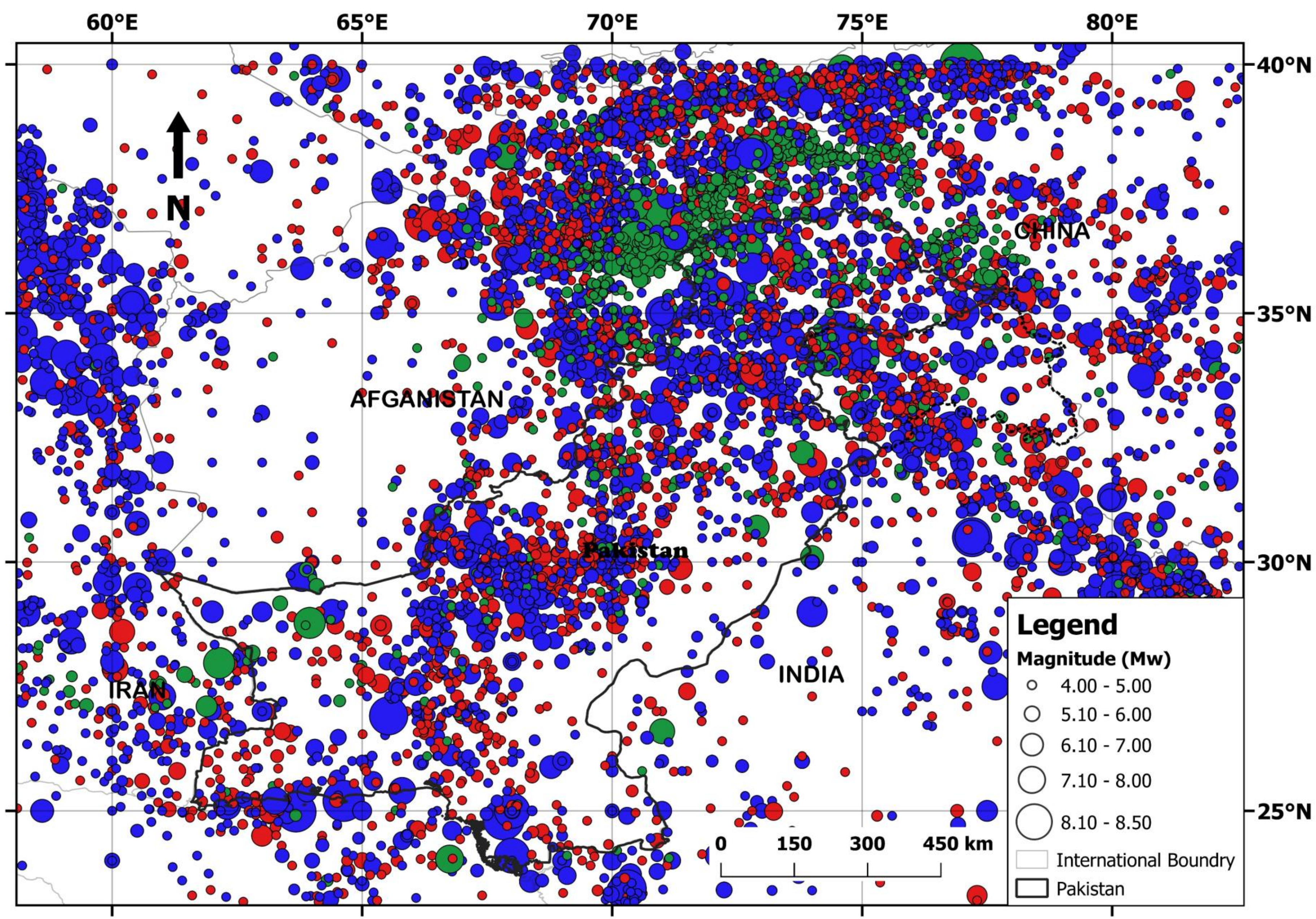
Methodology - Compilation of Earthquake Catalogue (Data Processing)

❑ Duplication

All the duplicated events were excluded from the combined catalogue that reduced the events to **34,104.**

Period	Source	N	Priority Order	Magnitude type
1902-2018	ISC-GEM	14807	1	mb, M_S, M_w, M_L, M_D
1902-2018	USGS	12913	2	M_S, mb, M_w, M_L
10-2018	NGDC	518	3	M_S, M_w, mb, M_L
1976-2016	GCMT	464	4	M_S, M_w, mb
1965-2012	ANSS	11030	5	M_w, mb, M_L
10-2016	(Khan et al., 2018)	7503	6	M_w, M_S
1965-2006	(Zare et al., 2014)	12925	7	M_w
1908-2018	PMD	11448	8	M_S, M_w, mb, M_L
1973-2018	WAPDA	1682	9	M_w, mb, M_L
1101-1964	SACAT	359	10	M_S, mb, M_w, M_L
25-1969	(Quittmeyer and Jacob, 1979)	294	11	mb, M_S, M_w,
1505-1945	(Ambraseys, 2000; Ambraseys and Douglas, 2004)	37	12	M_S, M_w
734-1994	(Ambraseys and Bilham, 2014)	323	13	M_S, M_w

N is the number of earthquakes reported by the sources; M_S = surface wave magnitude scale; mb = body wave magnitude scale; M_L = local magnitude scale; M_w = moment magnitude scale; M_D = duration magnitude scale.



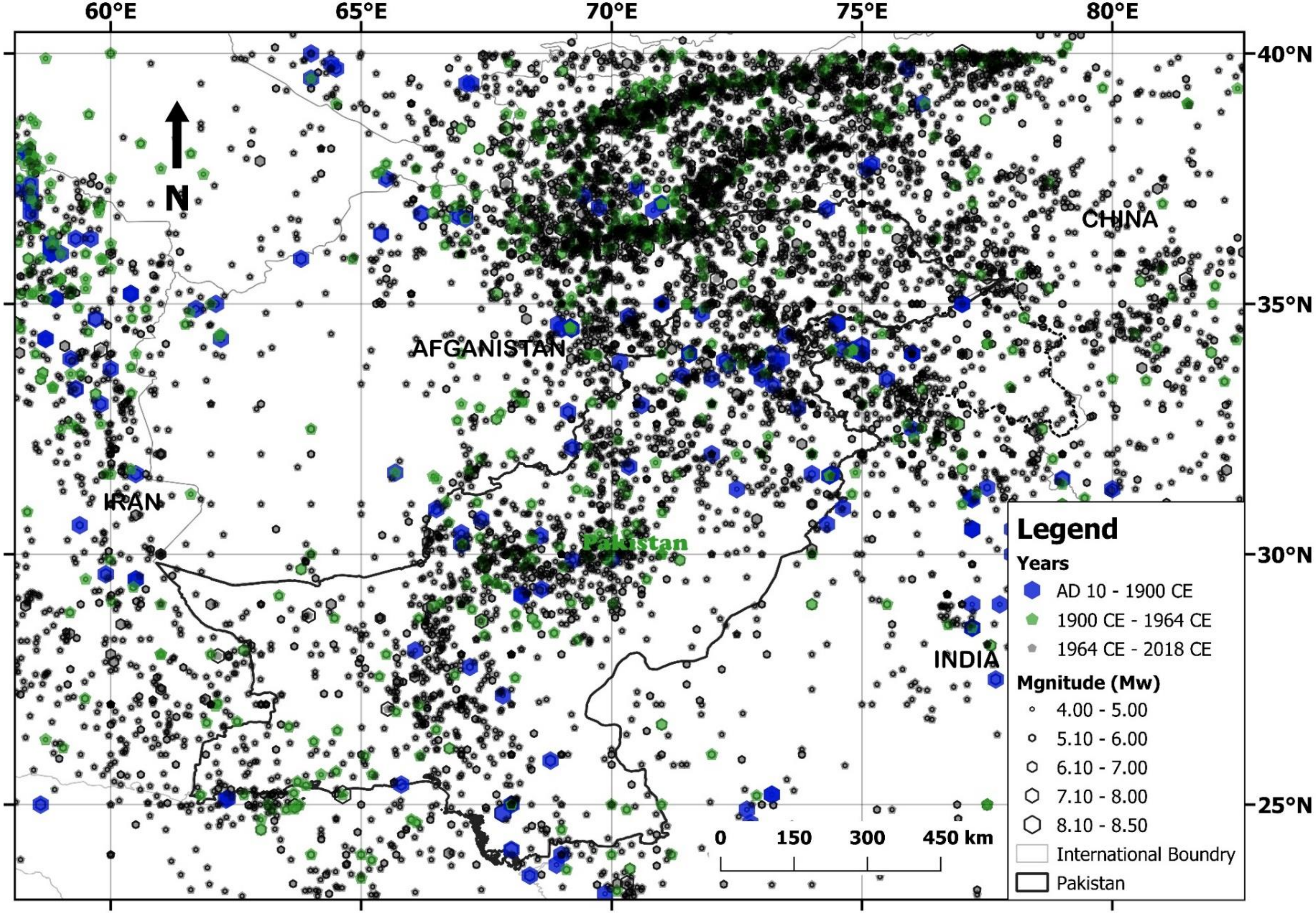
Blue 0 – 25 km **Red** 25 – 50 km **Green** 50 – 250 km

Methodology - Compilation of Earthquake Catalogue (Data Processing)

Declustering of Earthquake Events

Method	Total events	Number of clusters	Number of events remained	Number of events removed (%)
Gardner and Knopoff, (1974)	34,104	3454	8107	26,259 (76.93%)
Reasenberg, (1985)		4387	26,495	11,976 (35.12%)
Uhrhammer, (1986)		4629	15,706	18,378 (46.05%)
Gruenthal (Zare et al., 2014)		2688	4929	29,175 (85.54%)

Zare *et al.*, Journal of Seismology, (2014)


60°E
65°E
70°E
75°E
80°E
40°N
35°N
30°N
25°N
N
CHINA
AFGANISTAN
IRAN
Pakistan
INDIA
0
150
300
450 km
Legend
Years
AD 10 - 1900 CE
1900 CE - 1964 CE
1964 CE - 2018 CE
Mgnitude (Mw)
4.00 - 5.00
5.10 - 6.00
6.10 - 7.00
7.10 - 8.00
8.10 - 8.50
International Boundry
Pakistan

Methodology - Compilation of Earthquake Catalogue (Data Processing)

Data Incompleteness

Two techniques;

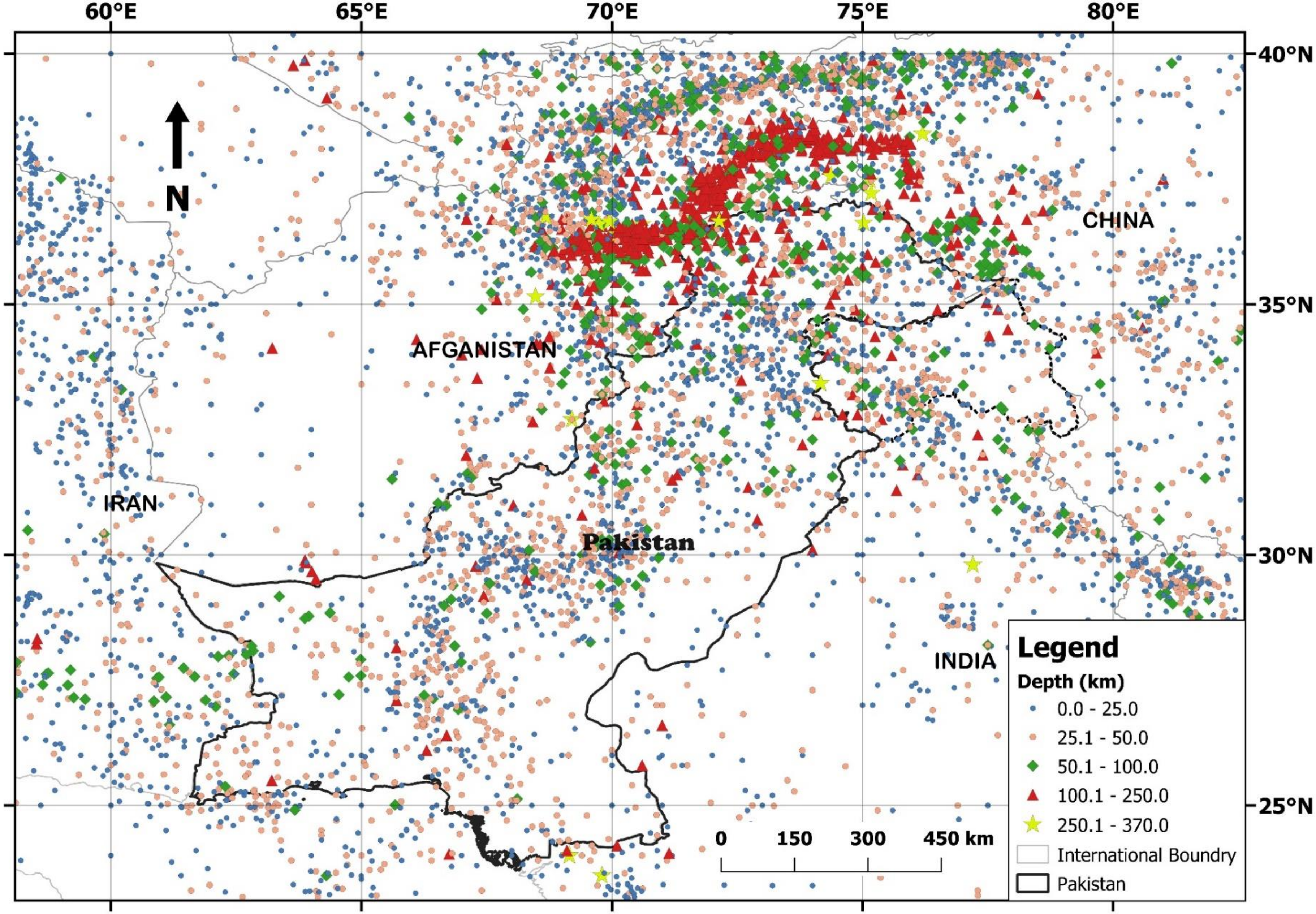
a) Visual Cumulative Method (CUVI)

b) Stepp (1973) were used which yielded similar completeness periods.

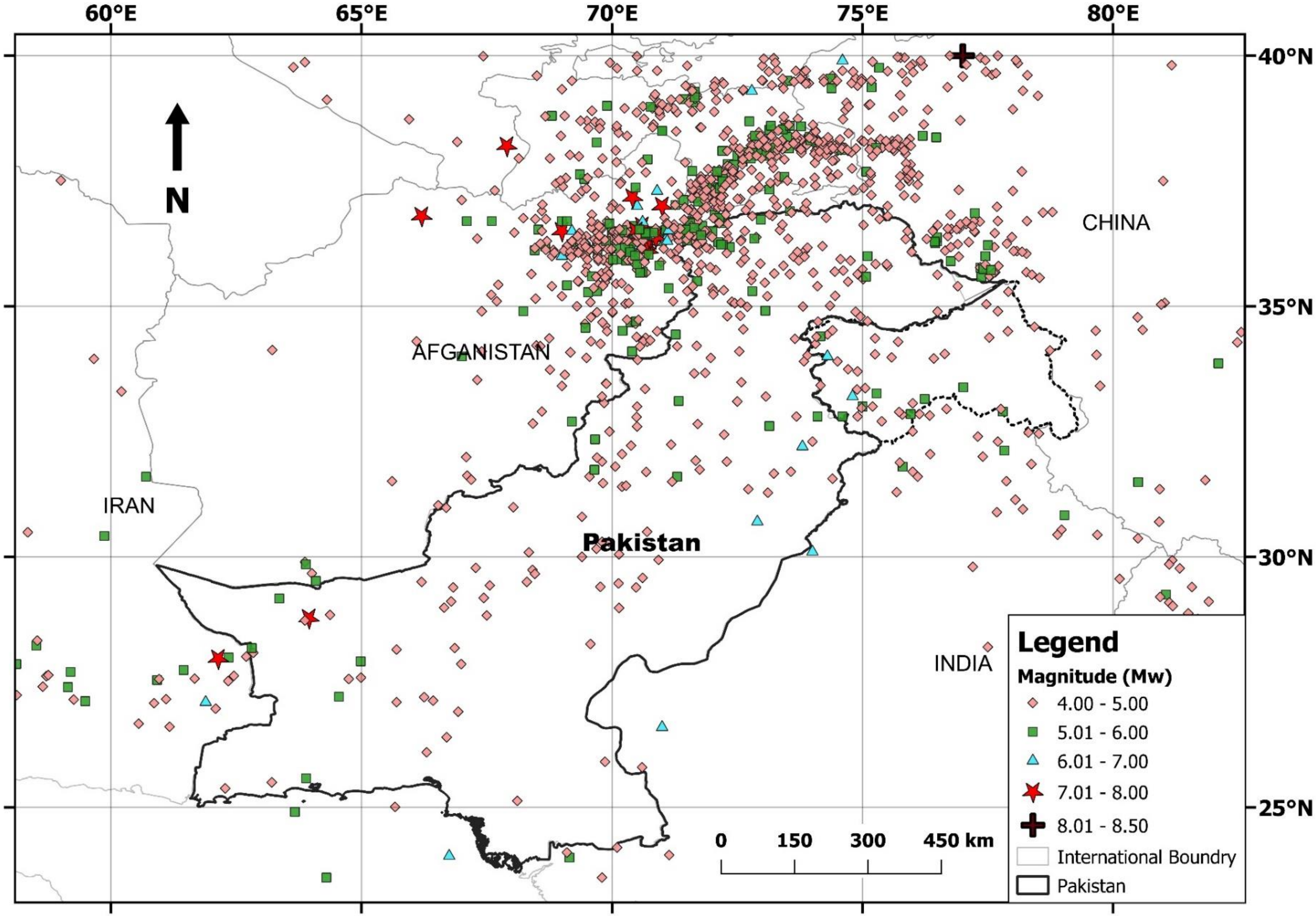
Magnitude class	Completeness period
$M_w \geq 4.0$	1990 – 2018 = 28
$M_w \geq 4.5$	1975 – 2018 = 43
$M_w \geq 5.0$	1951 – 2018 = 67
$M_w \geq 5.5$	1926 – 2018 = 92
$M_w \geq 6.0$	1900 – 2018 = 118
$M_w \geq 6.5$	1900 – 2018 = 118
$M_w \geq 7.0$	1900 – 2018 = 118
$M_w \geq 7.5$	1884 – 2018 = 134
$M_w \geq 8.0$	1878 – 2018 = 140

Seismogenic Depths

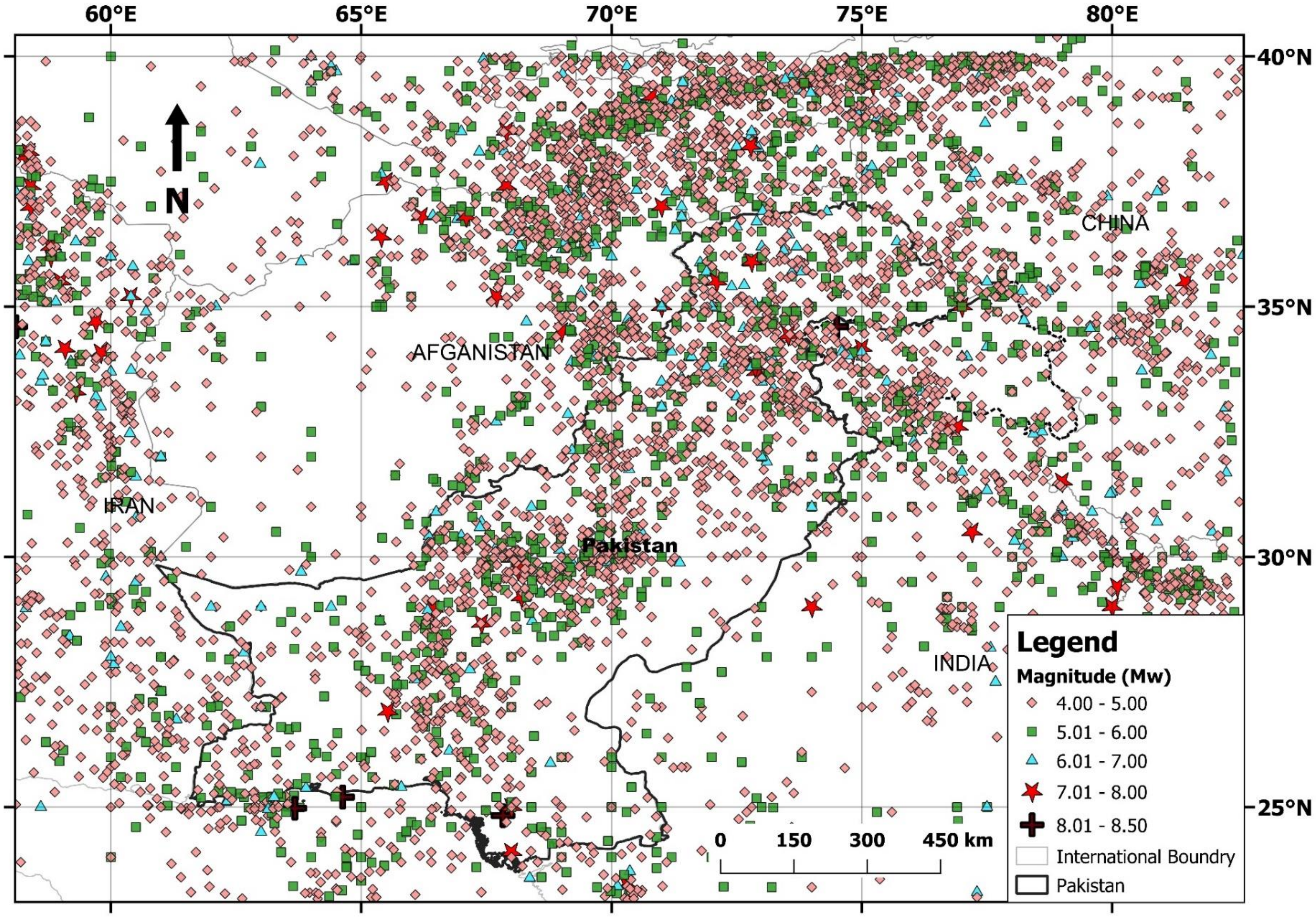
Determination of focal depths of earthquakes is extremely important (Maggi, Priestley and Jackson, 2002)



Deep Earthquakes
$(Depth > 50\ km)$

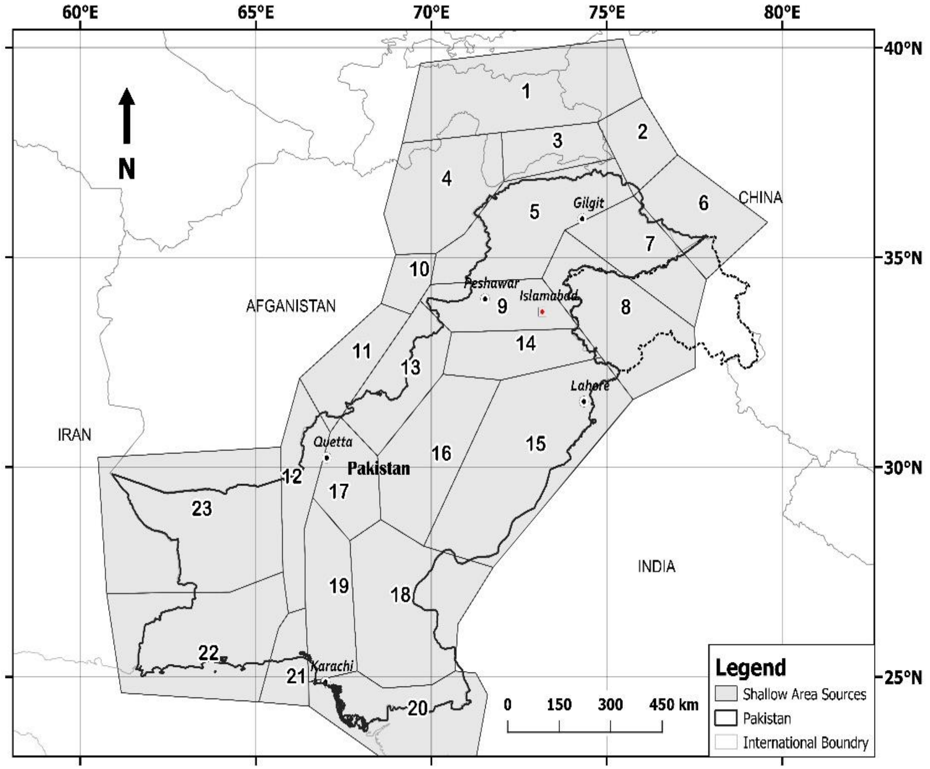


Shallow Earthquakes
$(Depth < 50\ km)$



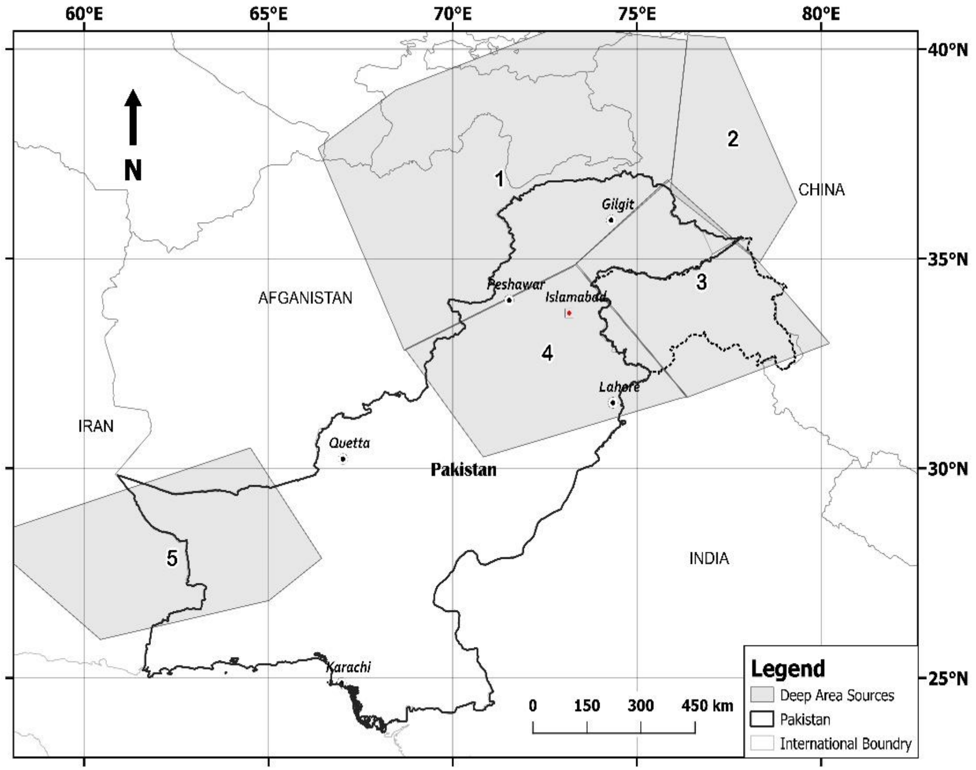
Seismic Area Source Model - Delineation of Seismic Area Sources

Shallow Area Sources (23)



4823 Earthquake Events

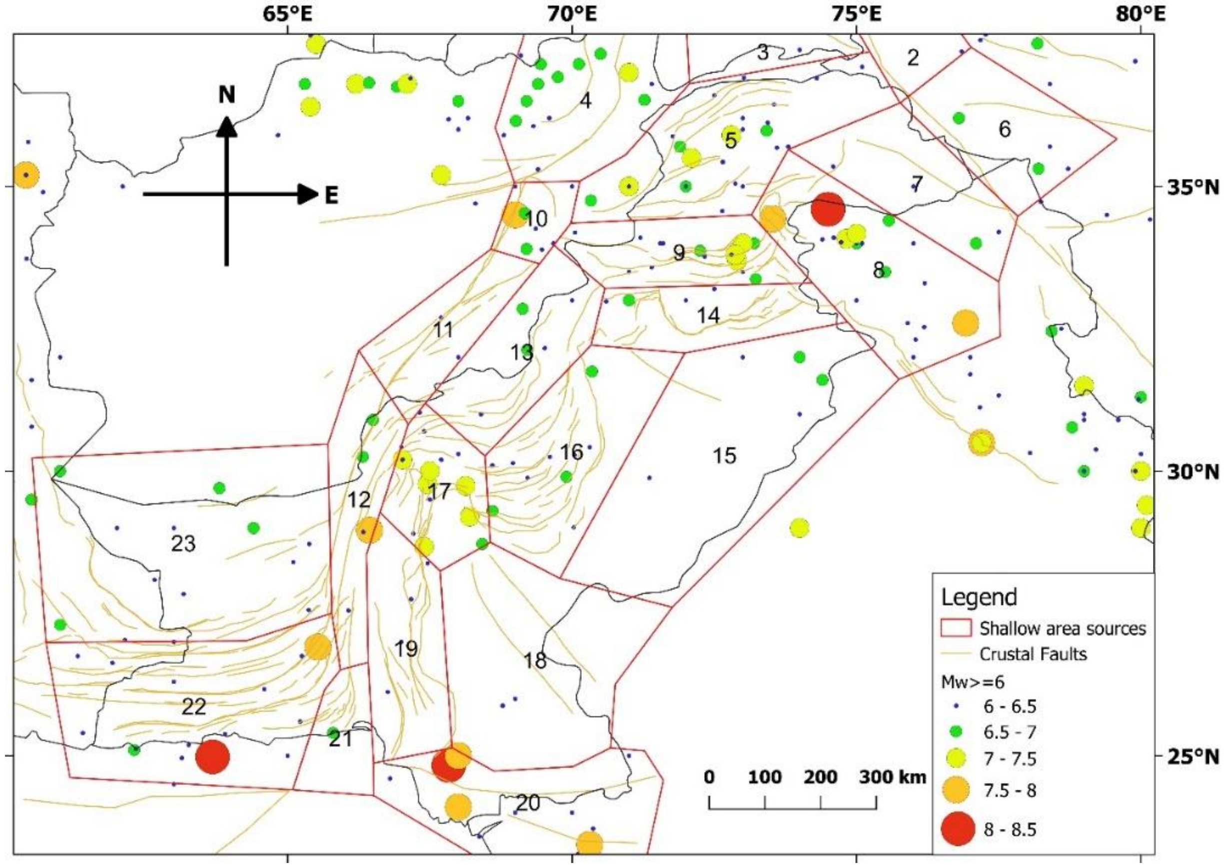
Deep Area Sources (5)



1457 Earthquake Events

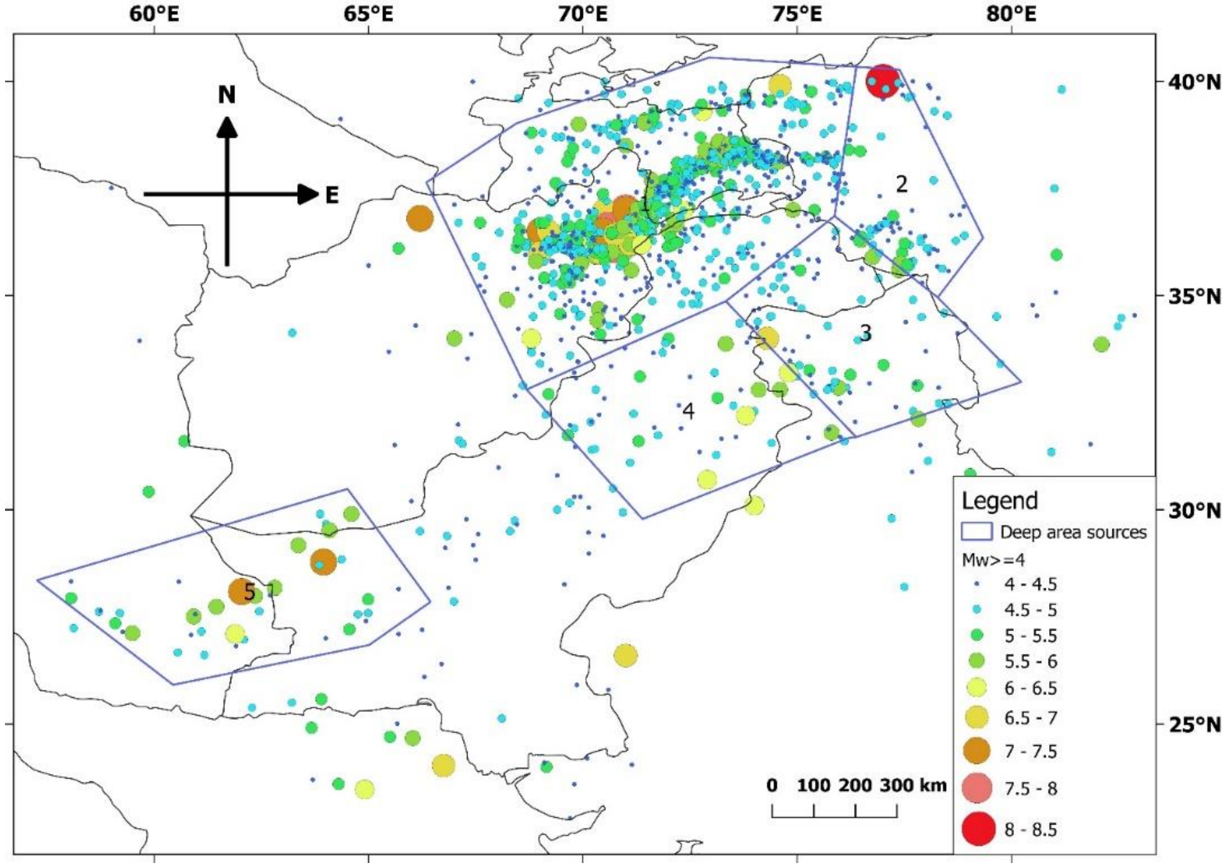
The Conventional Area source model

Shallow Area Sources (23)



4823 Earthquake Events

Deep Area Sources (5)

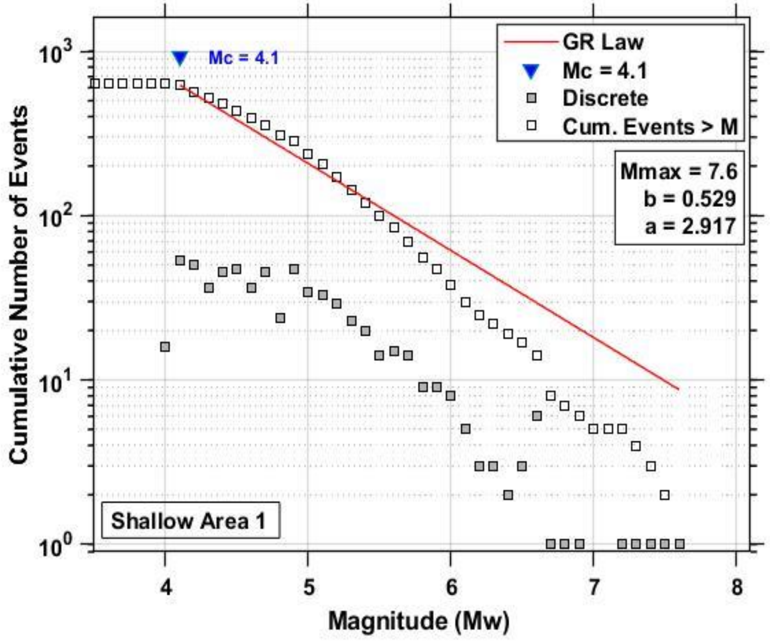


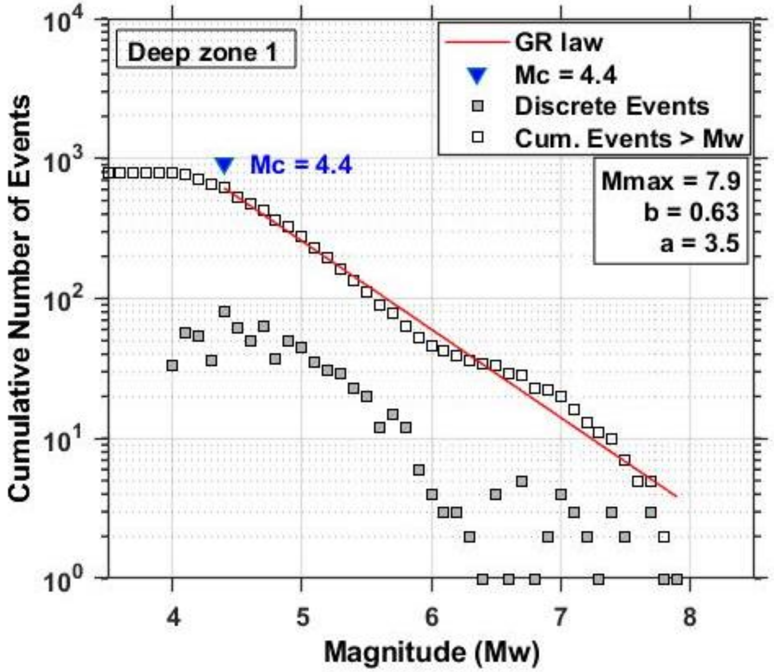
1457 Earthquake Events

Seismicity Parameters

The Seismicity Parameters (Recurrence Rates) are calculated by Gutenberg-Richter Law (1974)

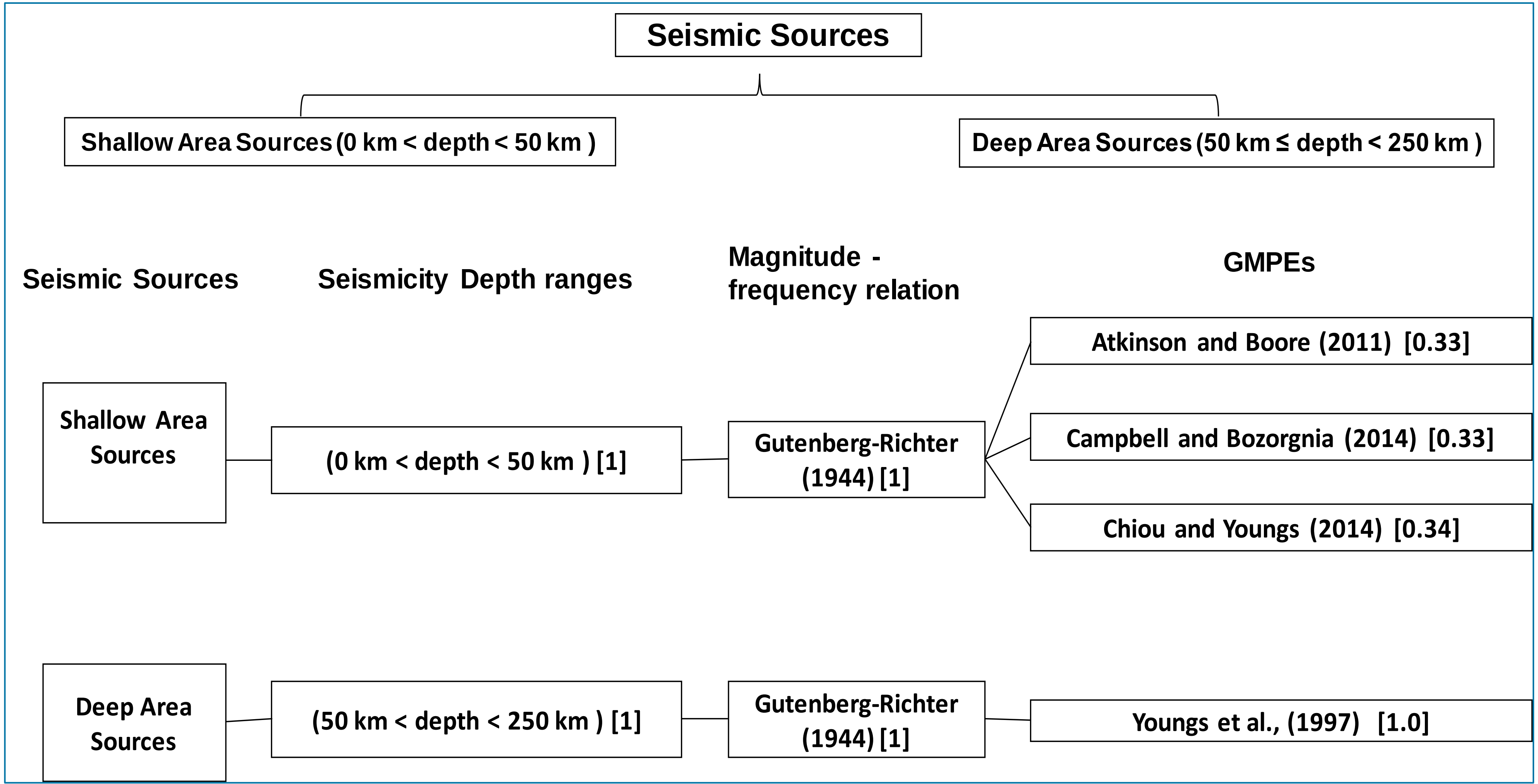
$$Log\,\lambda_M = a - b * M$$



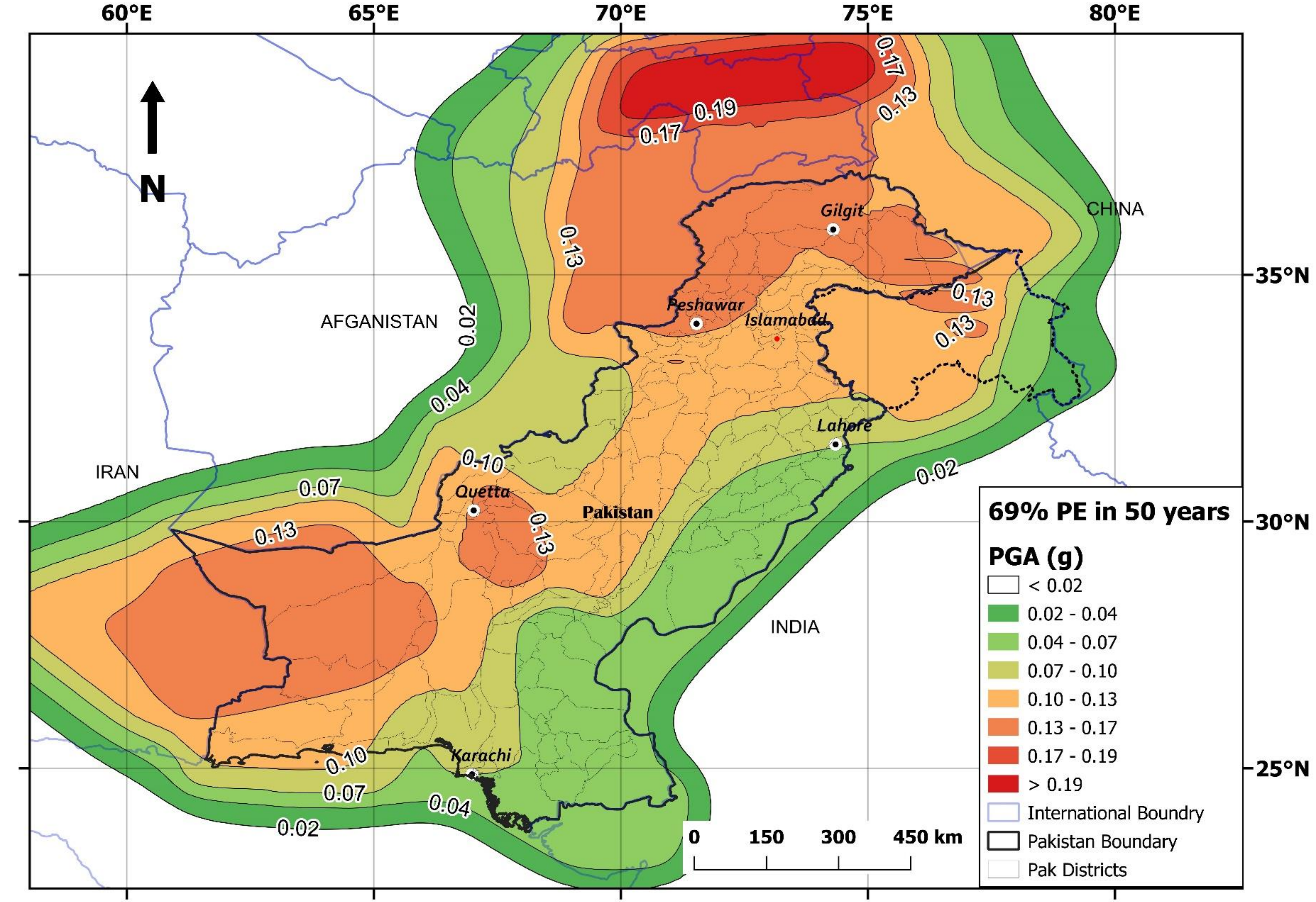


Probabilistic Seismic Hazard Analysis (PSHA)

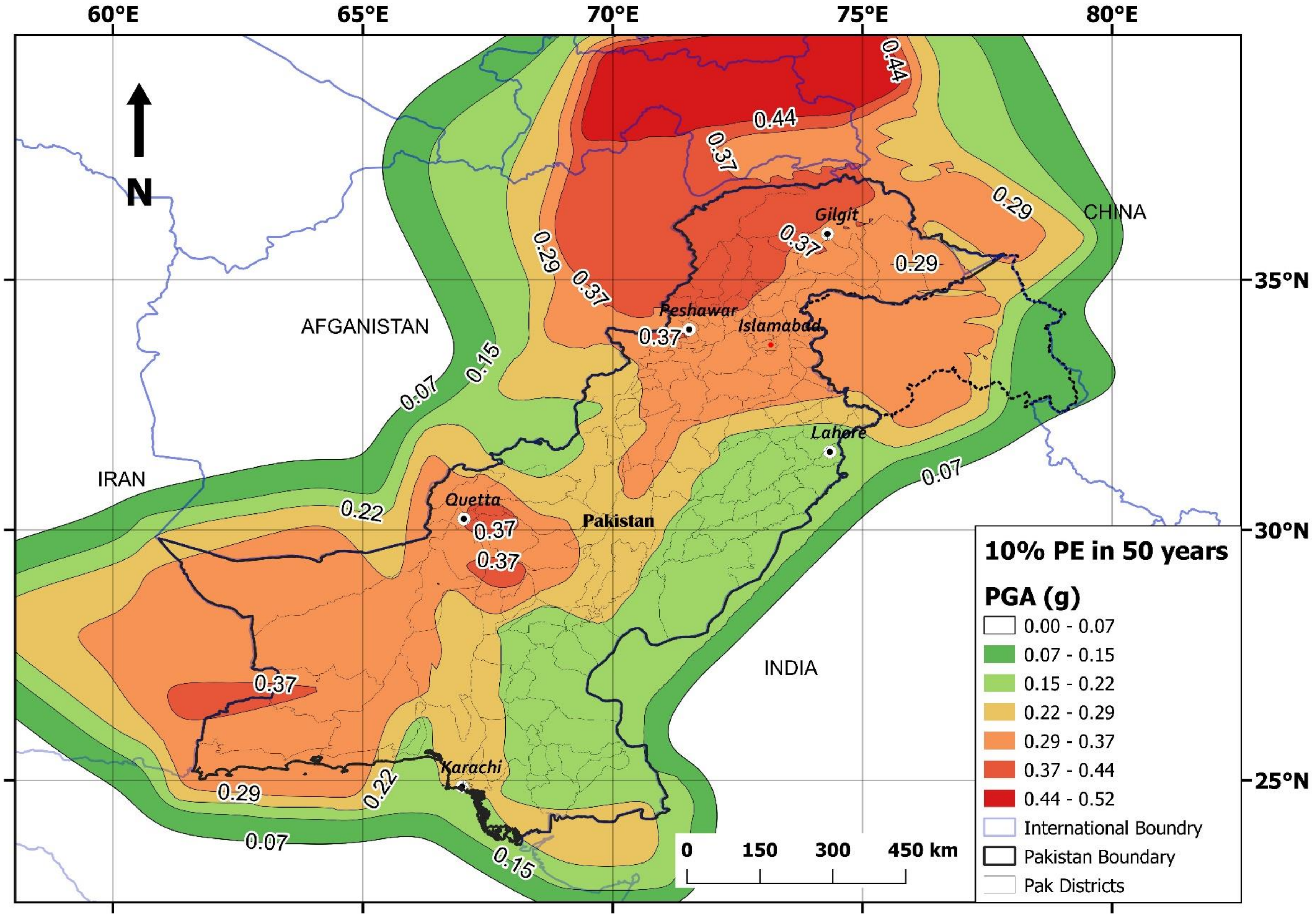
- The PSHA of Pakistan is carried out by using OpenQuake software (Pagani et al., 2014)



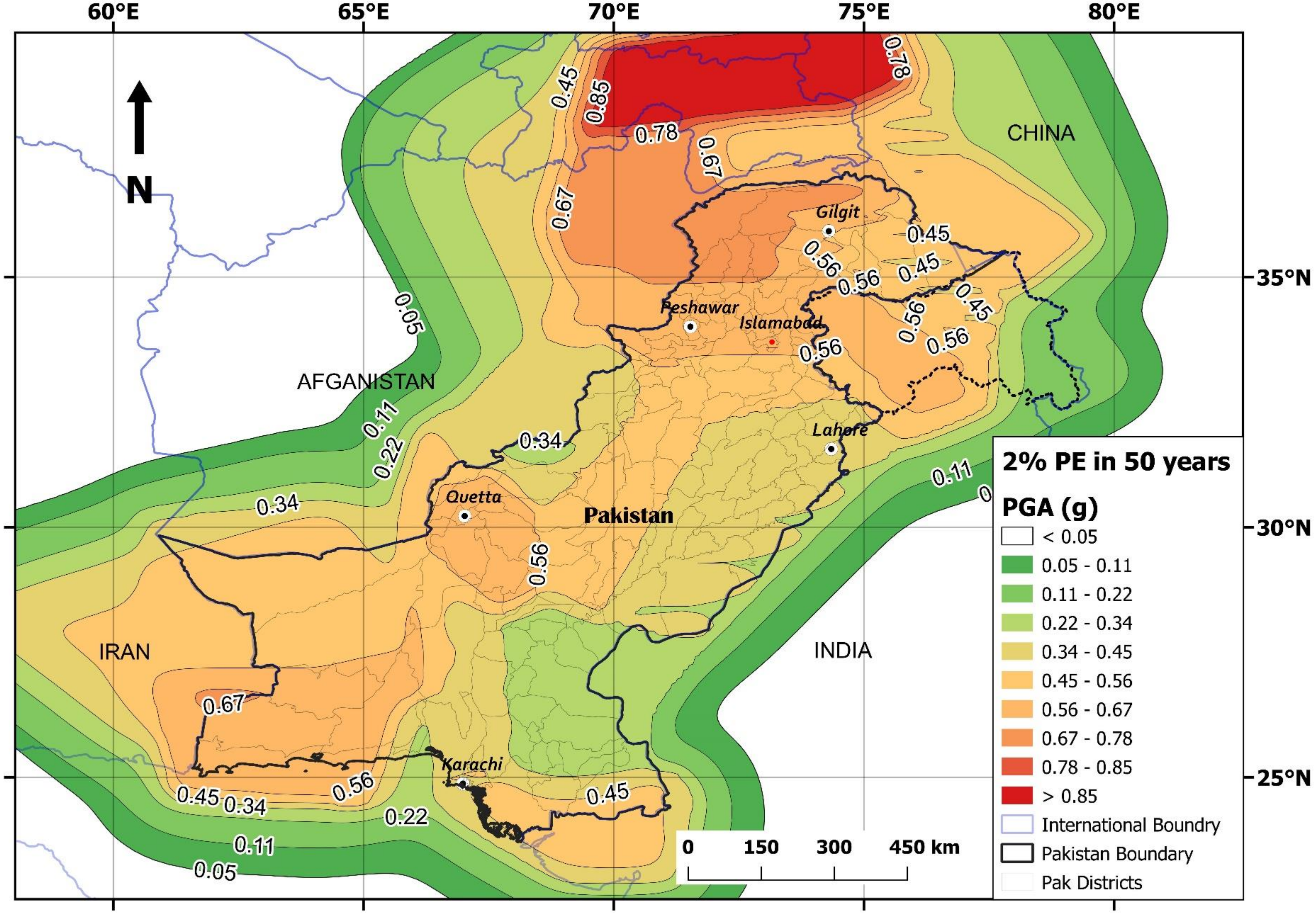
Peak Ground Acceleration (PGA) map for Service Level Earthquake (SLE)



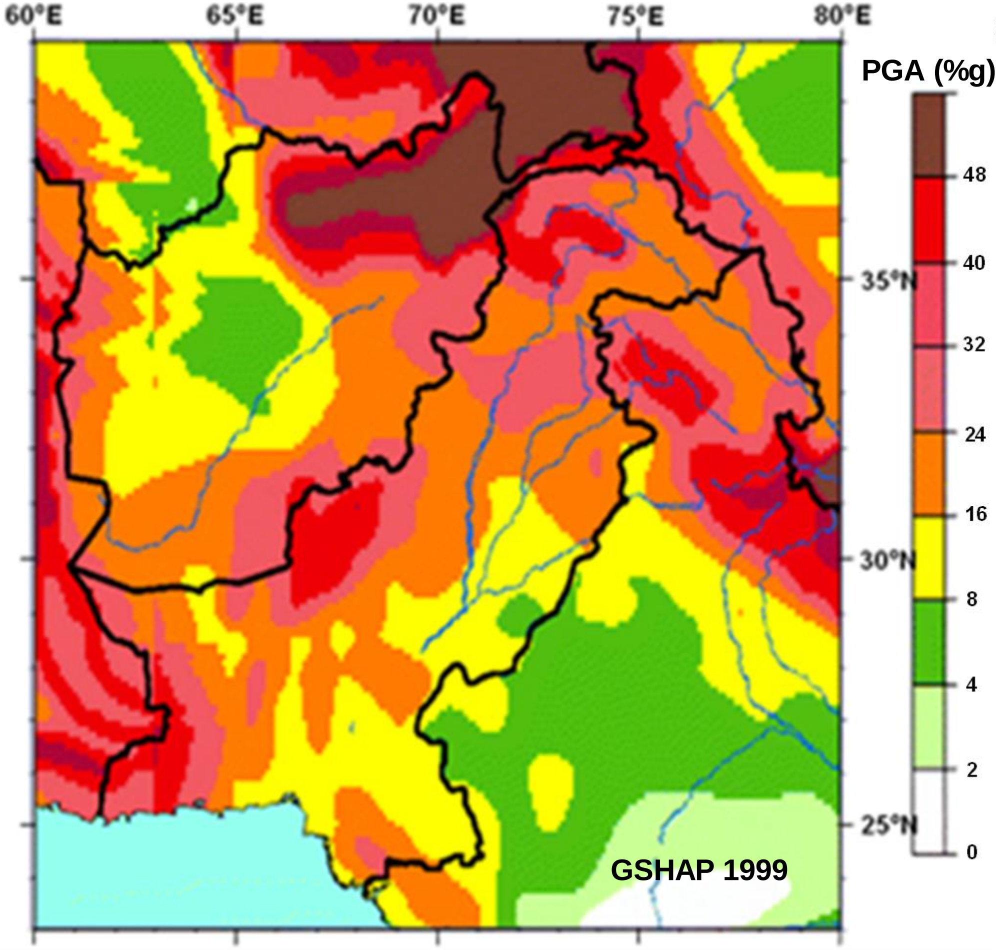
Peak Ground Acceleration (PGA) map for Design Basis Earthquake (DBE)

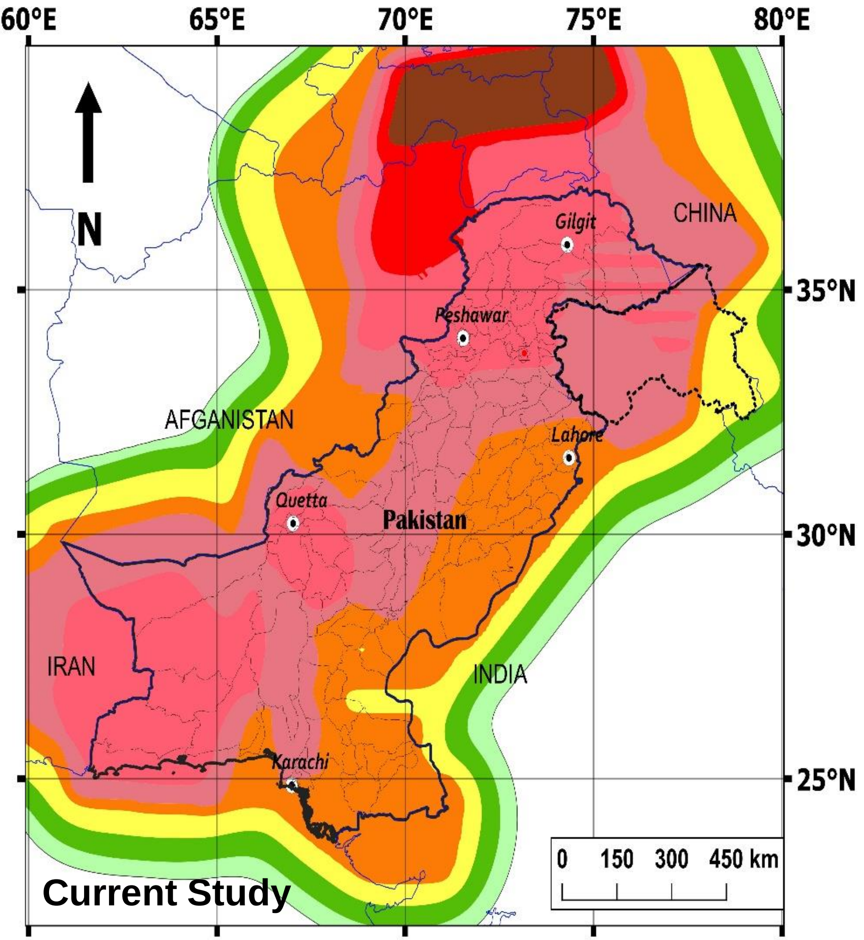


Peak Ground Acceleration (PGA) map for Maximum Credible Earthquake (MCE)



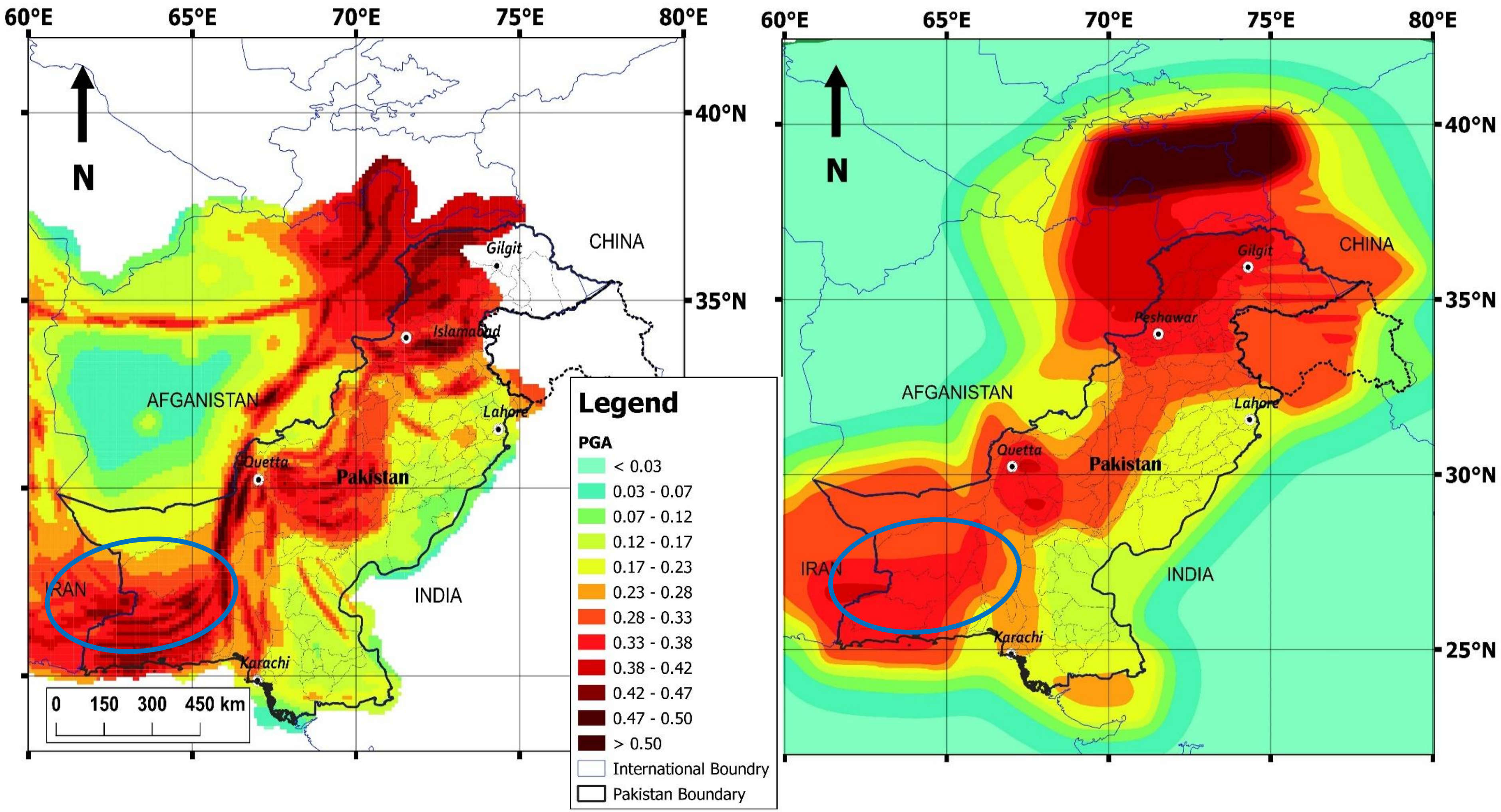
Comparison of GSHAP (1999) with current study (10% PE in 50 years)





- ☐ Similar Hazard Pattern throughout Pakistan
- ☐ PGA larger than previous studies
- ☐ Number of earthquake events in the catalogue is the reason of larger values

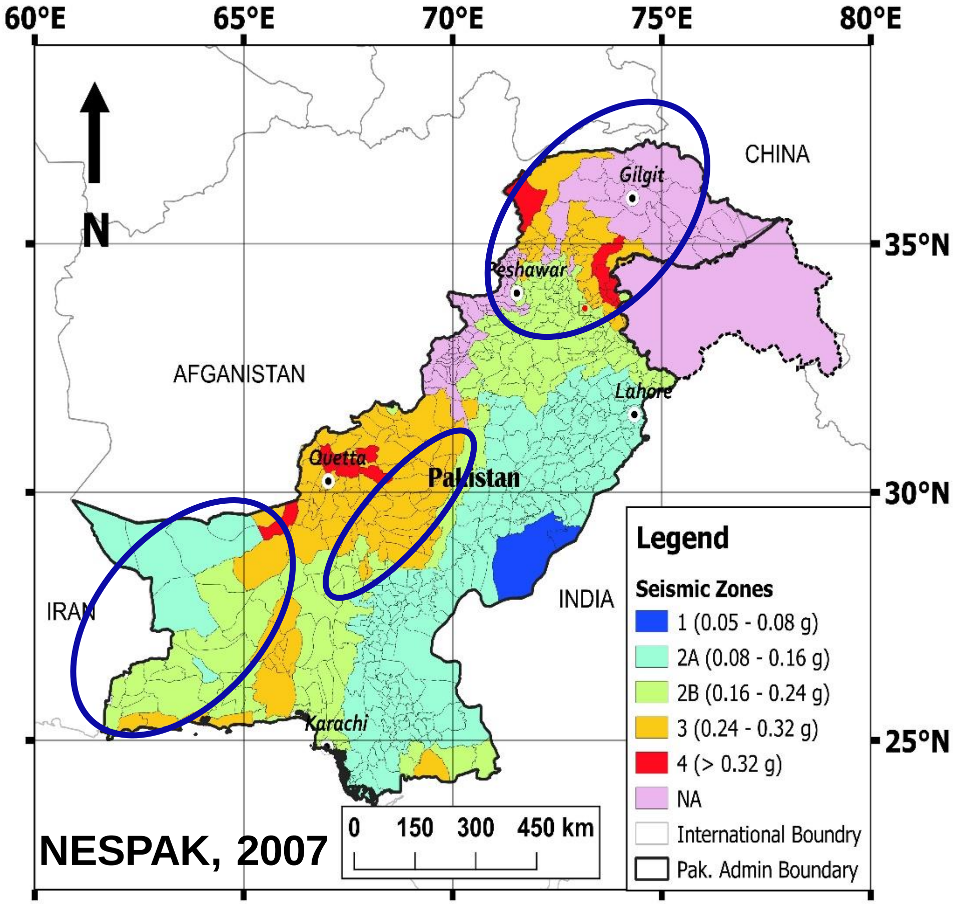
Comparison of EMME (2014) with current study (10% PE in 50 years)

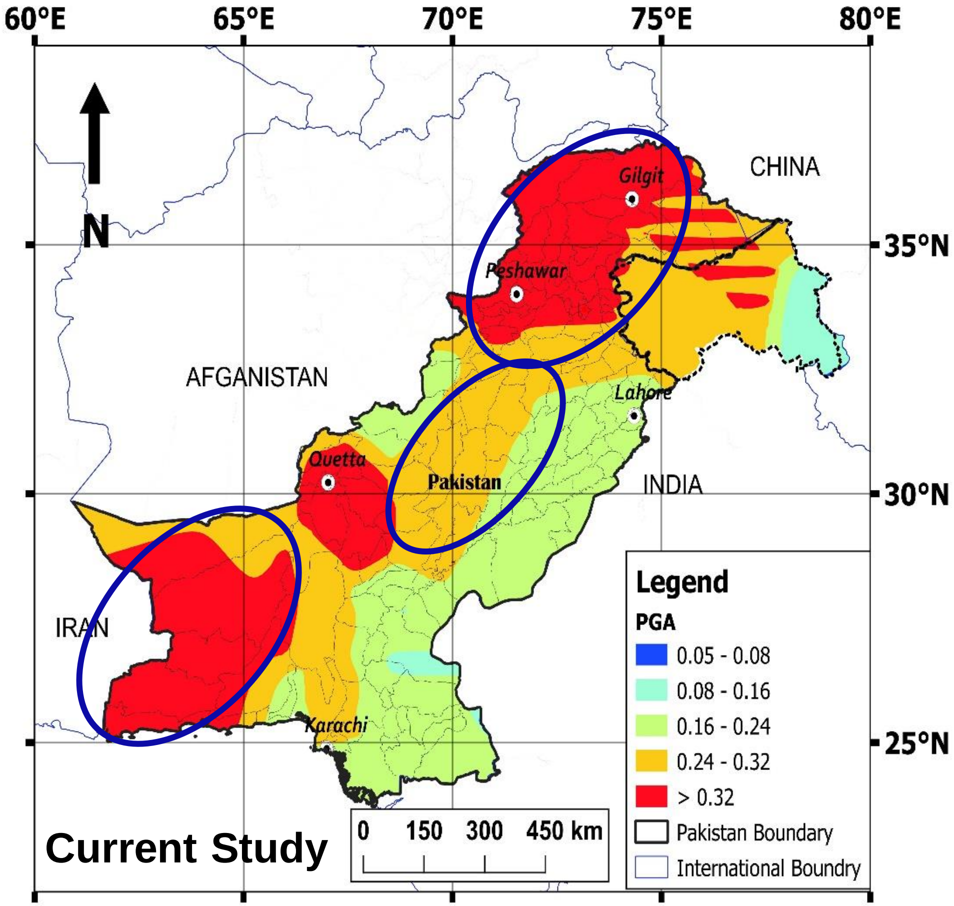


EMME, 2014

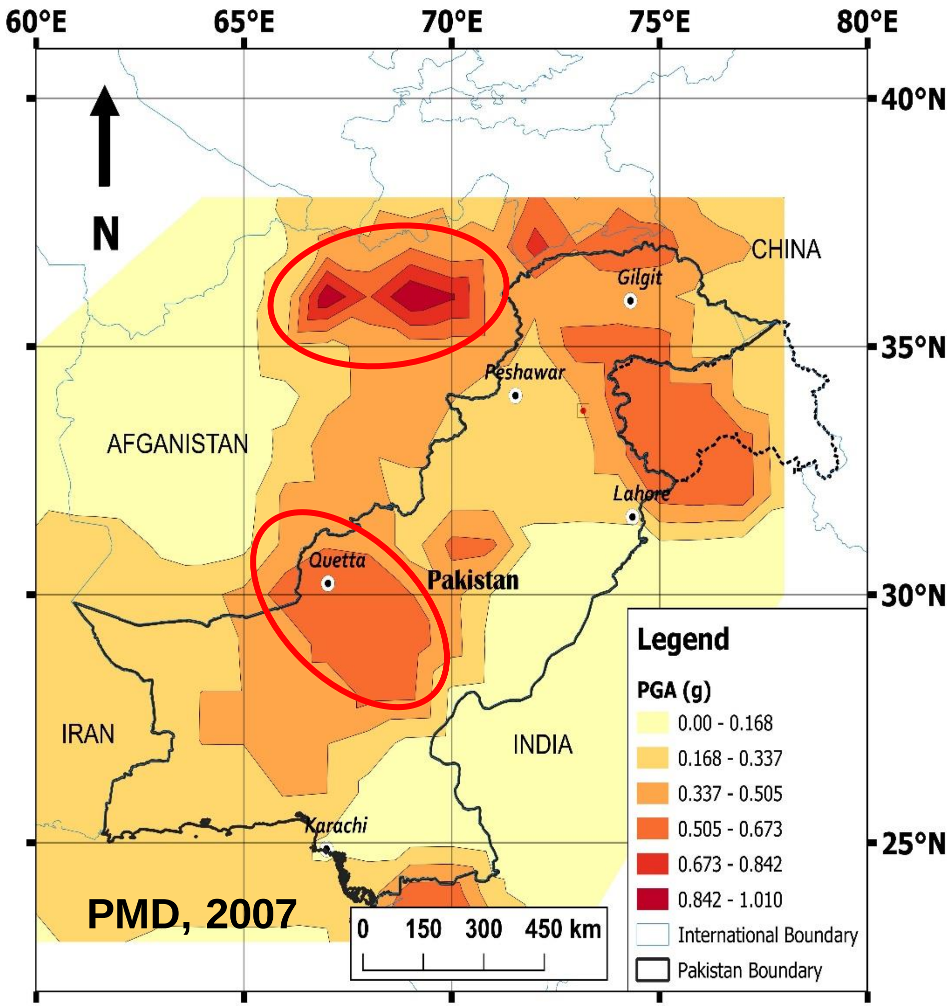
Current Study

Comparison of NESPAK (2007) with current study (10% PE in 50 years)

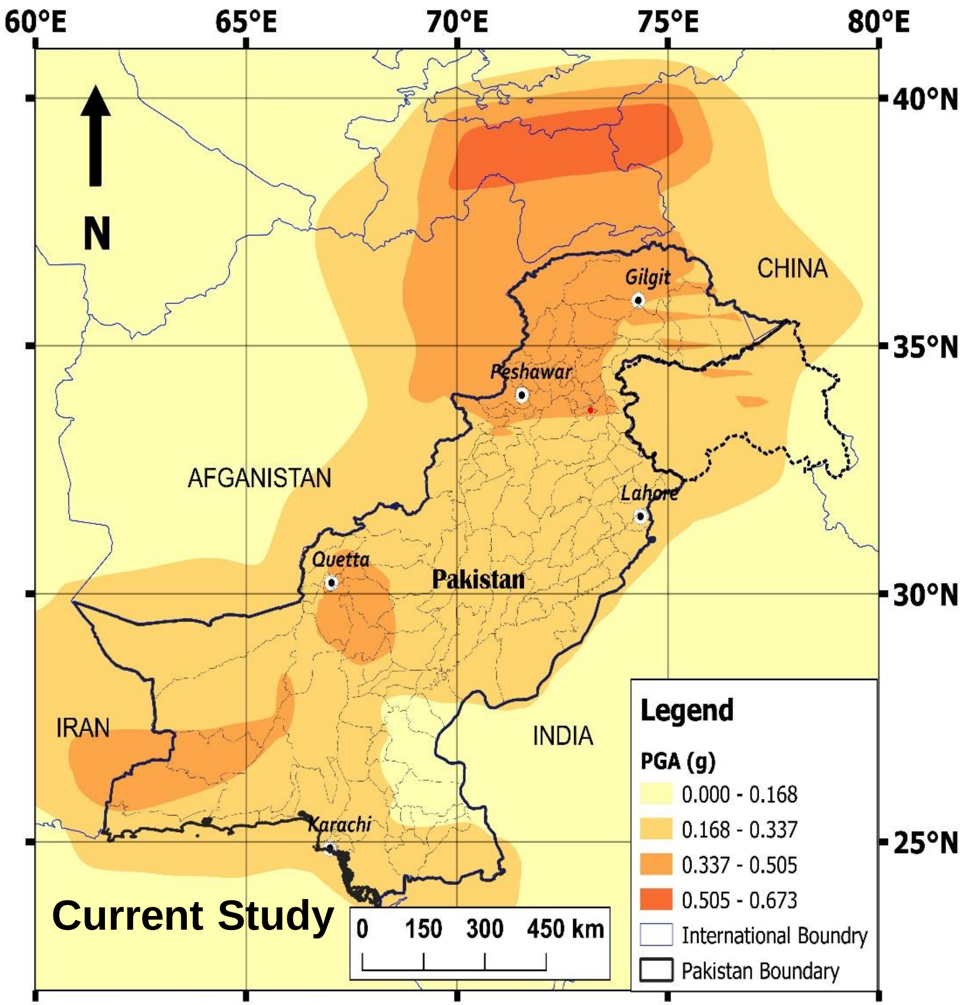




Comparison of PMD (2007) with current study (10% PE in 50 years)

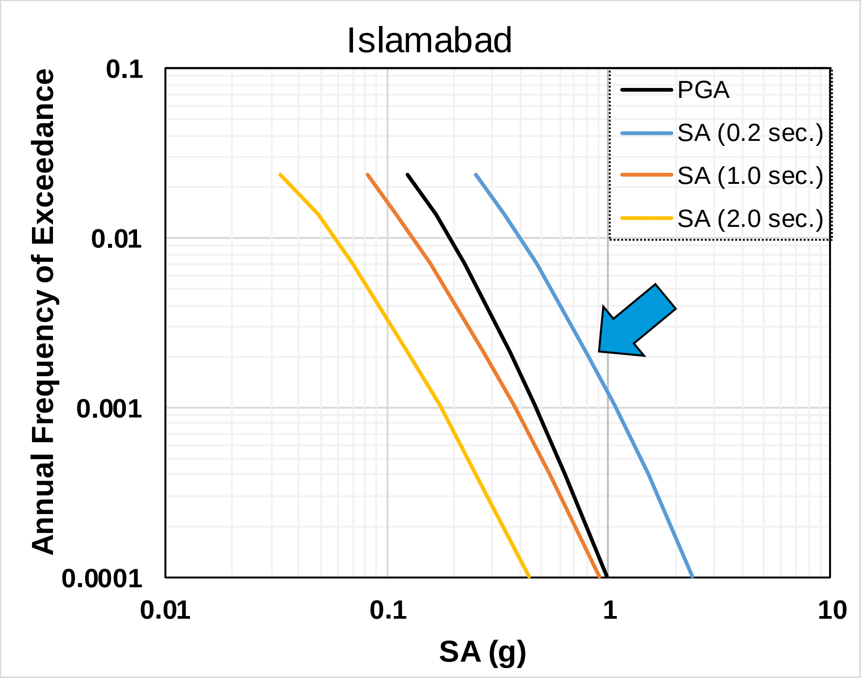


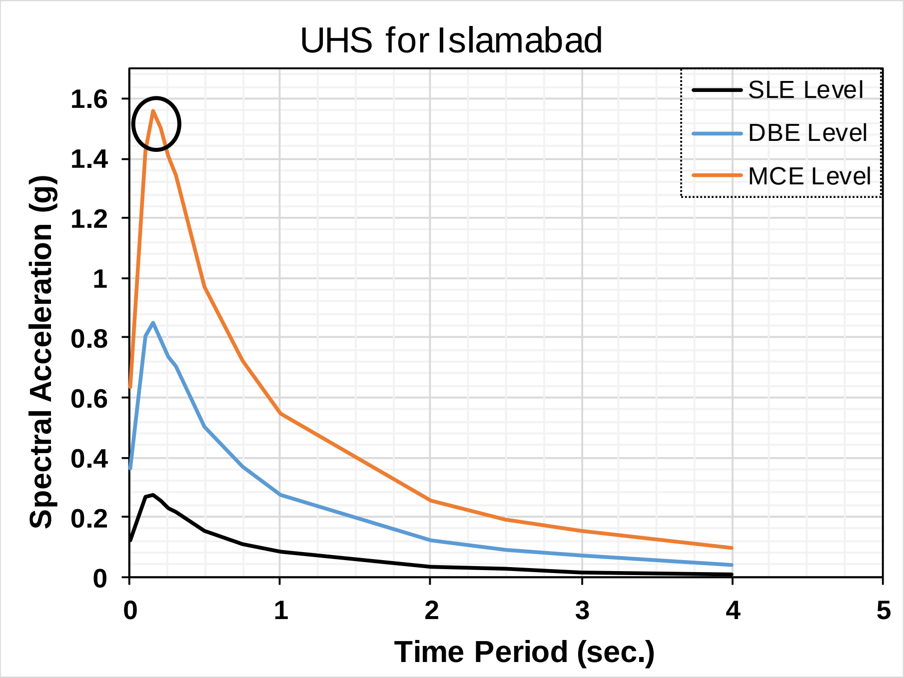
- Similar Hazard Pattern
- Very Coarse Grid (1º × 1º)



- Similar Hazard Pattern
- Very Fine Grid (0.1º × 0.1º)
- Hazard is greater in Makran Division

Seismic Hazard Curves and Uniform Hazard Spectra (UHS) for Islamabad



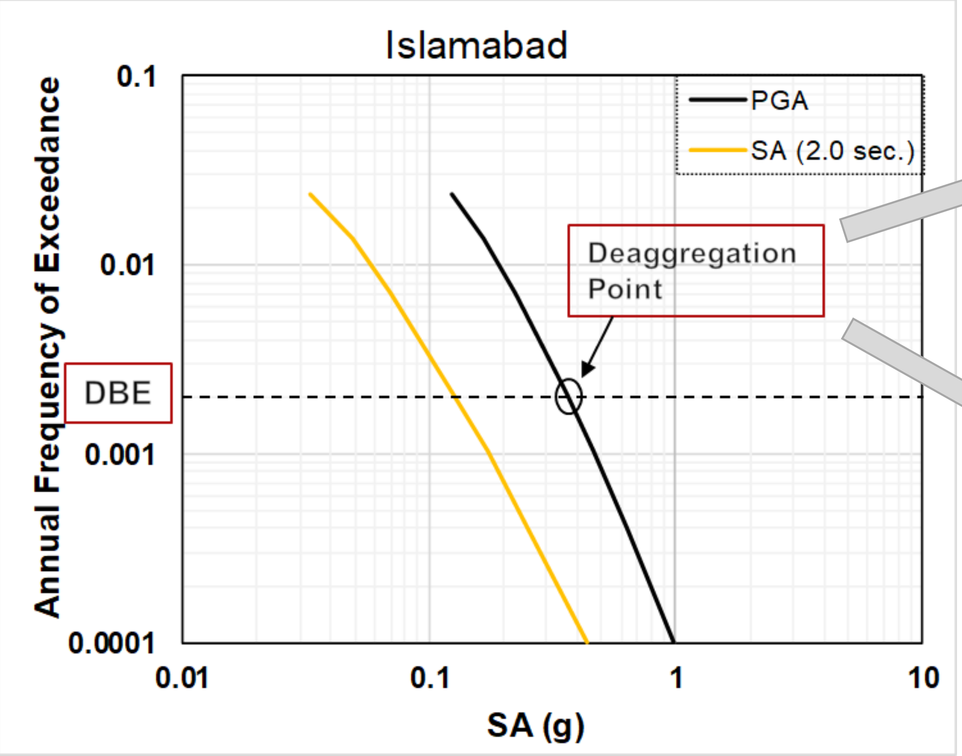


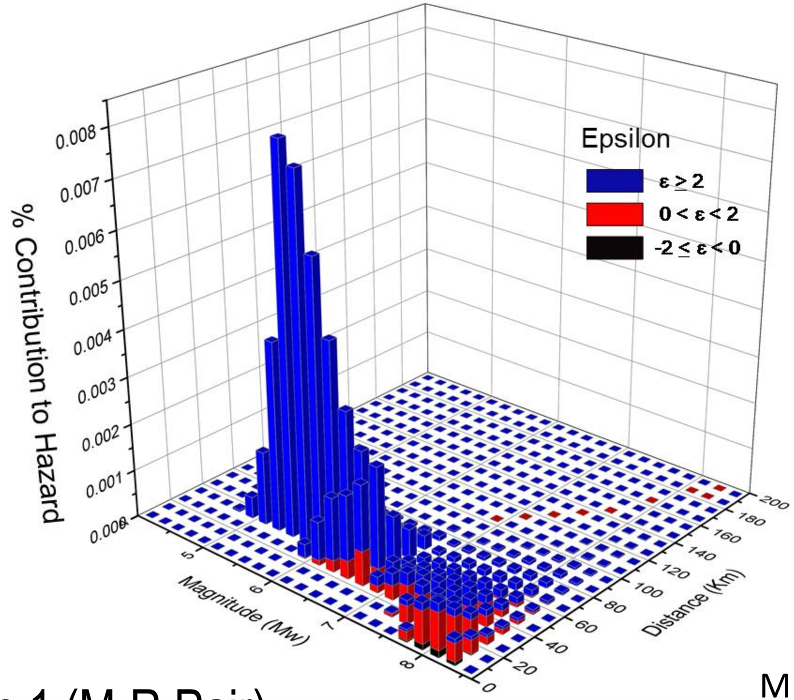
SLE Service Level Earthquake
69% PE in 50 yrs, 43 yrs Return Period

MCE Maximum Credible Earthquake
2% PE in 50 yrs, 2475 yrs Return Period

DBE Design Bases Earthquake
10% PE in 50 yrs, 475 yrs Return Period

Probabilistic Seismic Hazard Deaggregation





70% Source 1 (M-R Pair)

20% Source 2 (M-R Pair)

10% Source 3 (M-R Pair)

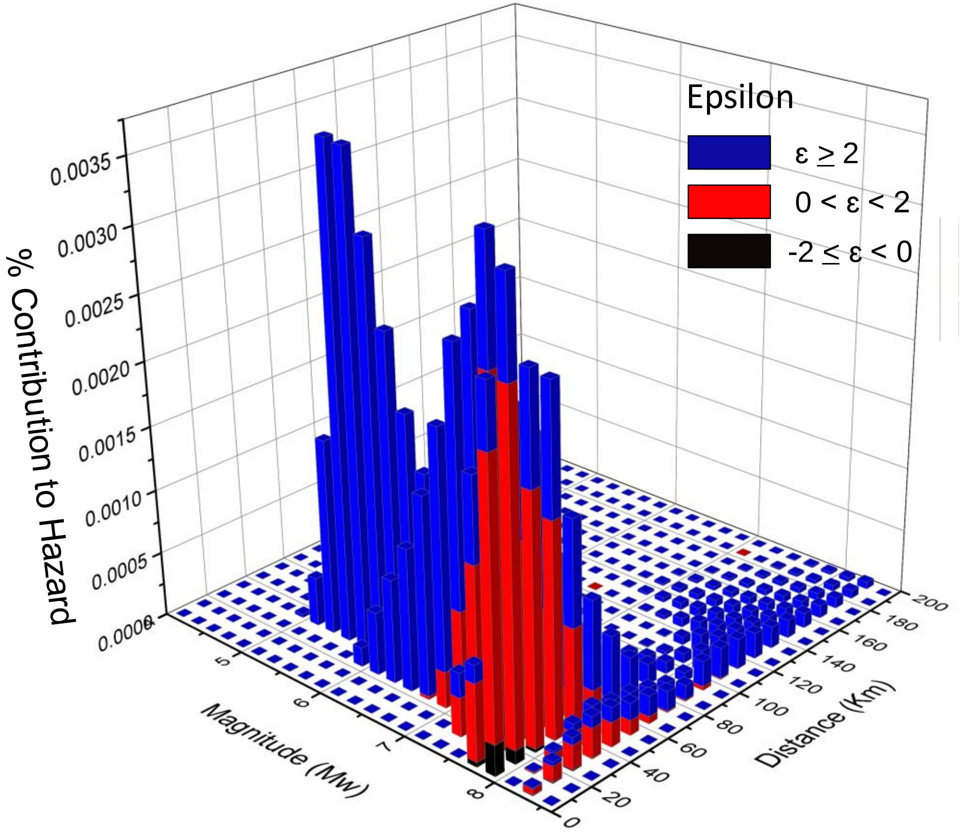
M: Magnitude
R Distance

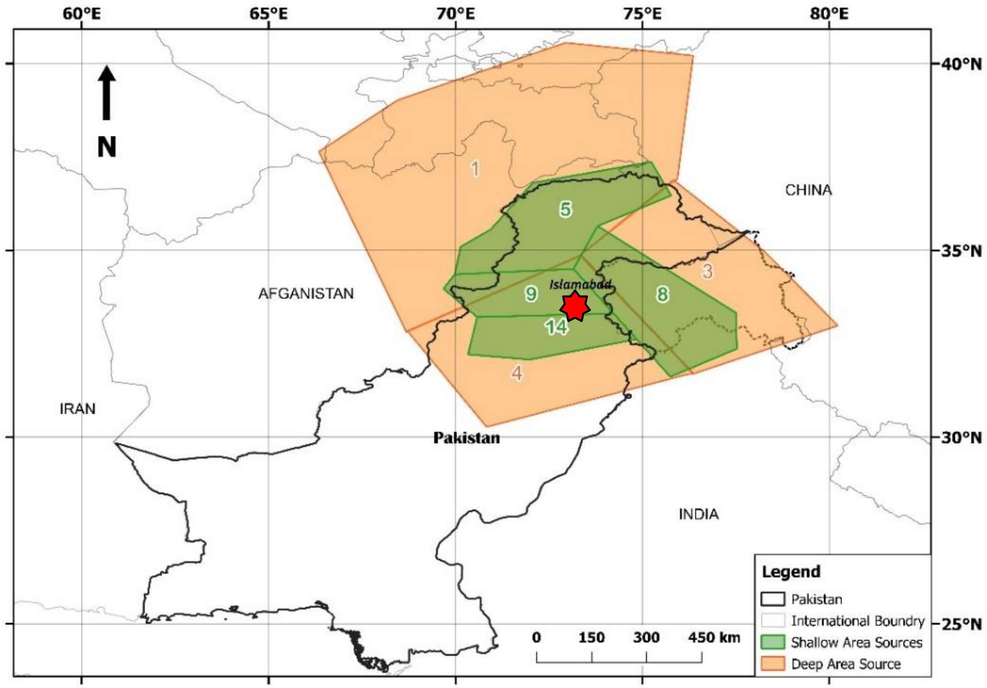
Seismic Hazard Deaggregation of PGA 10% PE in 50 years (Islamabad)

Islamabad 73.04º E, 33.87º N

- ❑ Mean (R,M,Ɛ) 78.2km, 7.2 Mw, 1.5

- ❑ PGA = 0.35 g Return Period 475 years
- ❑ Modal (R,M,Ɛ) 42km, 6.2 Mw, 2.0





Study 5:

Updated PSHA of Pakistan using both the conventional and Spatially Smoothed Background Seismicity and Crustal Faults Model

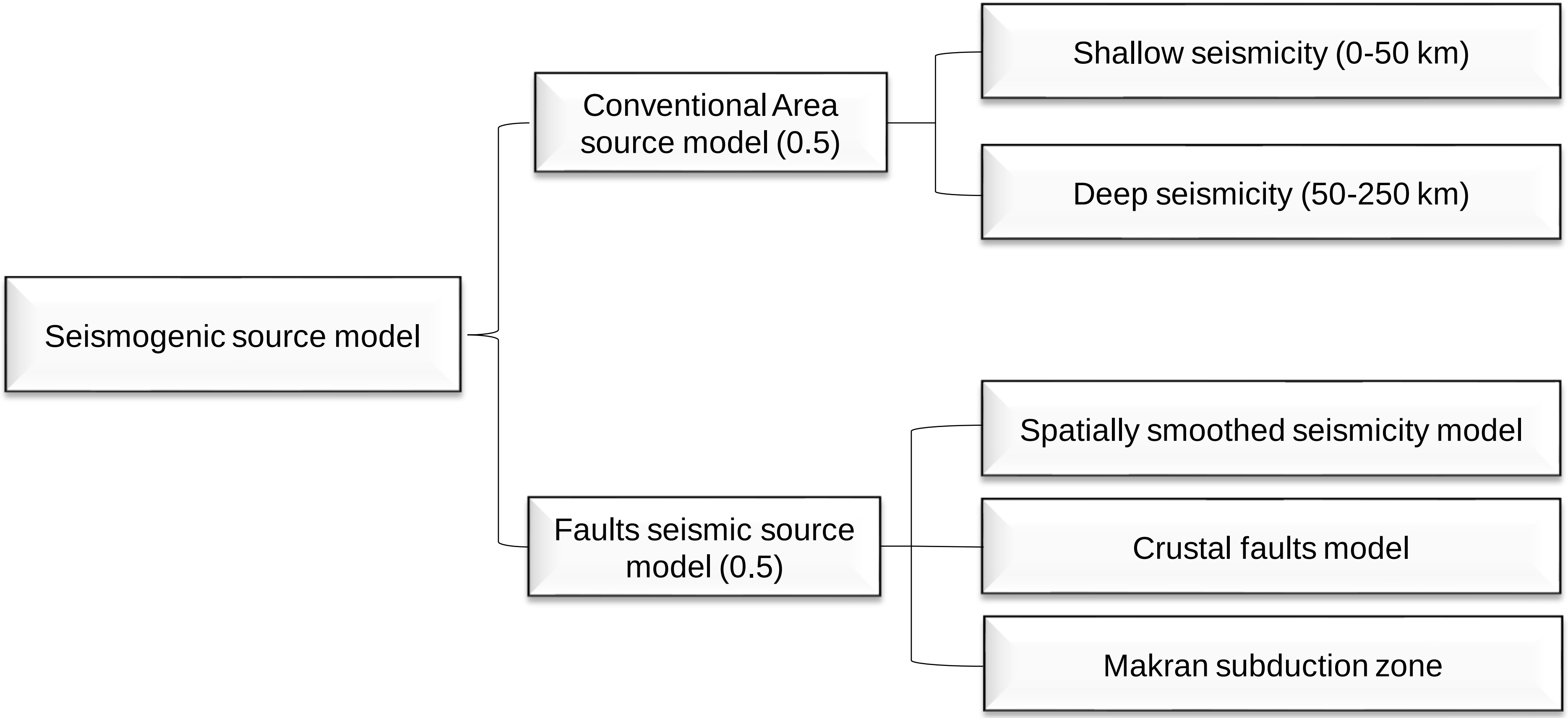
Asad ur Rehman

MS Structural Engineering (2017)

Summary of PSHA (Asad ur Rehman, Fawad Najam, Saeed Zaman, Atif Mehmood, Irfan Rana)

- Two following source modeling approaches are used and combined (50% weightage each) in a logic tree framework.
    - Standard Cornell–McGuire (1968–1976) approach
    - Spatially smoothed gridded seismicity with explicit modeling of crustal faults
- The computations are made over a rectangular grid of 0.1 degree. Software: OPEN QUAKE (Global Earthquake Model)
- The earthquake catalogue of Khan et al., (2018) is further improved as an attempt to develop a more complete catalogue.
- In standard Cornell–McGuire (1968–1976) approach, 23 shallow and 5 deep area sources are modeled using the Gutenberg–Richter recurrence law.
- In spatially smoothed gridded seismicity approach, the “a” values vary at each point while a constant “b” value is used for whole region. Besides, 110 active crustal faults are explicitly modeled in this approach with their slip rates obtained from Global Earthquake Model (GEM) active faults database. The characteristic and Gutenberg–Richter recurrence laws are used to model crustal faults (with a 50% weightage each in logic tree). The Makran Subduction is modeled as a complex sloping area source. Whereas the shallow (0-5 km) and deep in slab (55-250 km) seismicity is modeled as background seismicity.

Modeling of Seismic Sources



Seismogenic source model

Conventional Area source model (0.5)

Shallow seismicity (0-50 km)

Deep seismicity (50-250 km)

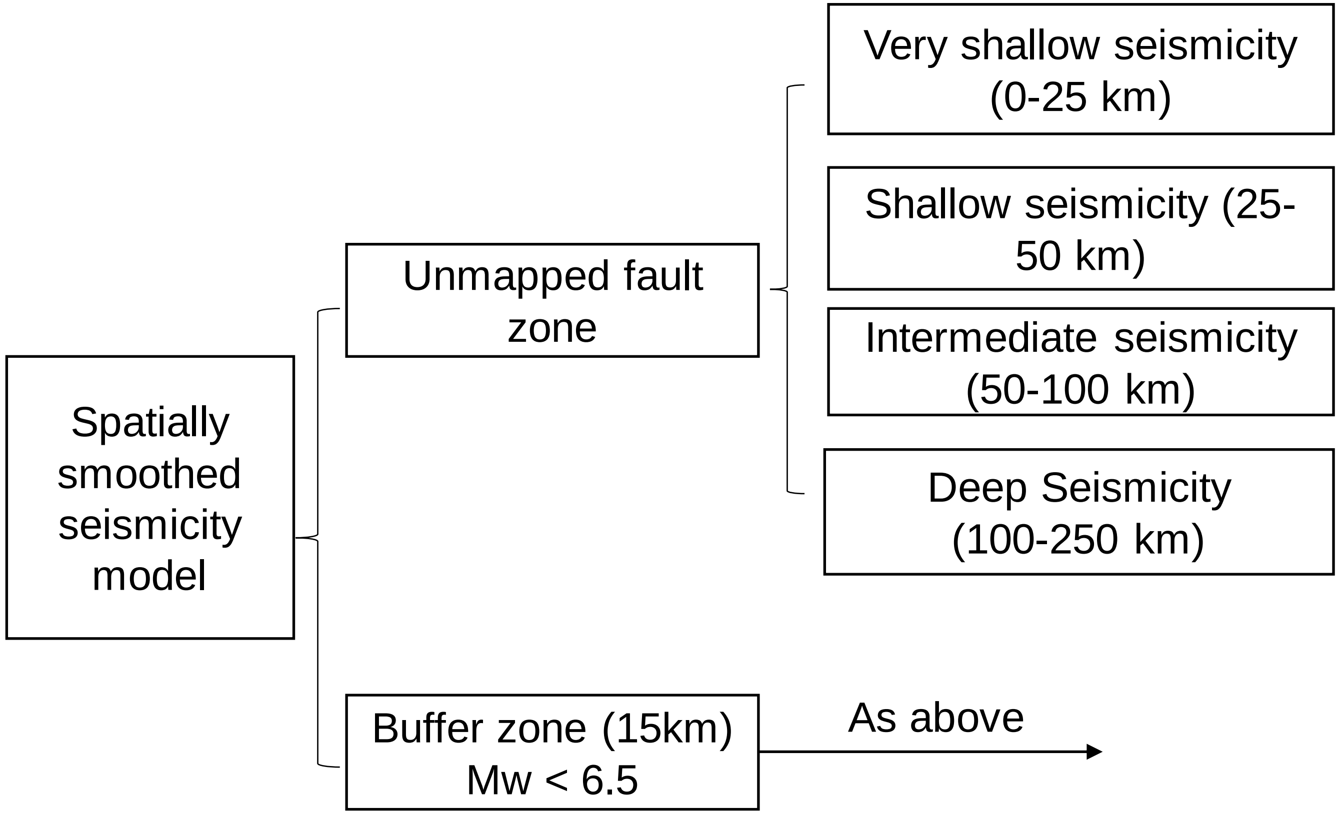
Faults seismic source model (0.5)

Spatially smoothed seismicity model

Crustal faults model

Makran subduction zone

Background Smoothed seismicity



Spatially smoothed seismicity model

Unmapped fault zone

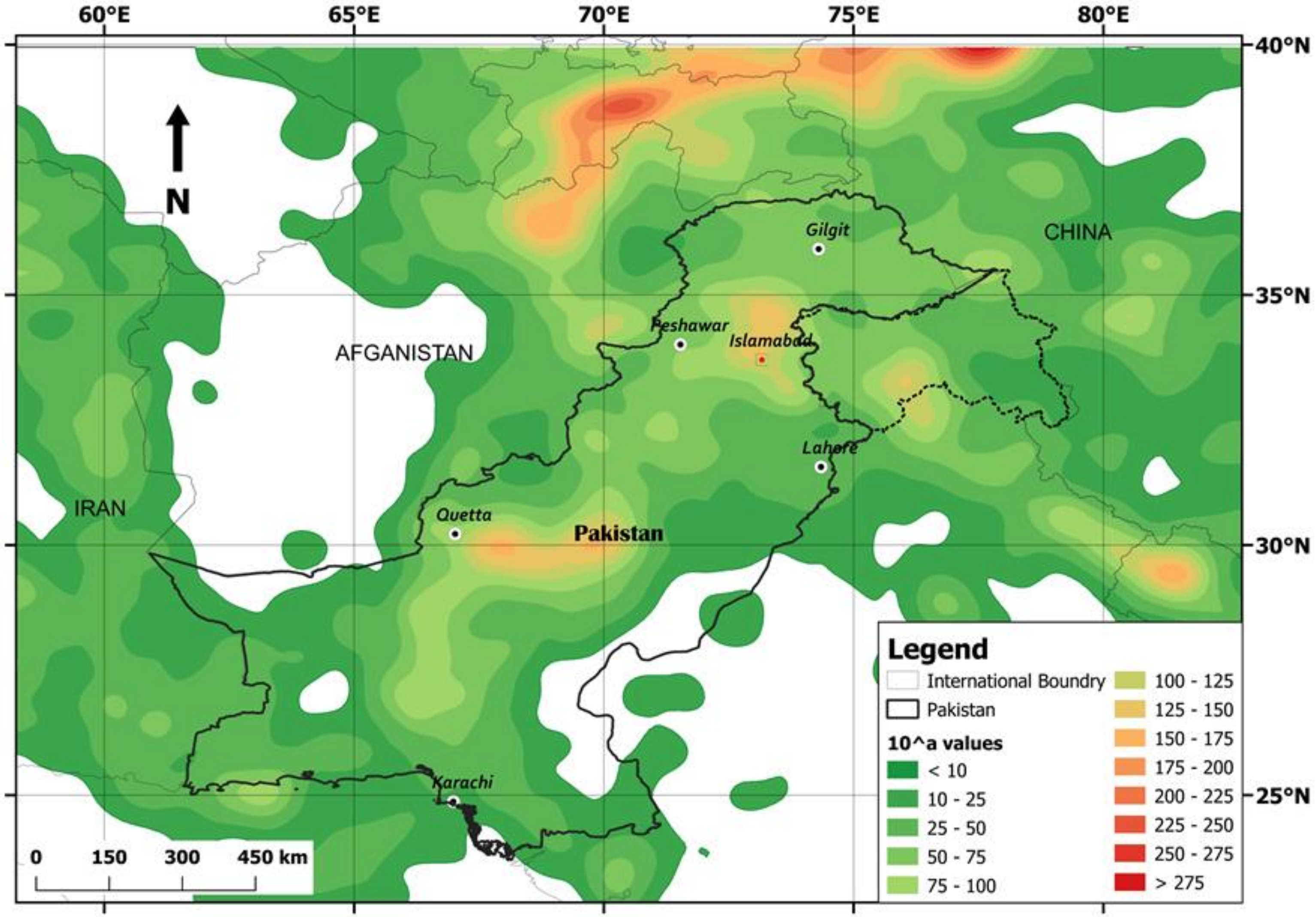
- Very shallow seismicity (0-25 km)
- Shallow seismicity (25-50 km)
- Intermediate seismicity (50-100 km)
- Deep Seismicity (100-250 km)

Buffer zone (15km) Mw < 6.5

As above

Background Smoothed seismicity

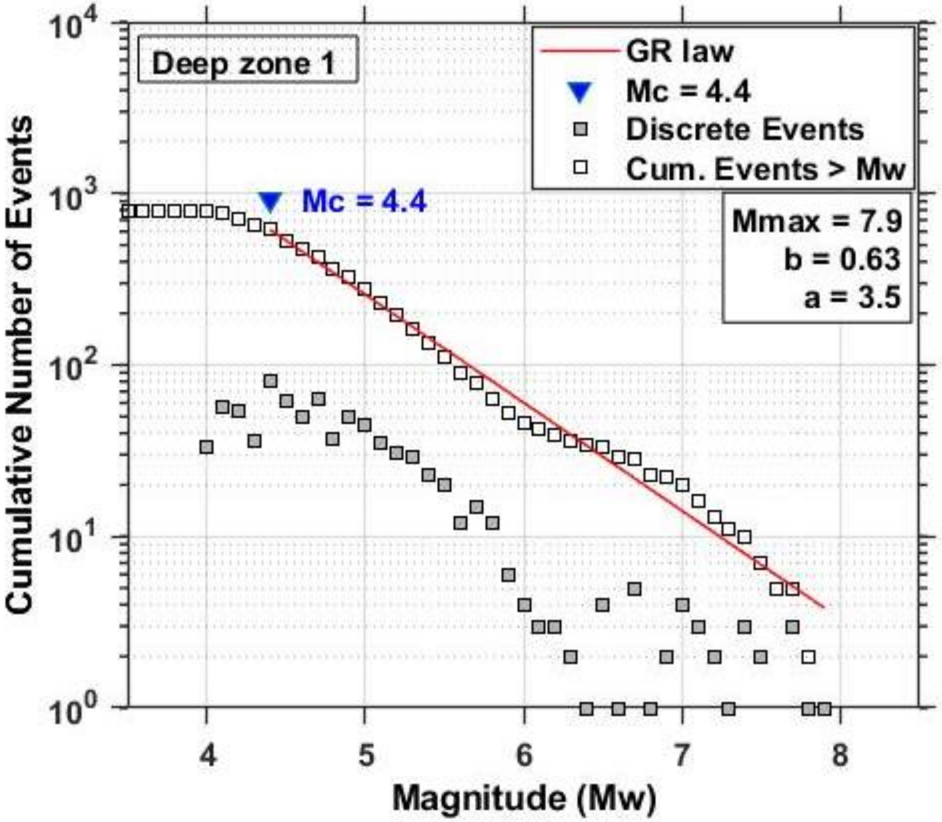
- Frankel (1995) spatially smoothening approach.
- Mw ≥ 4.0 used for Seismicity rate.
- Mmax=7.4
- The seismicity rate is spatially smoothed using a two-dimensional Gaussian moving operator with a correlation distance parameter c =50 km

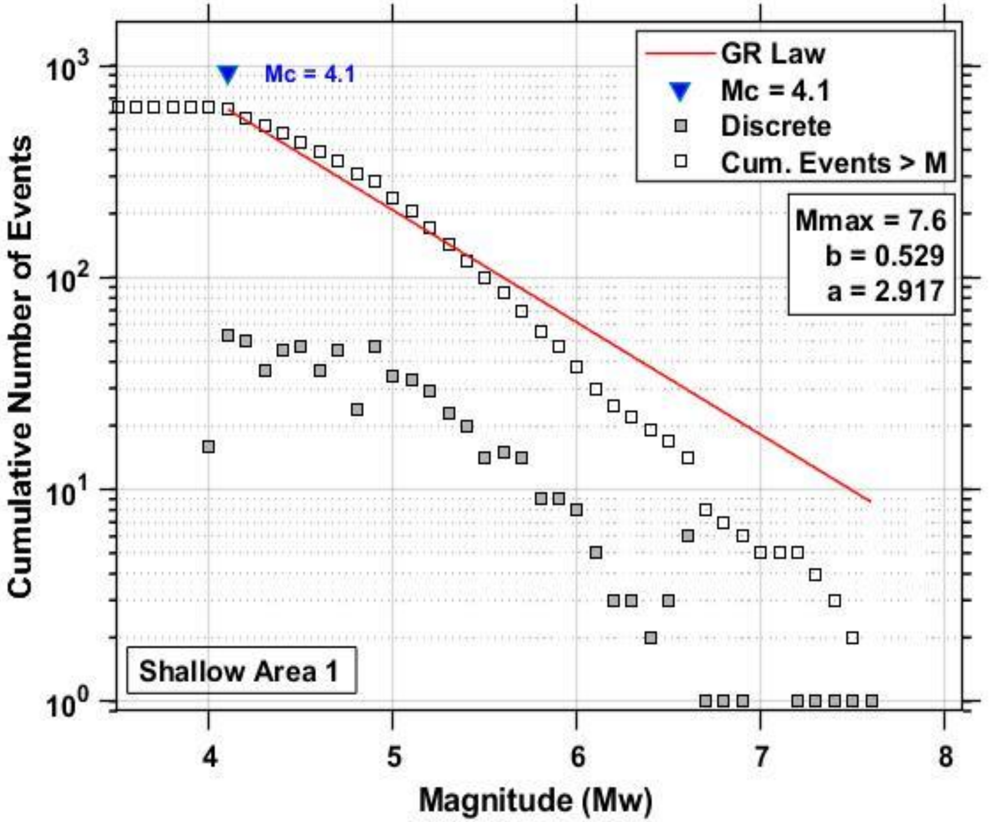


Recurrence Models and Seismicity Parameters

The Seismicity Parameters (Recurrence Rates) are calculated by Gutenberg-Richter Law (1974)

$$Log\,\lambda_M = a - b * M$$



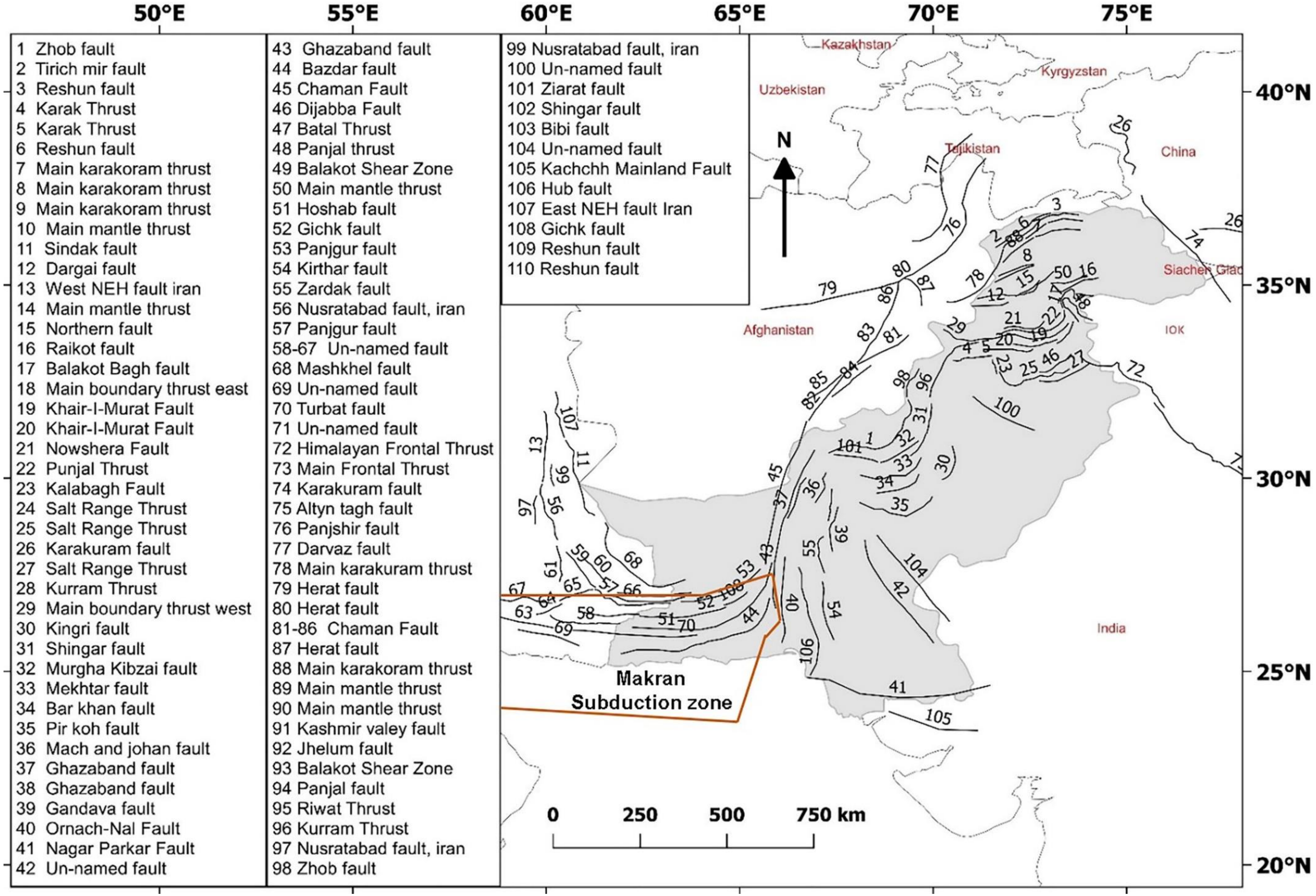


Active Faults

110 active crustal faults are used in this study

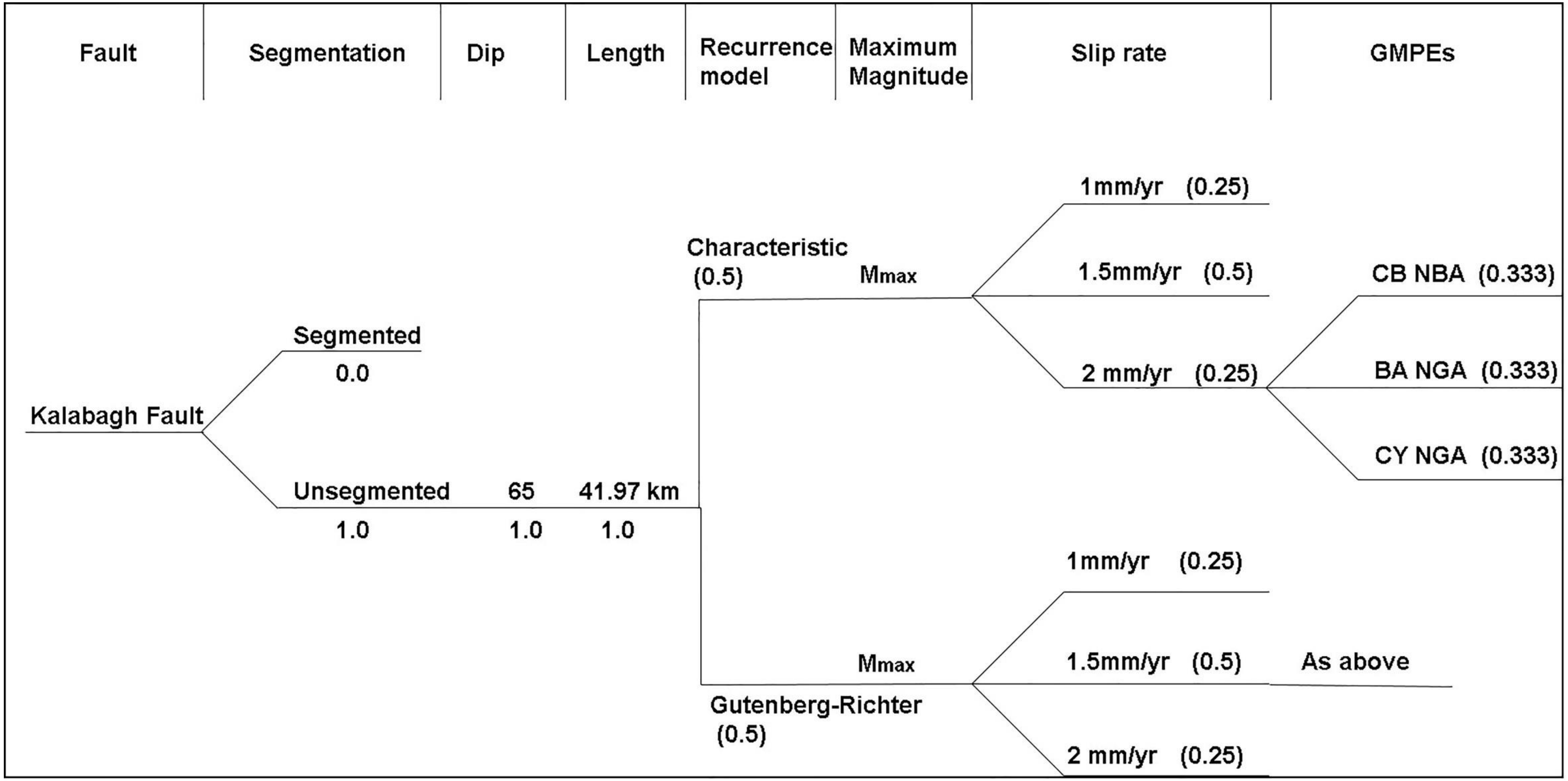
GEM active faults Database

Wells and Coppersmith (1994) empirical relationship is used to find the maximum magnitude

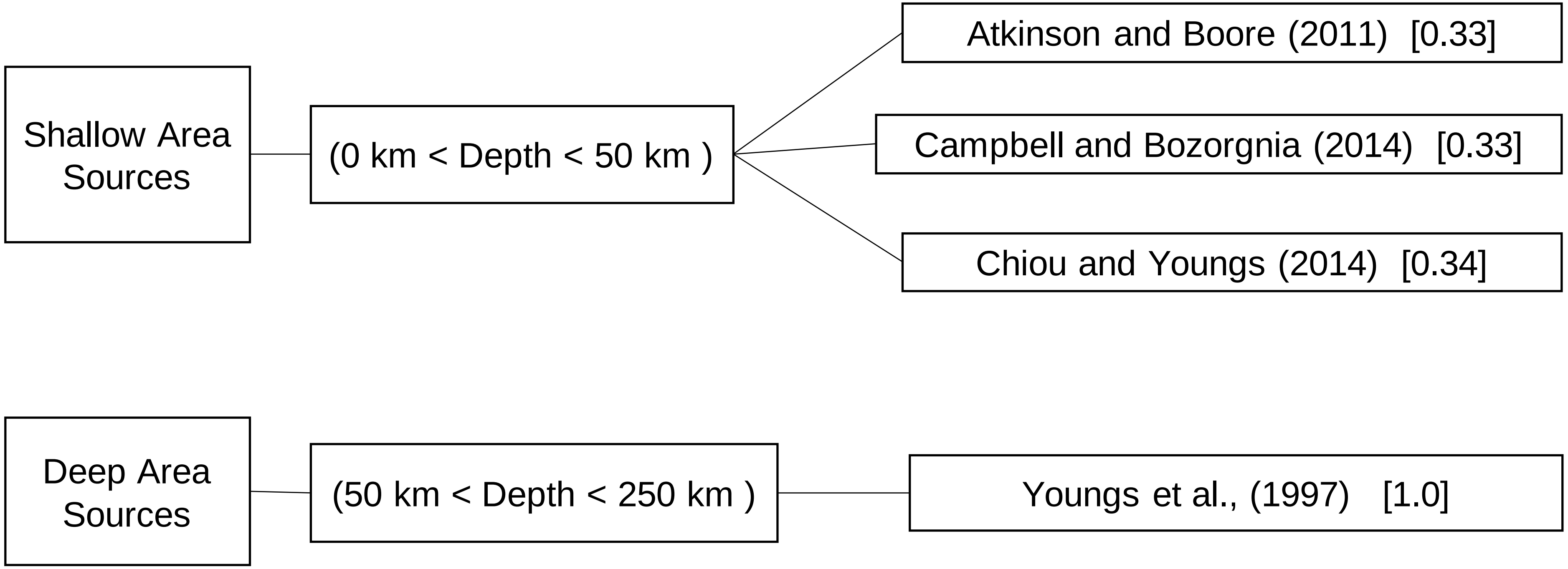


1 Zhob fault
2 Tirich mir fault
3 Reshun fault
4 Karak Thrust
5 Karak Thrust
6 Reshun fault
7 Main karakoram thrust
8 Main karakoram thrust
9 Main karakoram thrust
10 Main mantle thrust
11 Sindak fault
12 Dargai fault
13 West NEH fault iran
14 Main mantle thrust
15 Northern fault
16 Raikot fault
17 Balakot Bagh fault
18 Main boundary thrust east
19 Khair-I-Murat Fault
20 Khair-I-Murat Fault
21 Nowshera Fault
22 Punjal Thrust
23 Kalabagh Fault
24 Salt Range Thrust
25 Salt Range Thrust
26 Karakuram fault
27 Salt Range Thrust
28 Kurram Thrust
29 Main boundary thrust west
30 Kingri fault
31 Shingar fault
32 Murgha Kibzai fault
33 Mekhtar fault
34 Bar khan fault
35 Pir koh fault
36 Mach and johan fault
37 Ghazaband fault
38 Ghazaband fault
39 Gandava fault
40 Ornach-Nal Fault
41 Nagar Parkar Fault
42 Un-named fault
43 Ghazaband fault
44 Bazdar fault
45 Chaman Fault
46 Dijabba Fault
47 Batal Thrust
48 Panjal thrust
49 Balakot Shear Zone
50 Main mantle thrust
51 Hoshab fault
52 Gichk fault
53 Panjgur fault
54 Kirthar fault
55 Zardak fault
56 Nusratabad fault, iran
57 Panjgur fault
58-67 Un-named fault
68 Mashkhel fault
69 Un-named fault
70 Turbat fault
71 Un-named fault
72 Himalayan Frontal Thrust
73 Main Frontal Thrust
74 Karakuram fault
75 Altyn tagh fault
76 Panjshir fault
77 Darvaz fault
78 Main karakuram thrust
79 Herat fault
80 Herat fault
81-86 Chaman Fault
87 Herat fault
88 Main karakoram thrust
89 Main mantle thrust
90 Main mantle thrust
91 Kashmir valey fault
92 Jhelum fault
93 Balakot Shear Zone
94 Panjal fault
95 Riwat Thrust
96 Kurram Thrust
97 Nusratabad fault, iran
98 Zhob fault
99 Nusratabad fault, iran
100 Un-named fault
101 Ziarat fault
102 Shingar fault
103 Bibi fault
104 Un-named fault
105 Kachchh Mainland Fault
106 Hub fault
107 East NEH fault Iran
108 Gichk fault
109 Reshun fault
110 Reshun fault

Logic Tree for an Example Fault Source Model (Kalabagh Fault)



Ground Motion Prediction Equations (GMPEs)



Shallow Area Sources

(0 km < Depth < 50 km)

Atkinson and Boore (2011) [0.33]

Campbell and Bozorgnia (2014) [0.33]

Chiou and Youngs (2014) [0.34]

Deep Area Sources

(50 km < Depth < 250 km)

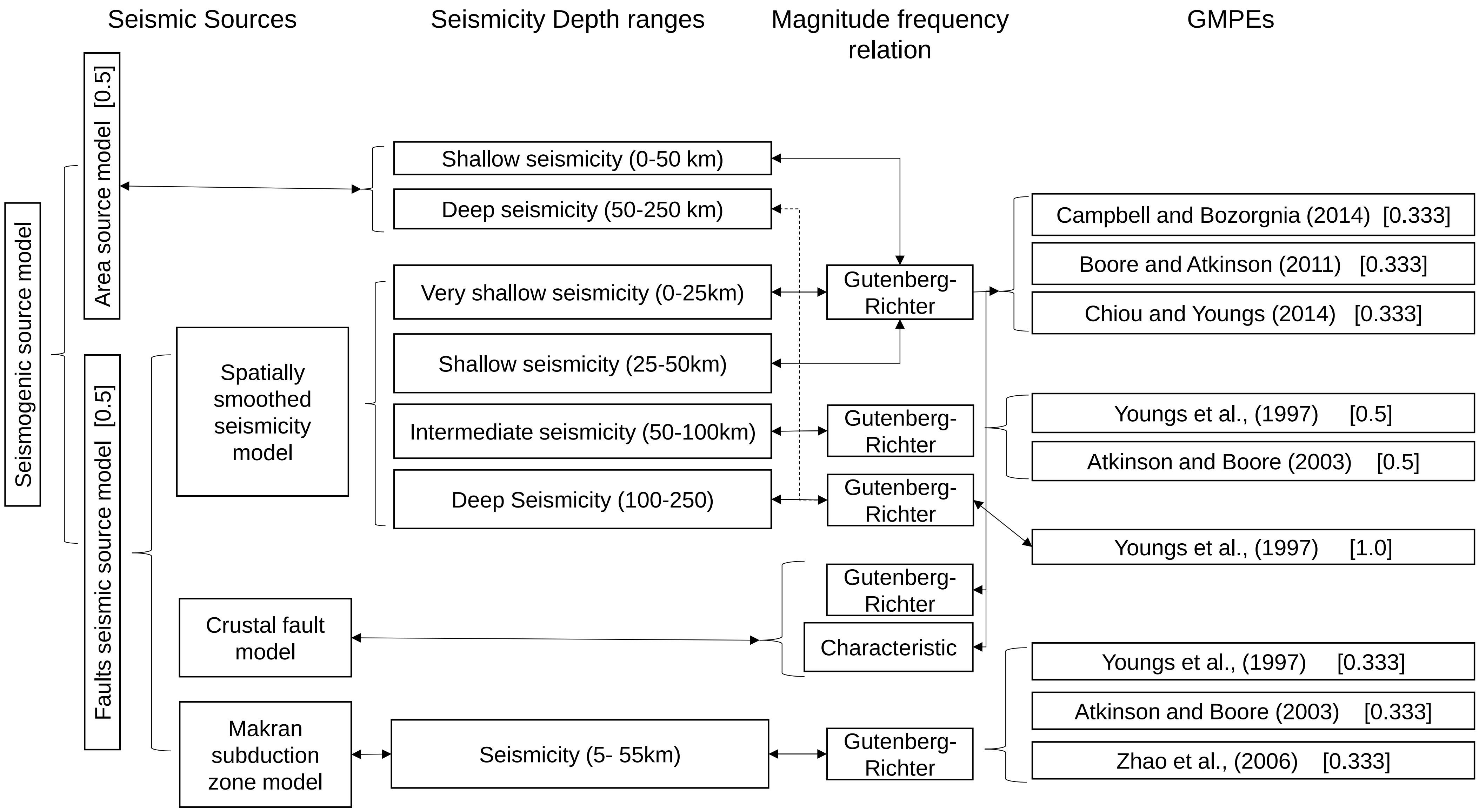
Youngs et al., (1997) [1.0]

Waseem et.al, Natural Hazards (2018)

Zaman, PhD Thesis (2016)

Nath et.al, Seismological Research Letters (2018)

Logic tree of the seismic source model and GMPEs



Seismic Sources

Seismicity Depth ranges

Magnitude frequency relation

GMPEs

Seismogenic source model

Area source model [0.5]

Shallow seismicity (0-50 km)

Deep seismicity (50-250 km)

Faults seismic source model [0.5]

Spatially smoothed seismicity model

Very shallow seismicity (0-25km)

Shallow seismicity (25-50km)

Intermediate seismicity (50-100km)

Deep Seismicity (100-250)

Crustal fault model

Makran subduction zone model

Seismicity (5- 55km)

Gutenberg-Richter

Gutenberg-Richter

Gutenberg-Richter

Gutenberg-Richter

Characteristic

Gutenberg-Richter

Campbell and Bozorgnia (2014) [0.333]

Boore and Atkinson (2011) [0.333]

Chiou and Youngs (2014) [0.333]

Youngs et al., (1997) [0.5]

Atkinson and Boore (2003) [0.5]

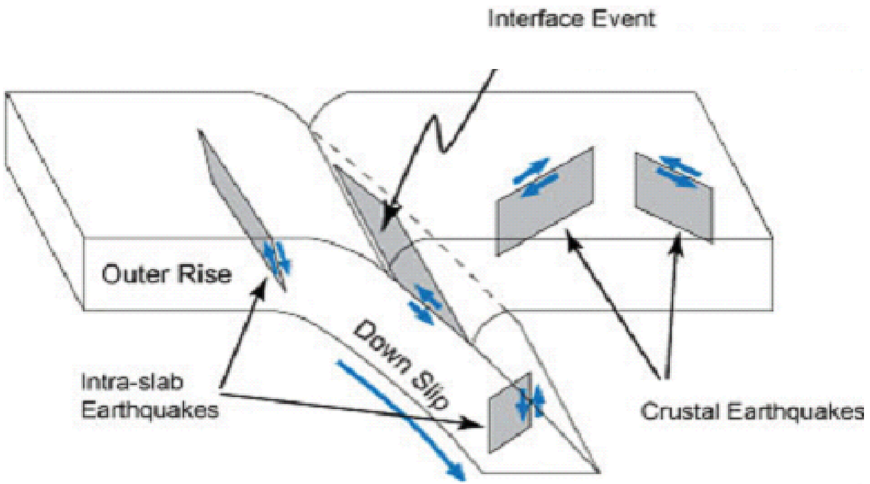
Youngs et al., (1997) [1.0]

Youngs et al., (1997) [0.333]

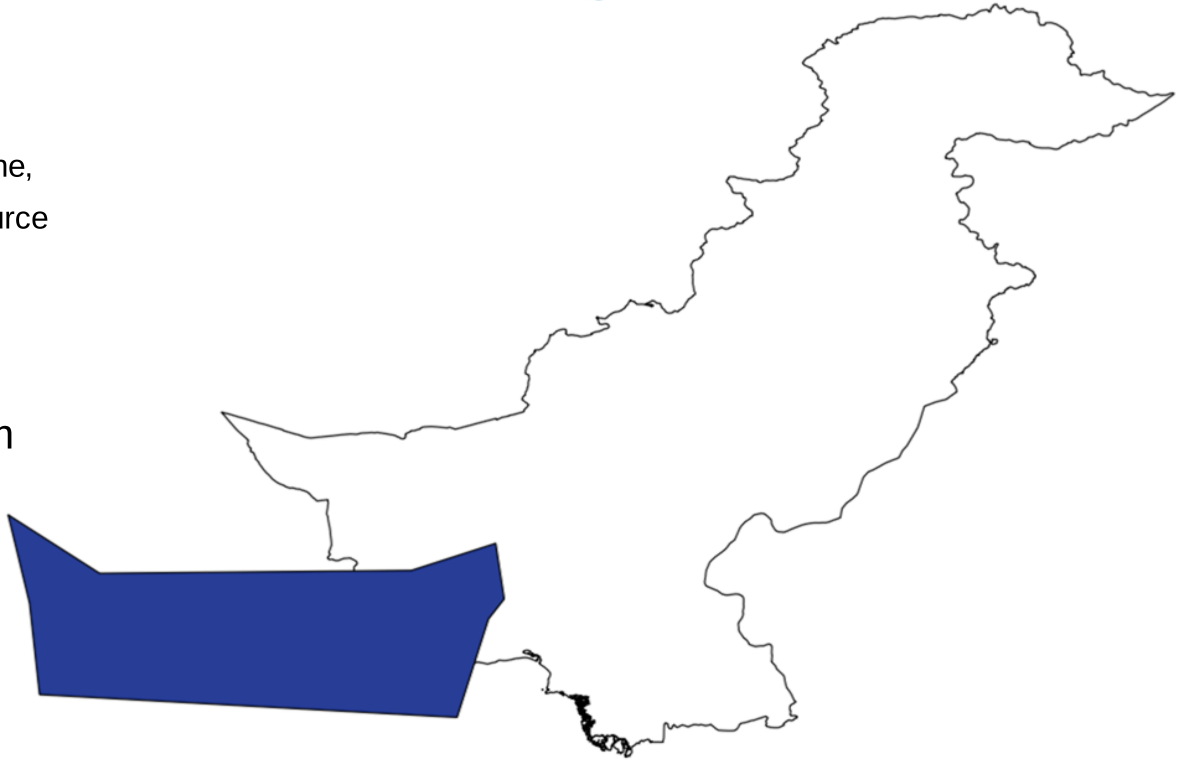
Atkinson and Boore (2003) [0.333]

Zhao et al., (2006) [0.333]

Modeling of Makran Subduction Zone



- The events in the subduction zone are divided into very shallow (0-5km), shallow (5-55km), intermediate (55-100km) and deep (100-250km).
- The activity is modeled using three types of seismogenic source models.
  - The faults and folds appearing on the upper surface of the subduction zone,
  - The shallow seismicity (5-55km) is modeled as complex inclined area source zone
  - The very shallow, intermediate and deep earthquakes are modeled as spatially smoothed seismicity.
- The earthquakes having a depth ranging from 5 km to 55 km are assumed to have occurred on the interface of plates.
- The 1945 earthquake of M_w 8.2 = M_{max}
- The Gutenberg-Richter magnitude recurrence model .



Comparison of the current study with the past PSHA studies

Study	**GSHAP (Zhang et al. 1999)**	**PMD and NORSAR**	**NESPAK**	**Zaman et al. (2012)**	**EMME (2014)**	**Current study**
Year	1992-1999	2007	2007	2012	2014	2019
Methodology	PSHA (Cornell 1968; McGuire 1976) approach using FRISK88M Software.	PSHA (Cornell 1968; McGuire 1976) approach using FRISK88M Software.	PSHA (Cornell 1968; McGuire 1976) approach using FRISK88M Software.	National Seismic Hazard Maps (NSHM) using USGS Software for PSHA.	Both (Cornell 1968; McGuire 1976) and NSHM methods with 60% and 40% probabilistic weights.	Both (Cornell 1968; McGuire 1976) and NSHM methods with 50% probabilistic weights assigned to each.
Source models characterization	More than 20 seismic area sources with uniform seismicity.	19 seismic area sources with uniform seismicity.	17 seismic area sources with uniform seismicity	Background spatially smoothed-gridded seismicity.	More than 18 seismic area sources with background spatially smoothed-gridded seismicity in two different source models.	23 seismic area sources with background spatially smoothed-gridded seismicity in two different source models.
Active crustal faults	Nil	Nil	28 active crustal faults modeled using characteristic fault model. Slip rate is not used to estimate the earthquake recurrence rate.	13 active crustal faults modeled, using both the characteristic and Gutenberg-Richter (GR) models with equal weightage to estimate the earthquake recurrence rate.	More than 100 active faults are modeled, using GR model by (Anderson and Luco 1983) to estimate the earthquake recurrence rate.	110 active crustal faults modeled using the GEM (2019) active faults catalogue. Both the characteristic and GR models by (Youngs and Coppersmith 1985) with equal probabilistic weightage are used to estimate the earthquake recurrence rate.

Study	GSHAP (Zhang et al. 1999)	PMD and NORSAR	NESPAK	Zaman et al. (2012)	EMME (2014)	Current study
Makran Subduction zone	Modeled as simple area source	Modeled as simple area source	Modeled as simple area source	The interface between two tectonic plates is modeled as sloping area source.	The inter slab seismicity (0-50 km) is modeled as complex inclined area source, whereas the in slab seismicity (50-150 km) is modeled as simple area source.	The seismicity associated to the interface between two tectonic plates (5-55 km) is modeled as a complex sloping area source. Whereas the shallow (0-5 km) and deep in slab (55-250 km) seismicity is modeled as background seismicity.
Earthquake catalogue	Pre-historic (before 1900) and historic (1900-1997) earthquake catalogue with $M_w > 5$.	102 years (1905-2007) earthquake catalogue with $M_w > 4.8$.	102 years (1904-2006) earthquake catalogue with $M_w > 4.5$.	107 years (1902-2009) earthquake catalogue with $M_w > 4.5$.	Pre-historic (before 1900) and historic (1900-2006) earthquake catalogue with $M_w > 4$.	Pre-historic (before 1900) and historic (1900- 2018) earthquake catalogue with $M_w > 4$.
Classification of Earthquake depth	Nil	Classify the seismicity of Hindukush region into shallow, intermediate and deep layers (0-30 km, 30-120 km and 120-300 km)	Nil	Classify the background seismicity into very shallow, shallow, intermediate and deep layer (0-25 km, 25-50 km, 50-100 km and 100-250 km) throughout the study area.	Classify the background seismicity into shallow, in slab and deep layer (0-40 km, 40-100 km and >100 km). Deep seismicity is considered only in Hindukush region. The in slab seismicity in subduction zone, whereas the remaining background seismicity is modeled using only shallow seismicity.	Classify the background seismicity into very shallow, shallow, intermediate and deep layer (0-25 km, 25-50 km, 50-100 km and 100- 250 km) for faults seismic source model, whereas for Area source model the BG seismicity is divided into shallow (0-50 km) and deep (50- 250) layers throughout the study area.

Study	GSHAP (Zhang et al. 1999)	PMD and NORSAR	NESPAK	Zaman et al. (2012)	EMME (2014)	Current study
GMPEs	Only single GMPE of (Huo and Hu 1992) was used for ground motion estimation. No multiple GMPEs were used to account for the epistemic uncertainty.	GMPE of (Ambraseys et al. 2005) was used. No multiple GMPEs were not used to account for the epistemic uncertainity.	GMPE of (Boore et al. 1997) was used. No multiple GMPEs were not used to account for the epistemic uncertainity.	Multiple GMPEs for different earthquake environments were used. For crustal faults, very shallow and shallow: three NGA west 1 GMPEs CB08(0.33), BA08(0.33), CY08(0.33) Intermediate: Y97(0.5), AB03(0.5) Deep: Y97(1.0) Subduction zone: Y97(0.25), AB03(0.25), Z06(0.5)	Multiple GMPEs for different earthquake environments were used. Active shallow crustal region: AK14(0.35), CY08(0.35), AC10(0.2), Z06(0.1) Stable shallow crustal region: AB06(0.4), C03(0.25), T97(0.35) Deep Seismicity: Y97(0.5), LL08(0.5) Subduction zone: Z06(0.4), Y97(0.2), AB03(0.2), LL08(0.2)	Multiple GMPEs for different earthquake environments were used. For crustal faults, very shallow and shallow: three NGA west 2 GMPEs CB14(0.33), BA11(0.33), CY14(0.33) Intermediate: Y97(0.5), AB03(0.5) Deep: Y97(1.0) Subduction zone: Y97(0.25), AB03(0.25), Z06(0.5)
Results	PGA map for 10% PE in 50 years (475 years return period).	PGA and SA (0.2, 0.5, 1.0 and 2.0s) values for return periods of 50, 100, 200, 500 and 1000 years. Hazard curves and UHSs for major cities were developed.	PGA map for 475 years return period. PGA values for major cities are also given.	Arithmetic mean PGA and SA (0.2, 1.0s and 2.0s) maps for return period of 475 and 2475 years. Hazard curves were developed for major cities of Pakistan.	Hazard results are reported in mean 5, 16, 50, 84 and 95% quartile ground motions. The PGA and SA (0.1, 0.15, 0.2, 0.25, 0.30, 0.50, 0.75, 1.0 and 2 s) maps are developed for return periods of 72, 475, 975, 2475 and 4975 years.	Hazard results are presented in mean ground motion. The PGA and SA (0.2, 1.0s and 2.0s) maps are developed for return period of 475 and 2475 years. Hazard curves and UHSs were developed for five major cities of Pakistan.

Probabilistic seismic Hazard Assessment

The OpenQuake hazard analysis platform is used.

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xmlns:gml="http://www.opengis.net/gml"
>
    <sourceModel
    name="Pakistan Source Model Containing Area Source"
    >
        <sourceGroup
        name="group 1"
        tectonicRegion="Shallow Seismicity"
        >
            <areaSource
            id="1"
            name="Area Source"
            tectonicRegion="Shallow Seismicity"
            >
                <areaGeometry>
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                        <gml:exterior>
                            <gml:LinearRing>
                                <gml:posList>
                                    75.45210891 40.21414551         76.00755968 38.81471679
                                    74.72584174 38.22364231         69.17468761 37.72395839
                                    69.69383313 39.62784177         69.69383313 39.62784177
                                    75.45210891 40.21414551         75.45210891 40.21414551
                                </gml:posList>
                            </gml:LinearRing>
                        </gml:exterior>
                    </gml:Polygon>
                    <upperSeismoDepth>
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                    </upperSeismoDepth>
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                        5.0000000E+01
                    </lowerSeismoDepth>
                </areaGeometry>
                <magScaleRel>
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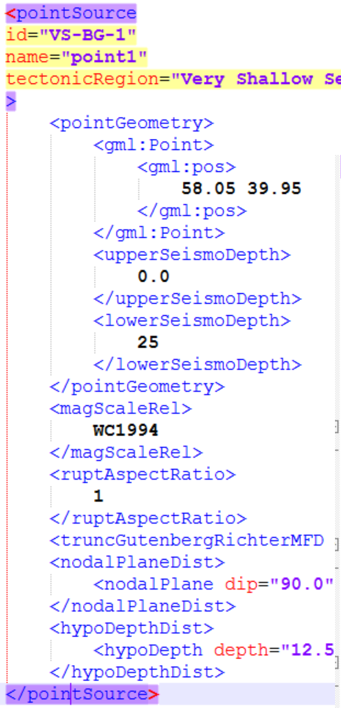
Python code developed for automation of Point sources modeling



```xml
<pointSource
id="VS-BG-1"
name="point1"
tectonicRegion="Very Shallow Seismicity"
>
    <pointGeometry>
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            <gml:pos>
                58.05 39.95
            </gml:pos>
        </gml:Point>
        <upperSeismoDepth>
            0.0
        </upperSeismoDepth>
        <lowerSeismoDepth>
            25
        </lowerSeismoDepth>
    </pointGeometry>
    <magScaleRel>
        WC1994
    </magScaleRel>
    <ruptAspectRatio>
        1
    </ruptAspectRatio>
    <truncGutenbergRichterMFD
    <nodalPlaneDist>
        <nodalPlane dip="90.0"
    </nodalPlaneDist>
    <hypoDepthDist>
        <hypoDepth depth="12.5
    </hypoDepthDist>
</pointSource>
```
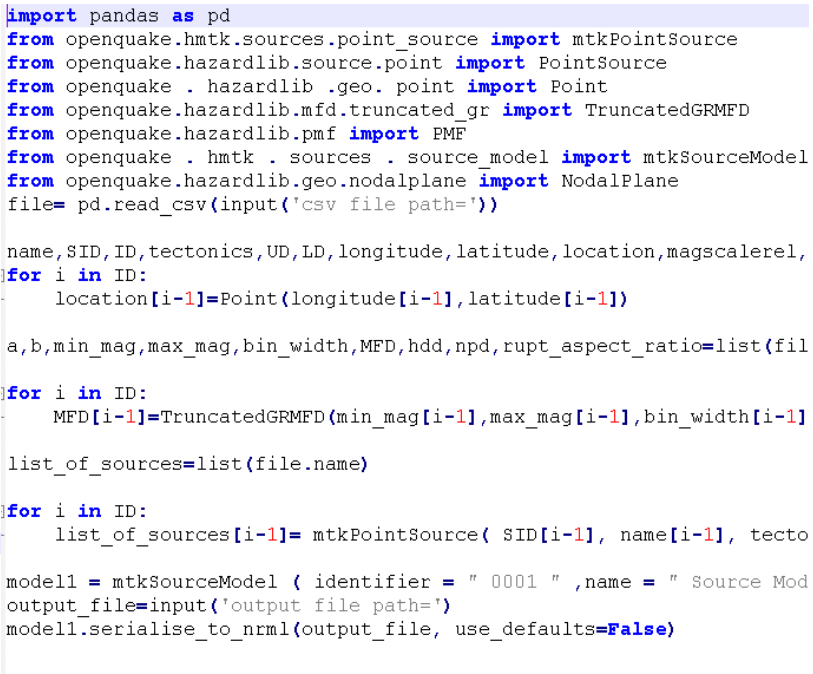
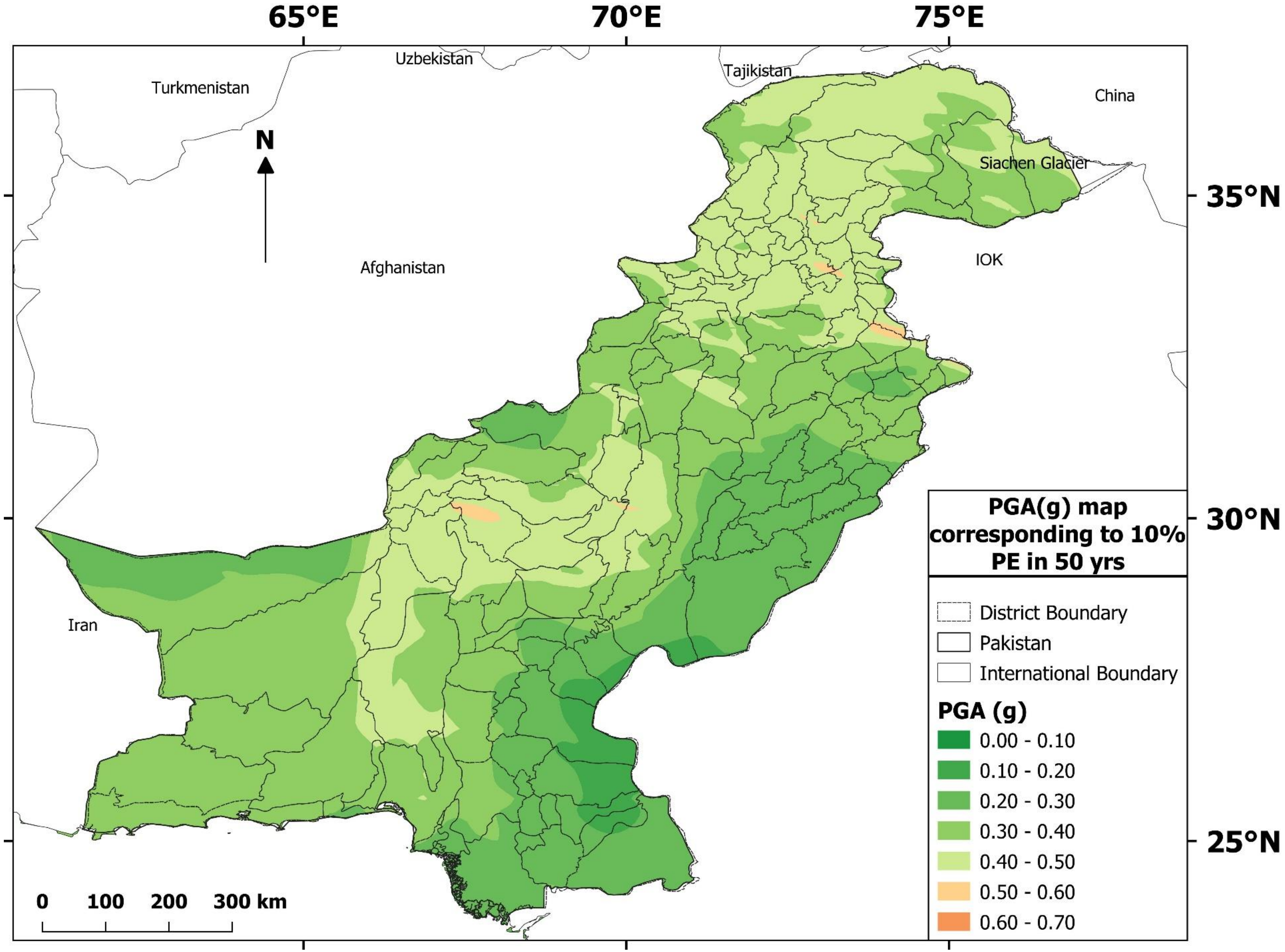



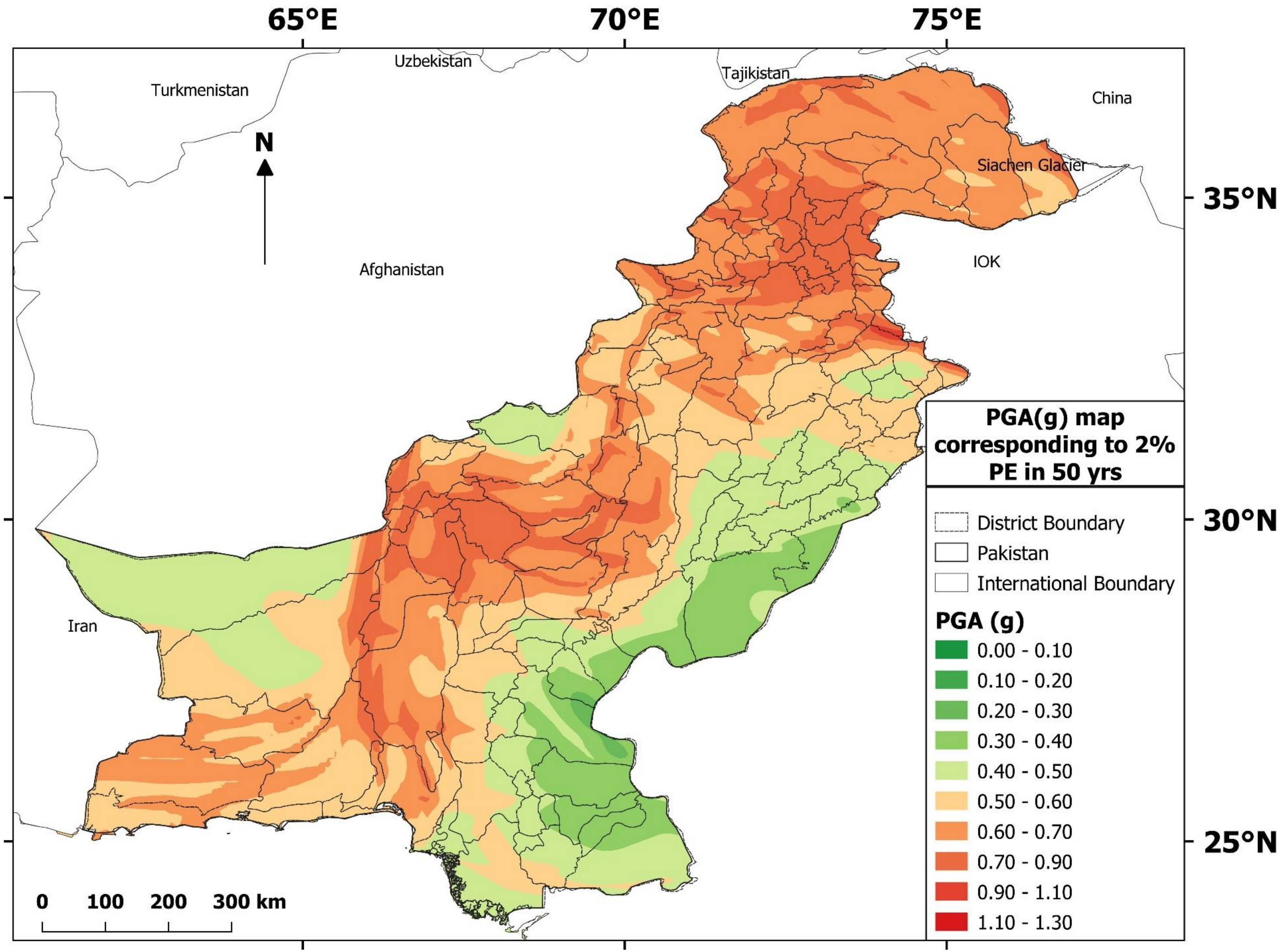
```python
import pandas as pd
from openquake.hmtk.sources.point_source import mtkPointSource
from openquake.hazardlib.source.point import PointSource
from openquake . hazardlib .geo. point import Point
from openquake.hazardlib.mfd.truncated_gr import TruncatedGRMFD
from openquake.hazardlib.pmf import PMF
from openquake . hmtk . sources . source_model import mtkSourceModel
from openquake.hazardlib.geo.nodalplane import NodalPlane
file= pd.read_csv(input('csv file path='))

name,SID,ID,tectonics,UD,LD,longitude,latitude,location,magscalerel,
for i in ID:
    location[i-1]=Point(longitude[i-1],latitude[i-1])

a,b,min_mag,max_mag,bin_width,MFD,hdd,npd,rupt_aspect_ratio=list(fil

for i in ID:
    MFD[i-1]=TruncatedGRMFD(min_mag[i-1],max_mag[i-1],bin_width[i-1]

list_of_sources=list(file.name)

for i in ID:
    list_of_sources[i-1]= mtkPointSource( SID[i-1], name[i-1], tecto

model1 = mtkSourceModel ( identifier = " 0001 " ,name = " Source Mod
output_file=input('output file path=')
model1.serialise_to_nrml(output_file, use_defaults=False)
```

Peak Ground Acceleration (PGA) map for 475 years RP (10% PE in 50 years)

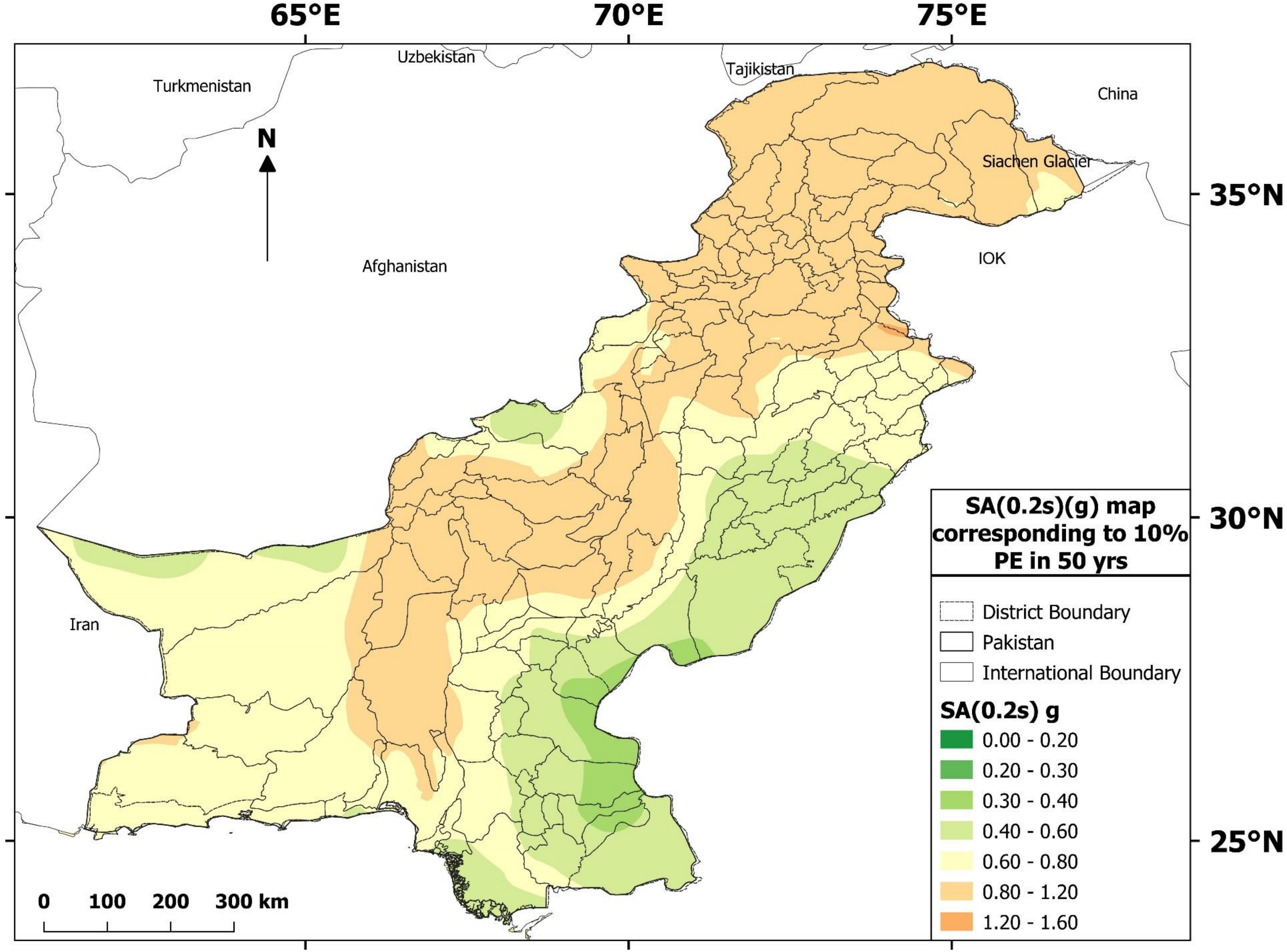


Peak Ground Acceleration (PGA) map for 2475 years RP (2% PE in 50 years)

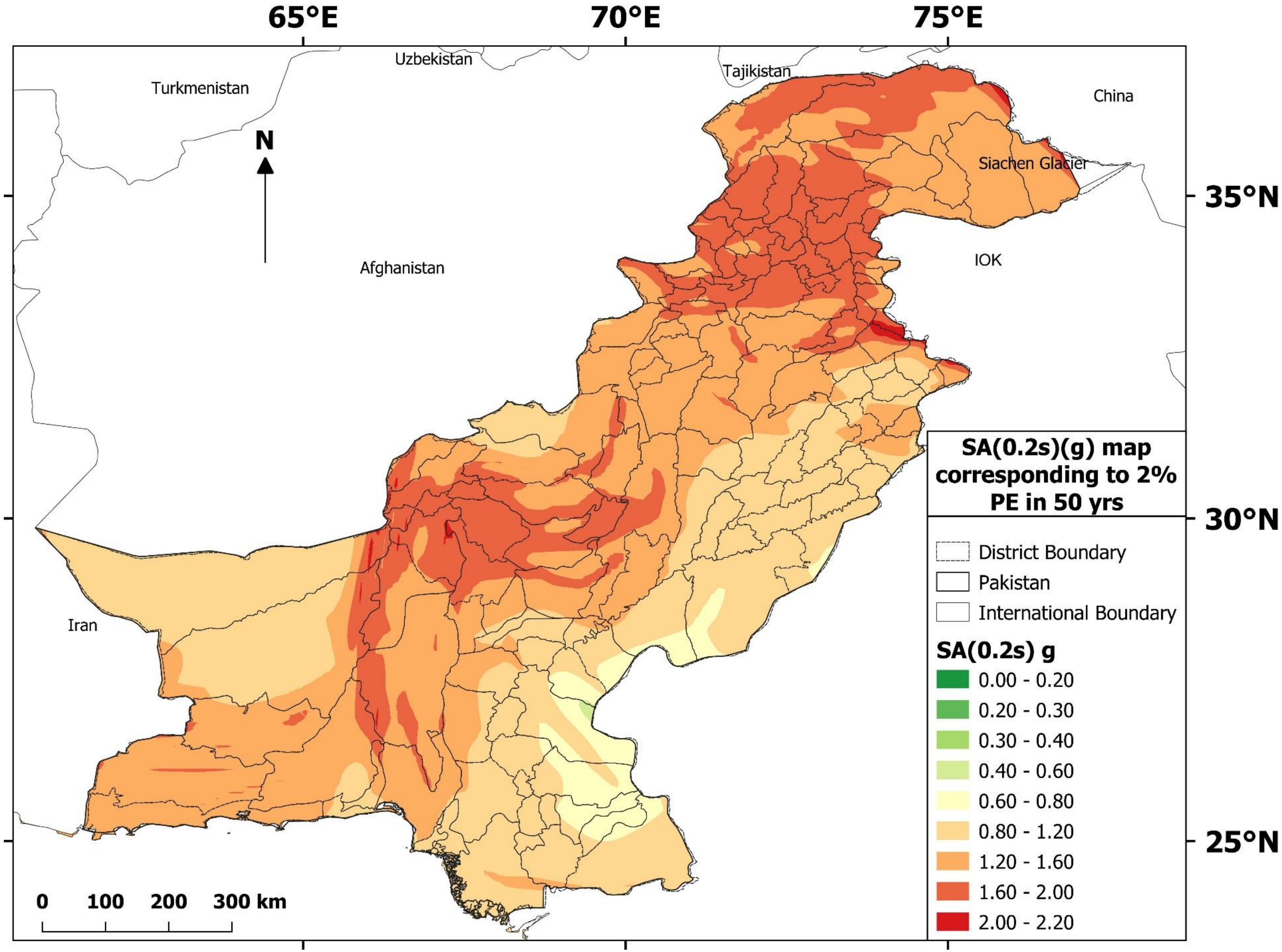
Source: Rahman et al. (2021)



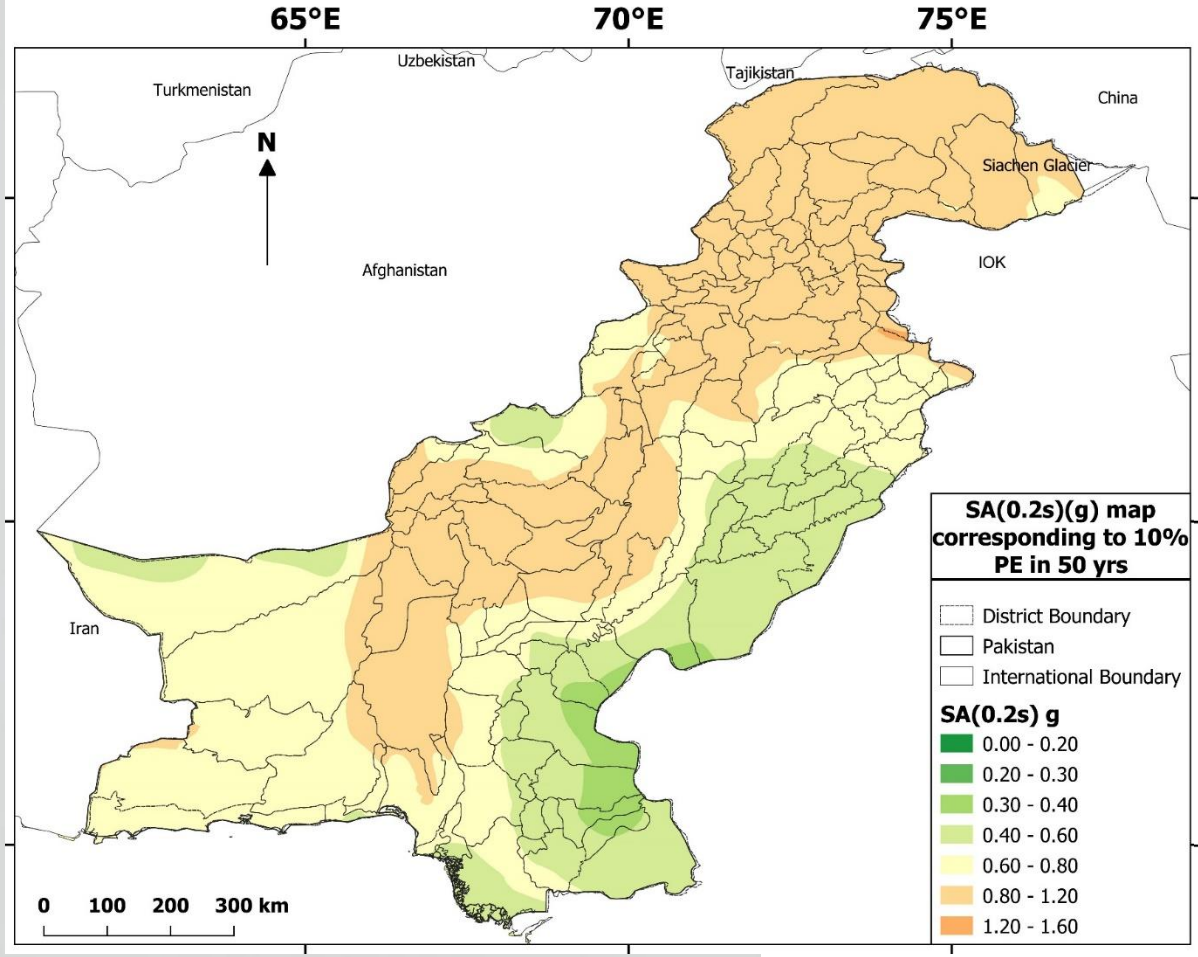
Spectral Acceleration (SA) at 0.2 sec. map for 475 years RP (10% PE in 50 years)



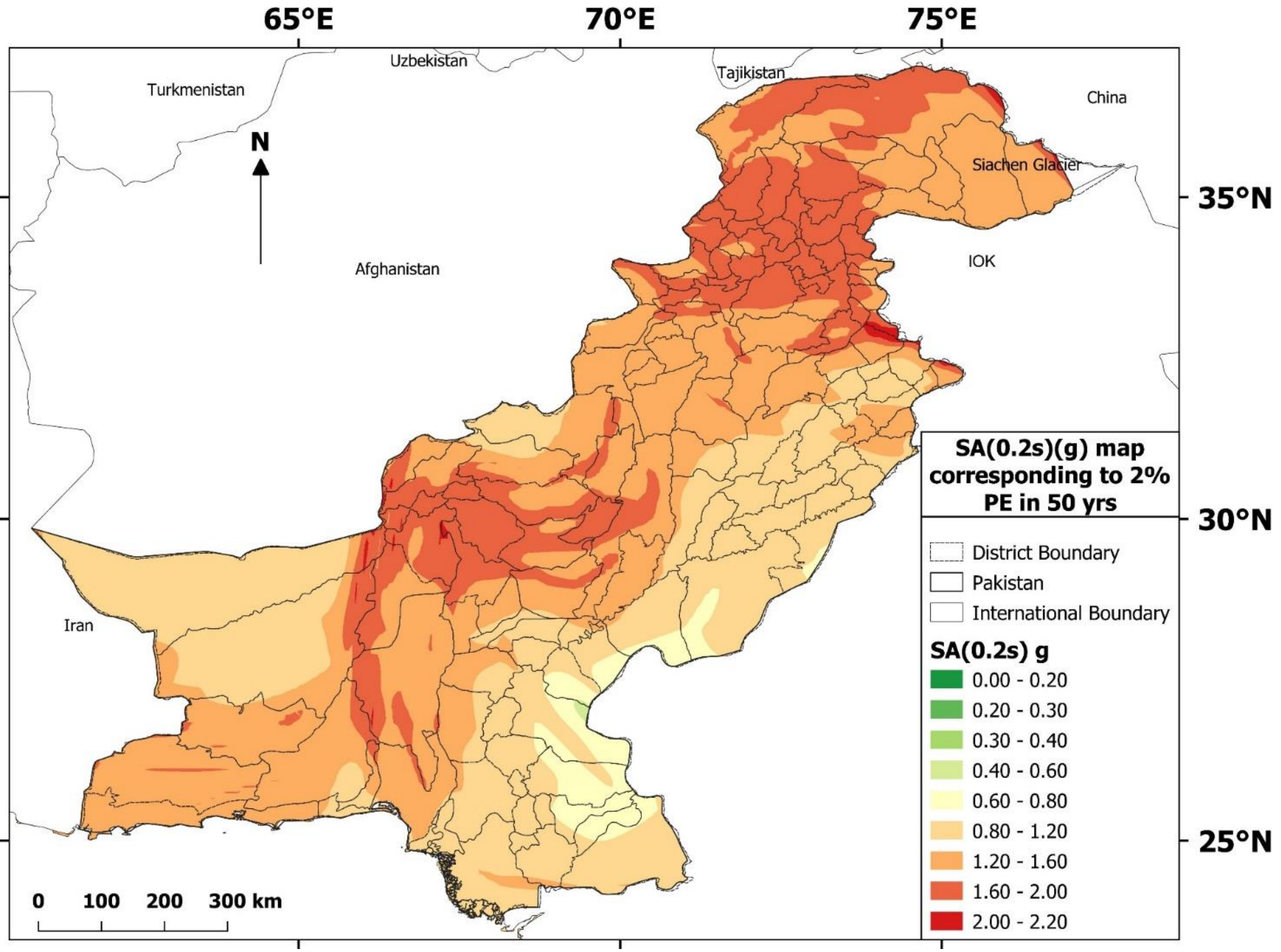
Spectral Acceleration (SA) at 0.2 sec. map for 2475 years RP (2% PE in 50 years)



Source: Rahman et al. (2021)

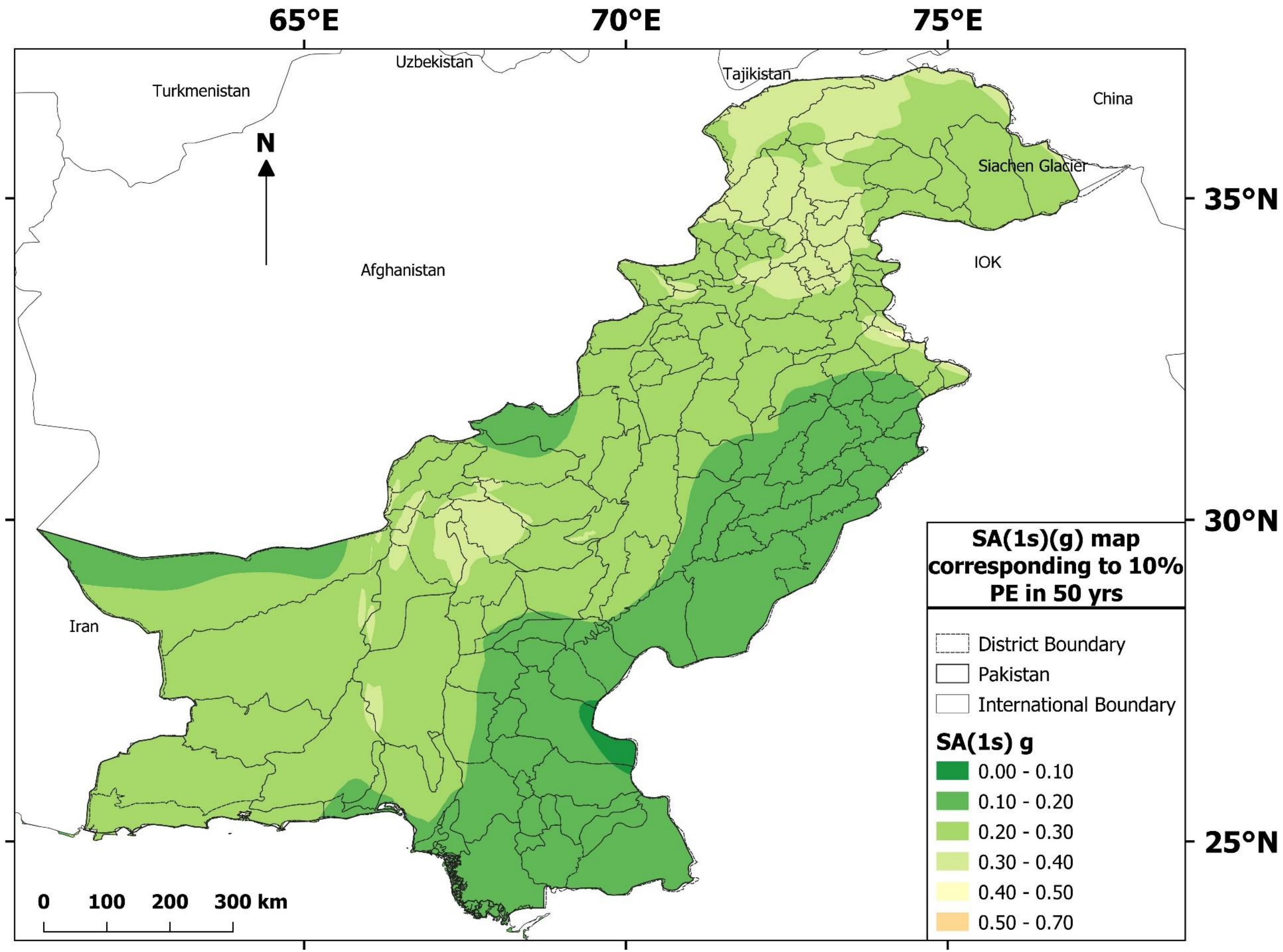


Spectral Acceleration (SA) at 0.2 sec. map for 475 years RP (10% PE in 50 years)

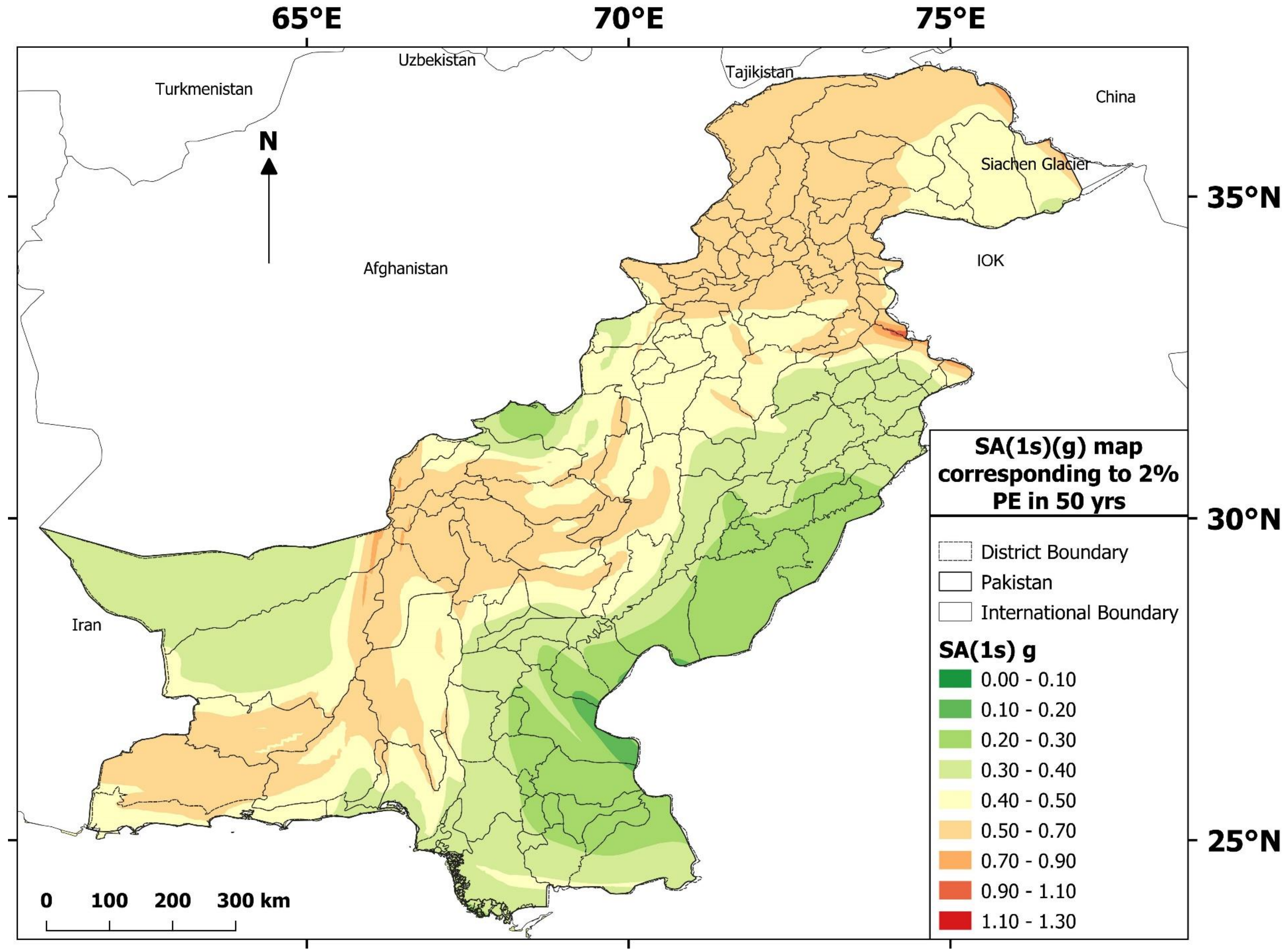


Spectral Acceleration (SA) at 0.2 sec. map for 2475 years RP (2% PE in 50 years)

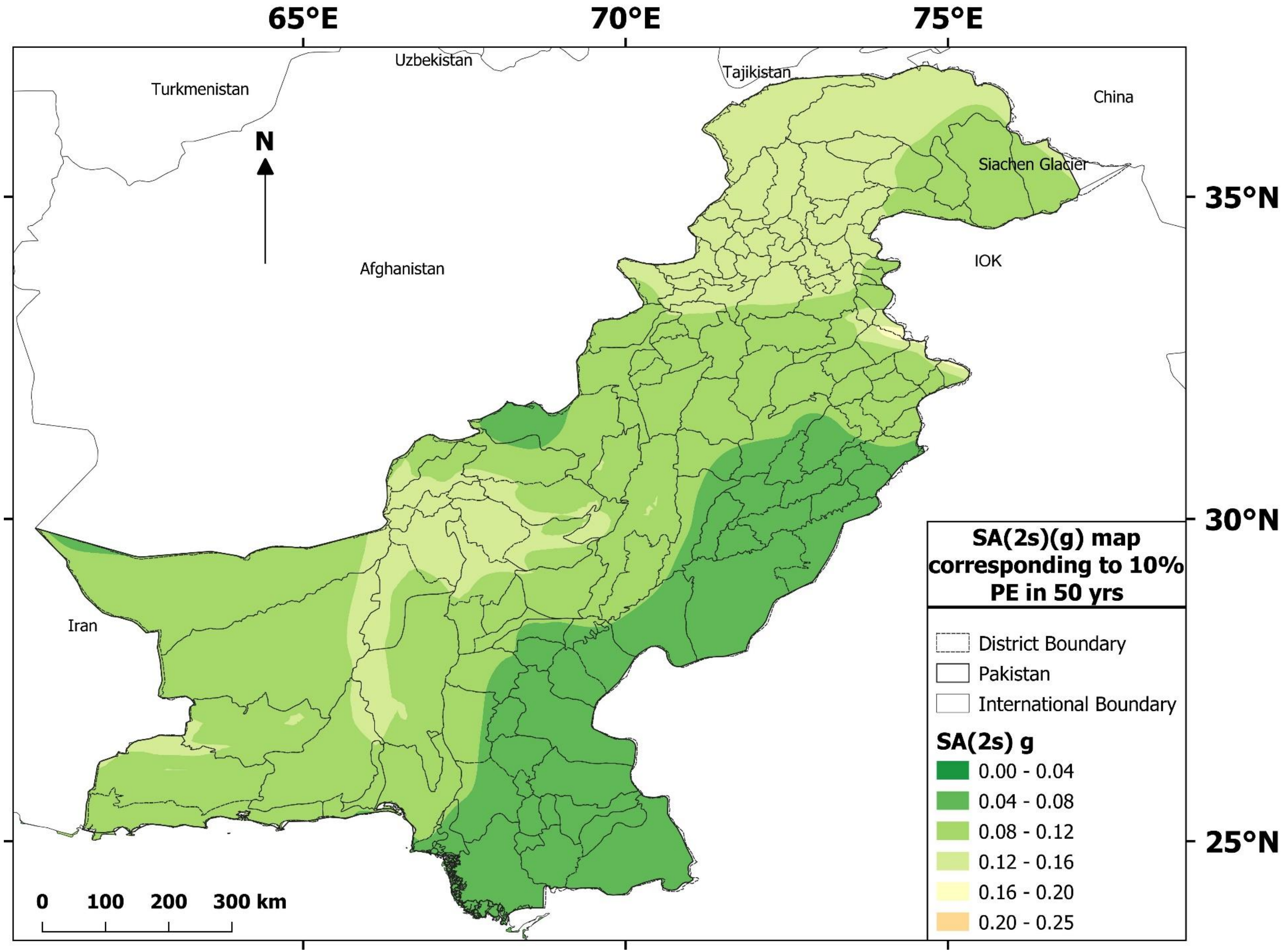
Spectral Acceleration (SA) at 1.0 sec. map for 475 years RP (10% PE in 50 years)



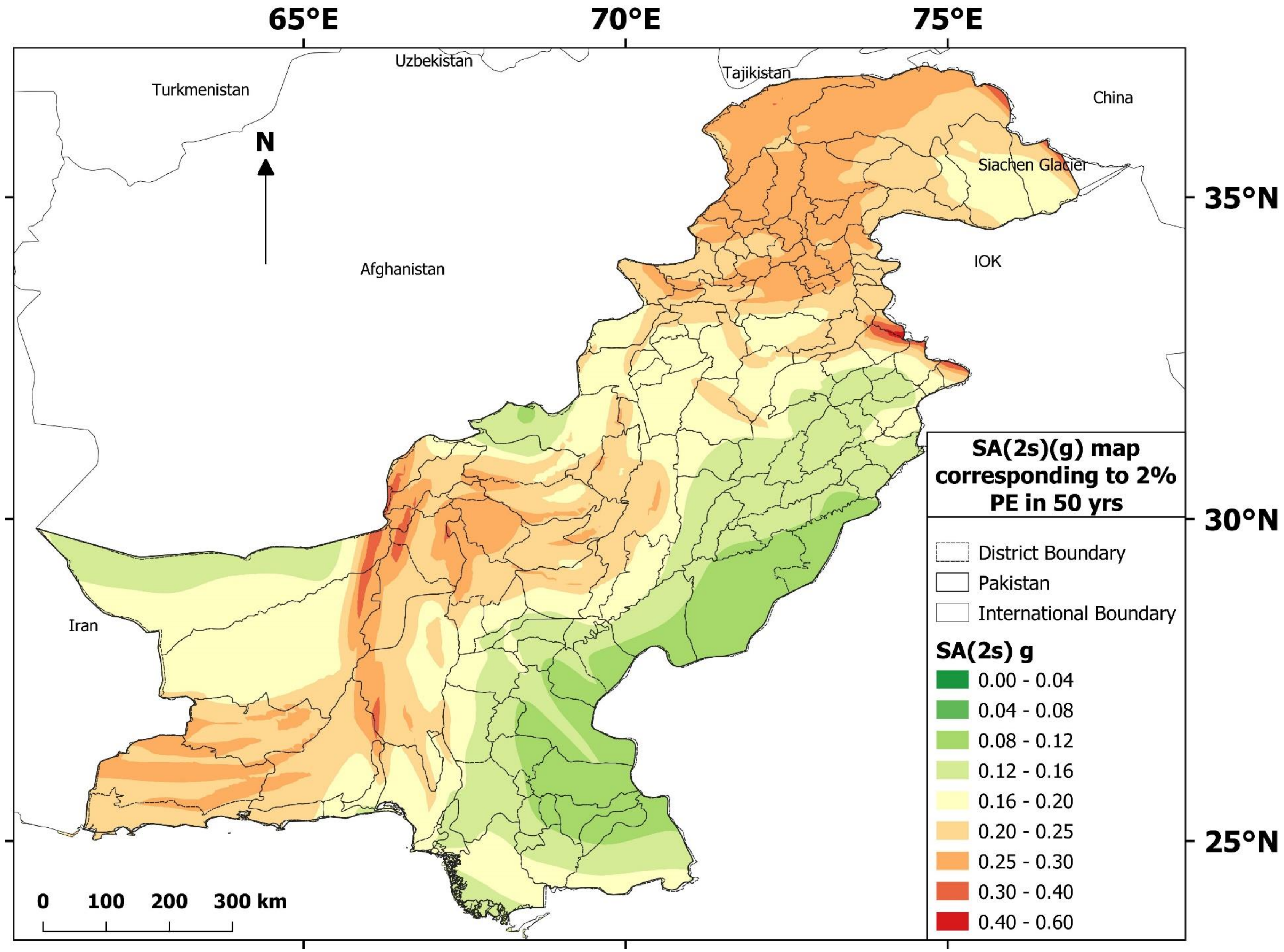
Spectral Acceleration (SA) at 1.0 sec. map for 2475 years RP (2% PE in 50 years)



Spectral Acceleration (SA) at 2.0 sec. map for 475 years RP (10% PE in 50 years)

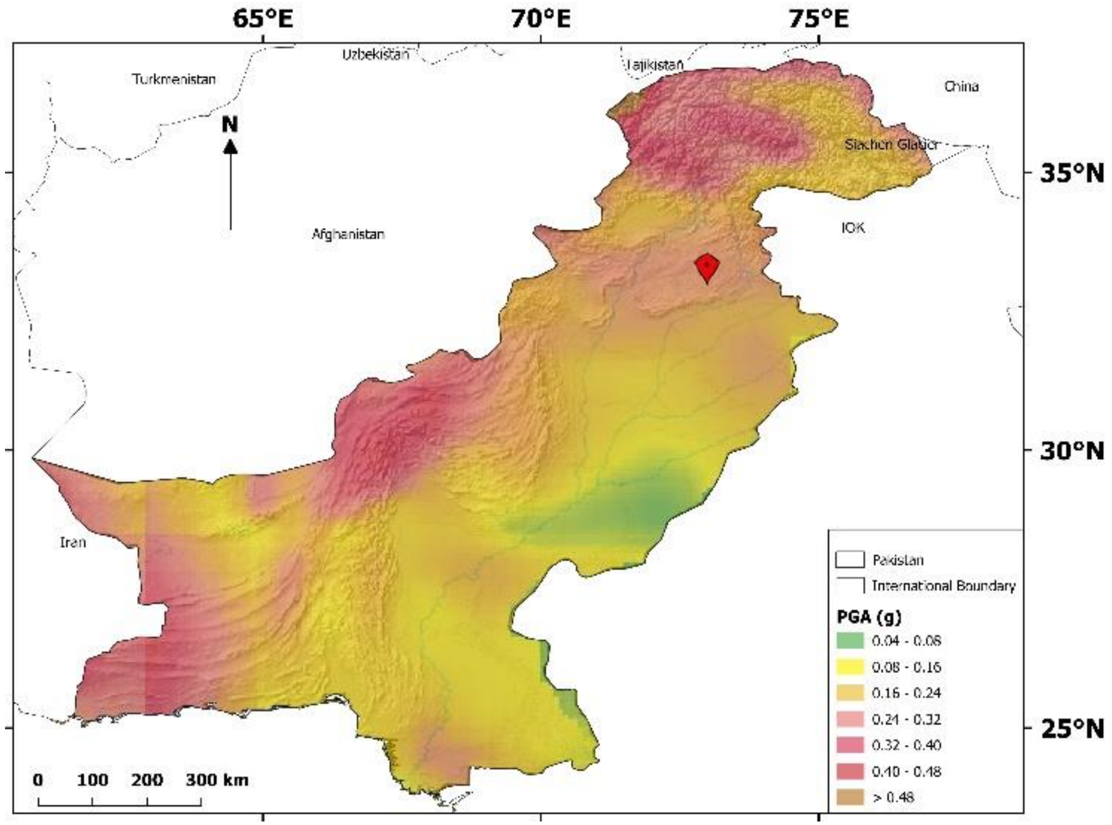


Spectral Acceleration (SA) at 2.0 sec. map for 2475 years RP (2% PE in 50 years)

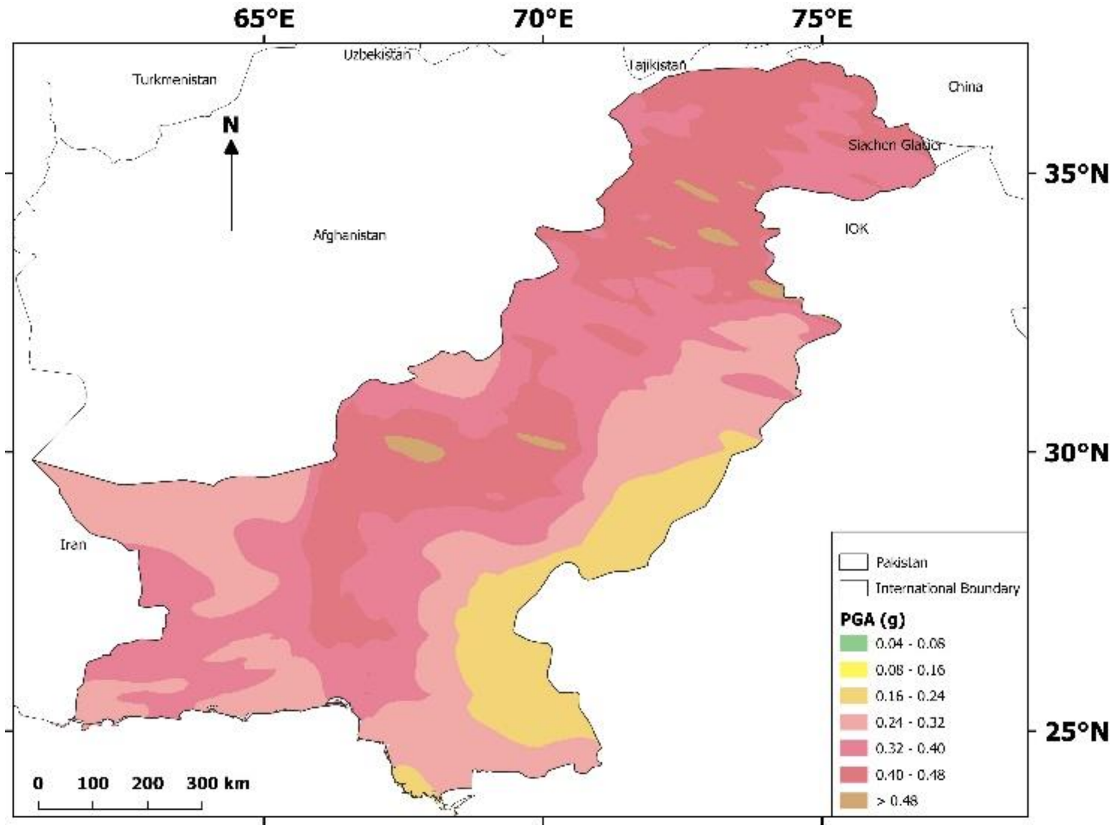


Comparison with previous studies

Comparison of GSHAP (1999) with current study (10% PE in 50 years)



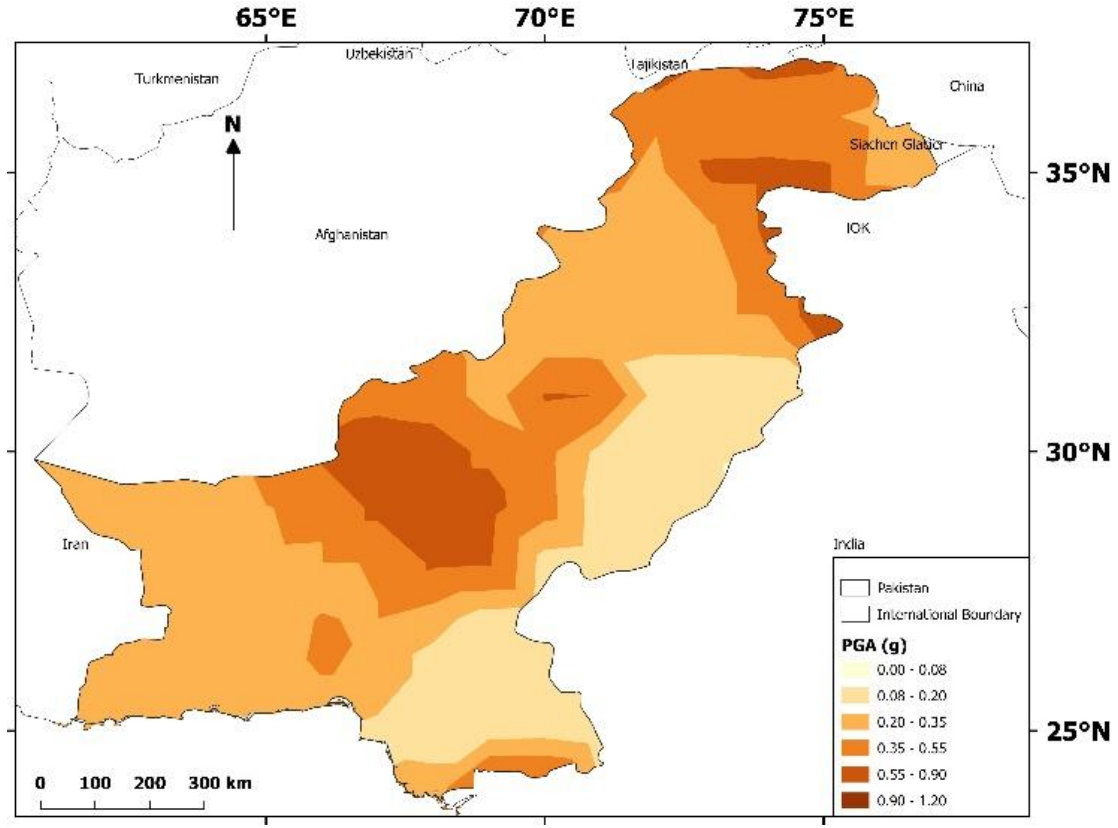
GSHAP (1999)



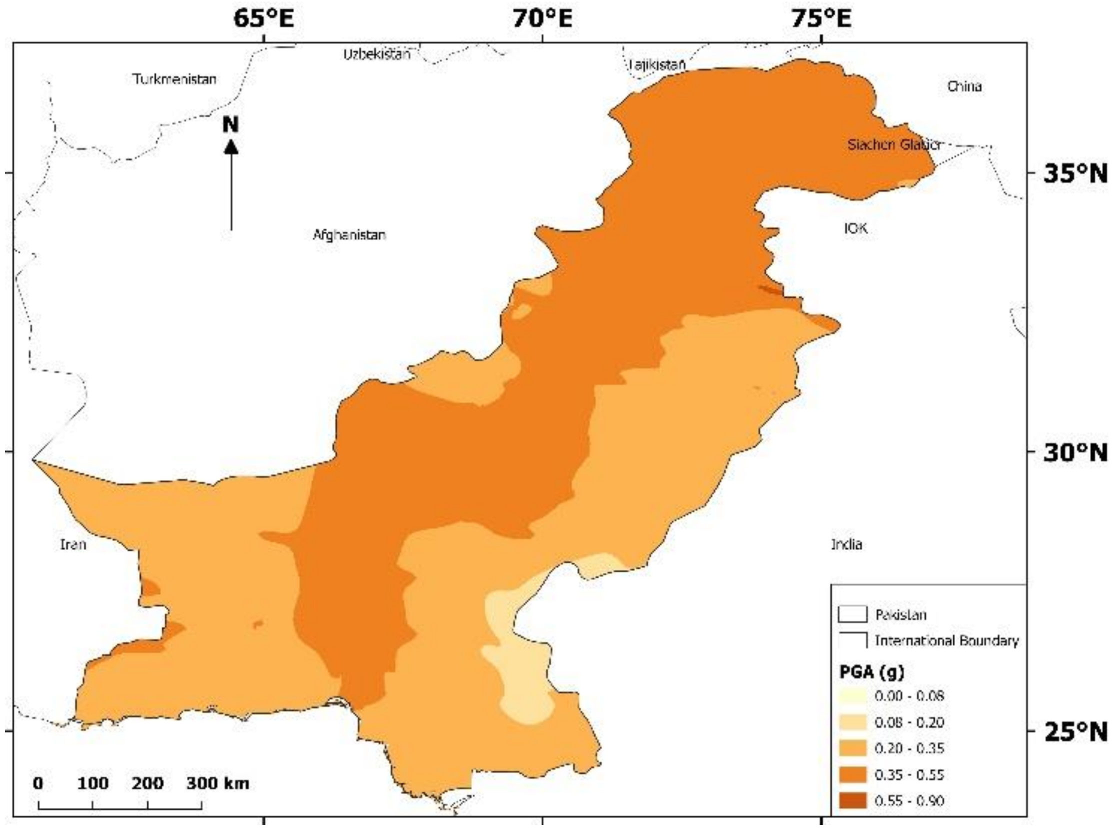
Current study

Comparison with previous studies

Comparison of PMD (2007) with current study (10% PE in 50 years)



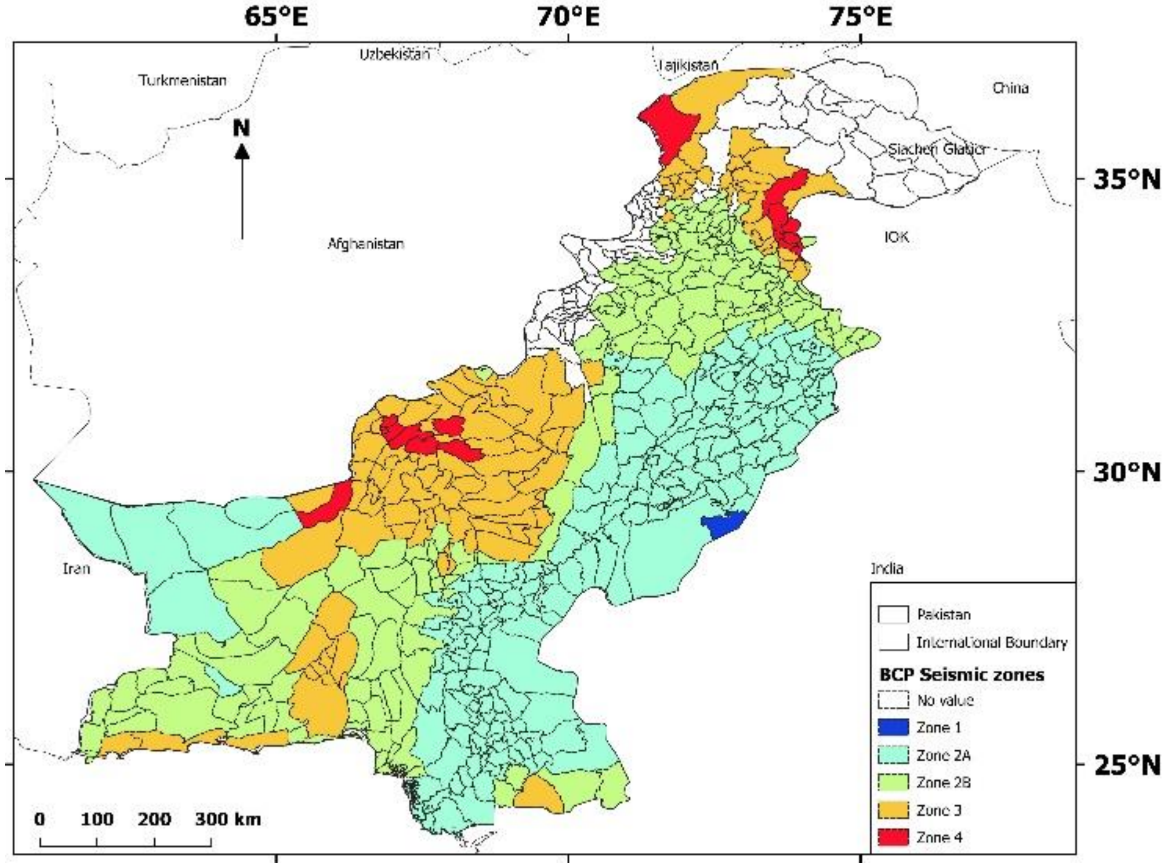
PMD and NORSAR (2007)



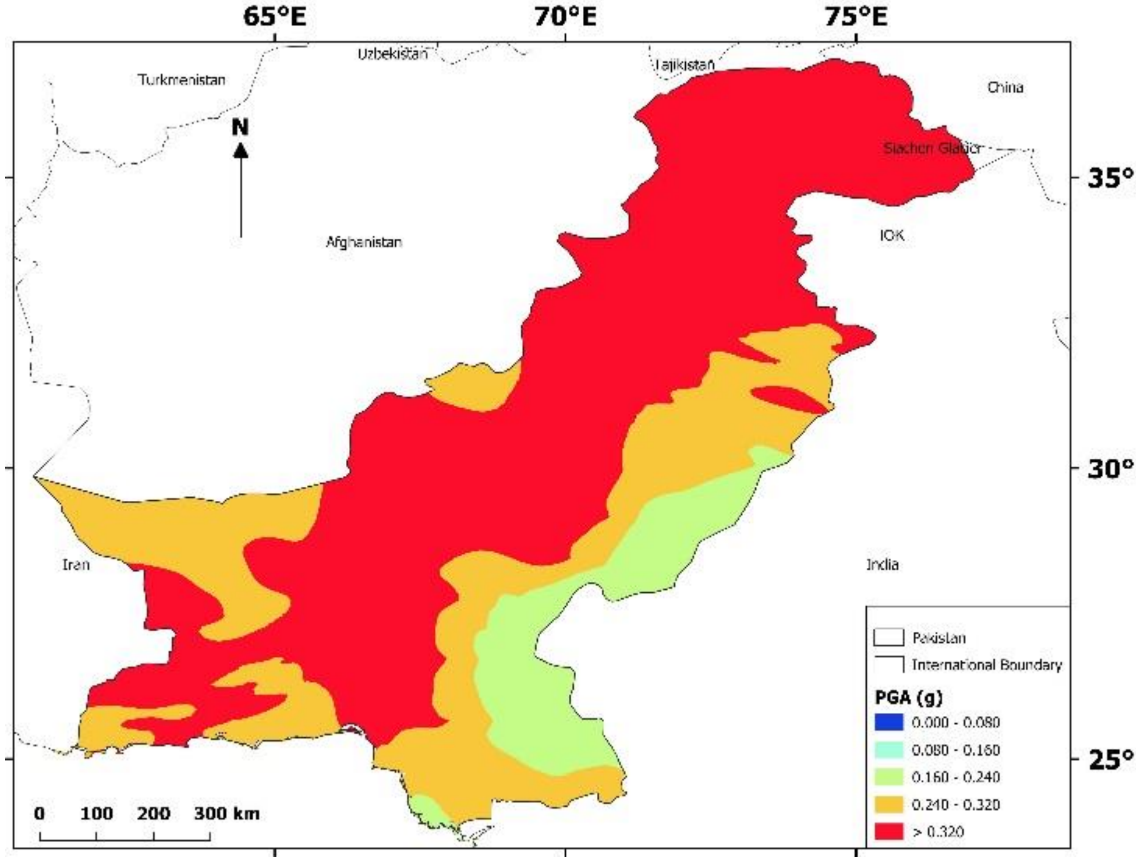
Current study

Comparison with previous studies

Comparison of NESPAK (2007) with current study (10% PE in 50 years)



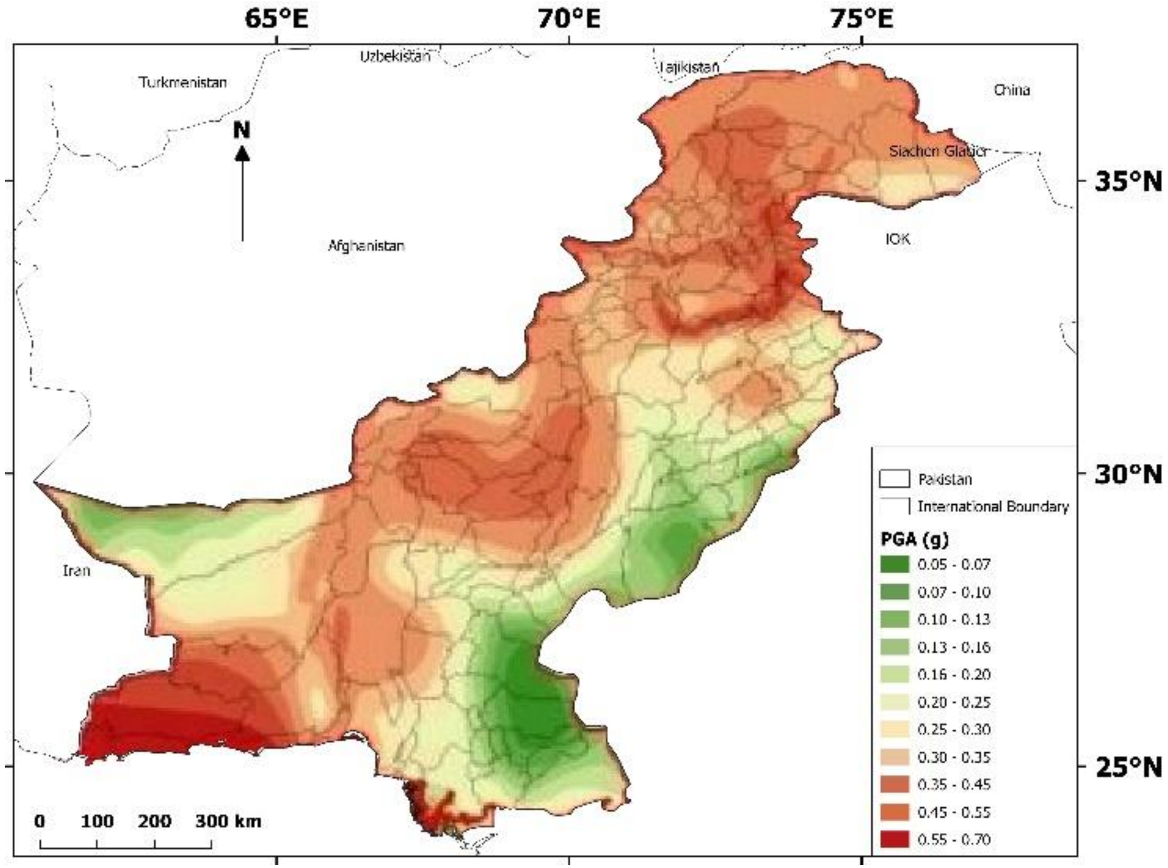
NESPAK (2007)



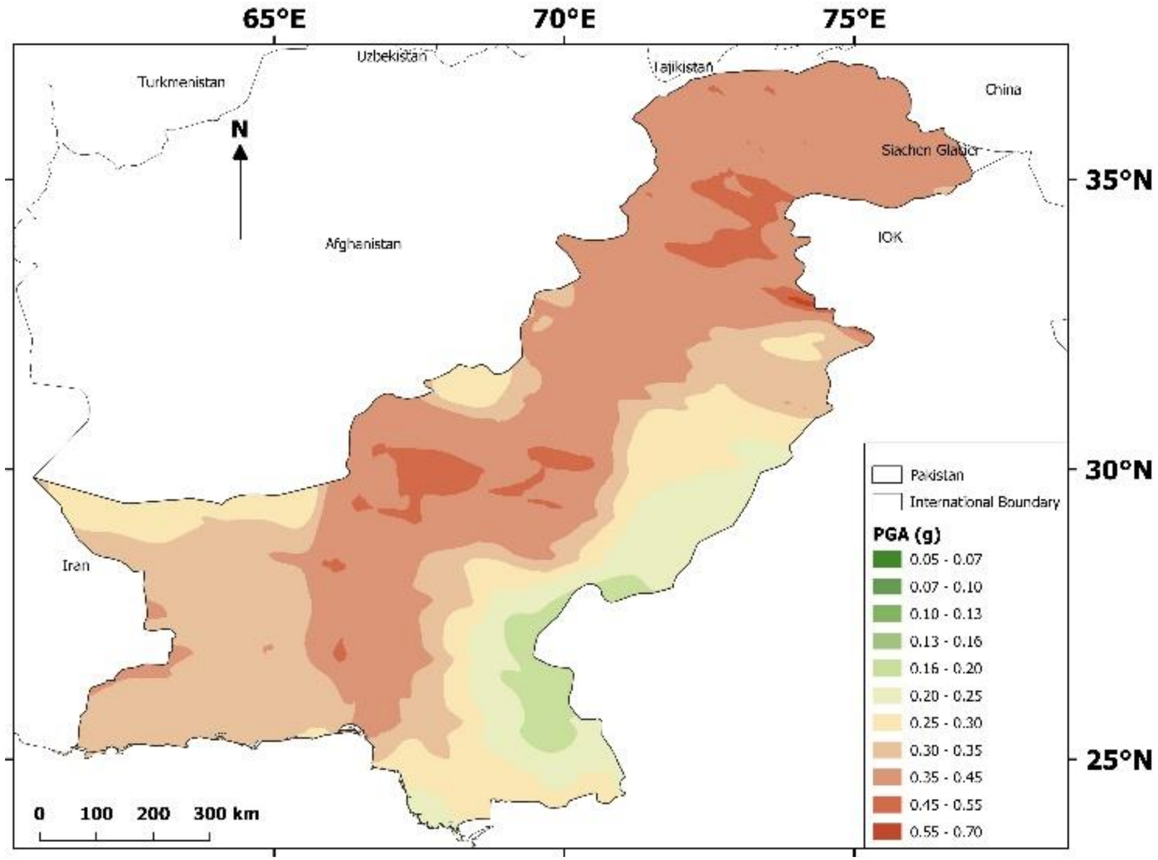
Current study

Comparison with previous studies

Comparison of Zaman (2012) with current study (10% PE in 50 years)



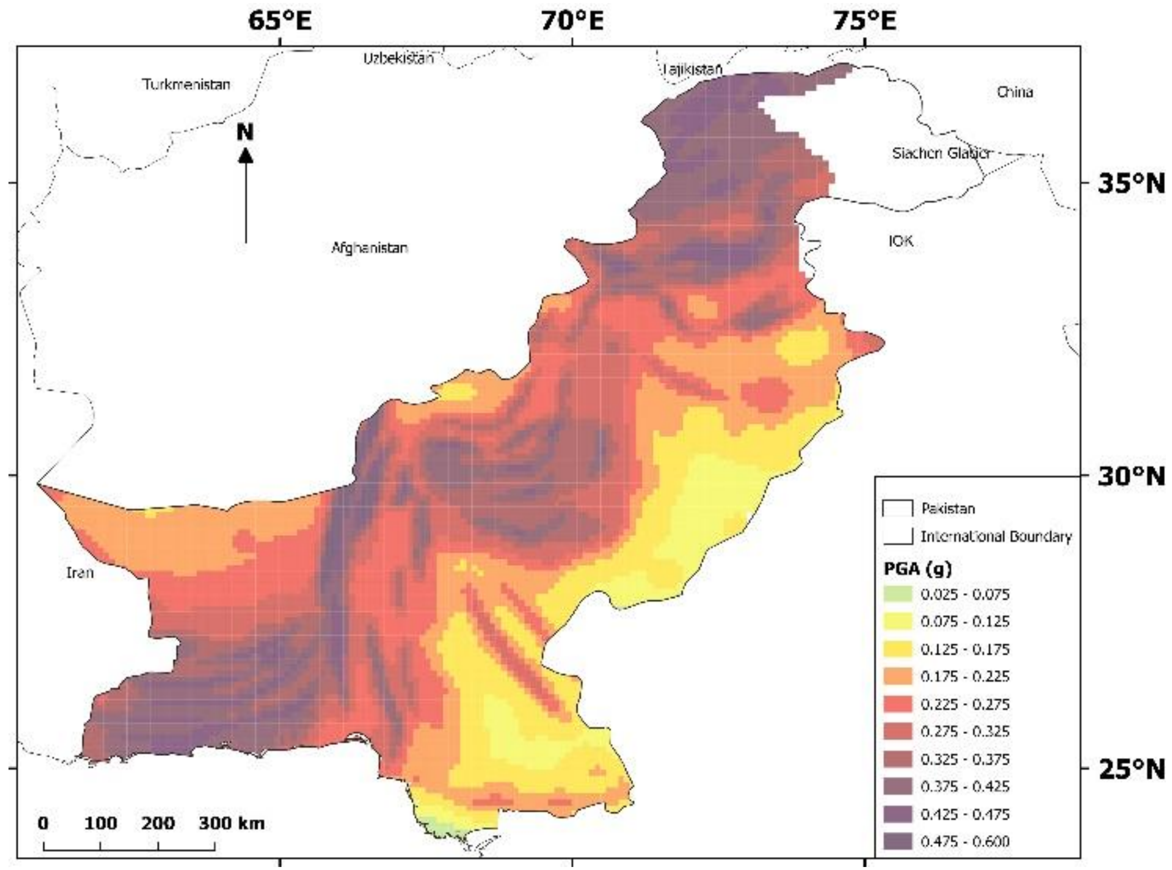
Zaman et al. (2012)



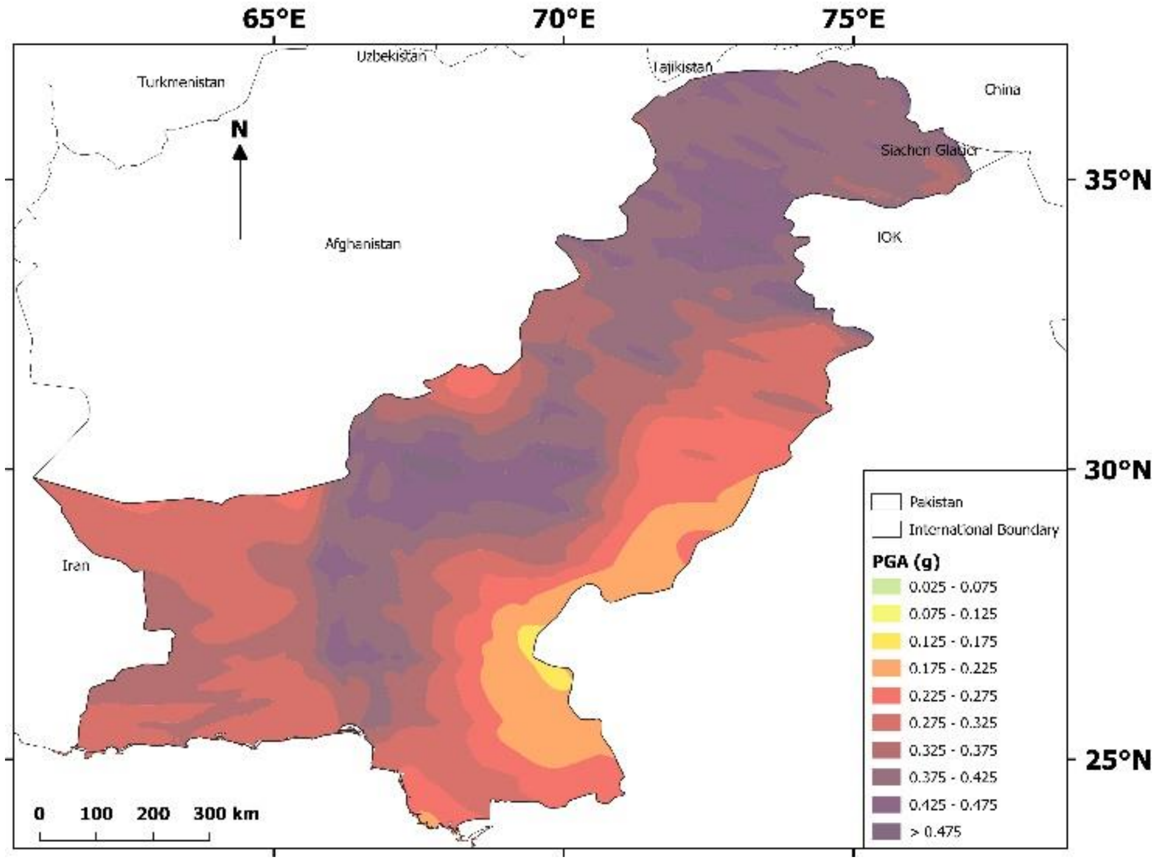
Current study

Comparison with previous studies

Comparison of EMME (2018) with current study (10% PE in 50 years)



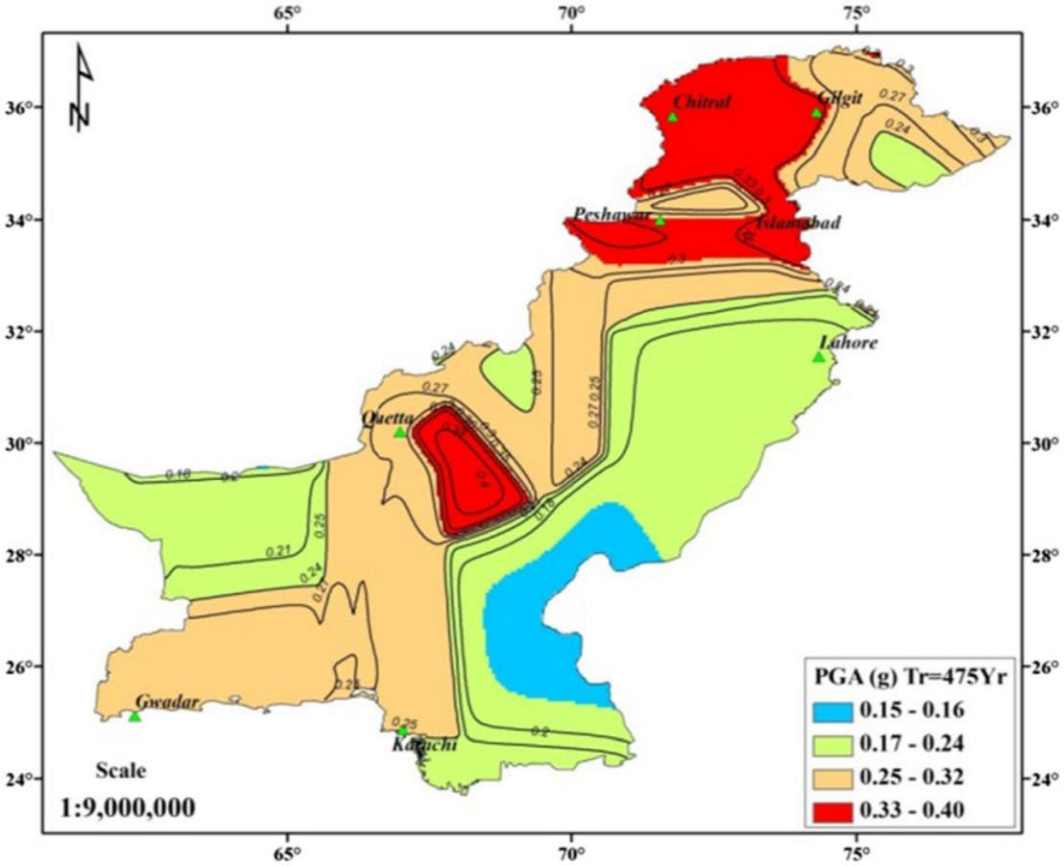
EMME (Şeşetyan et al. 2018)



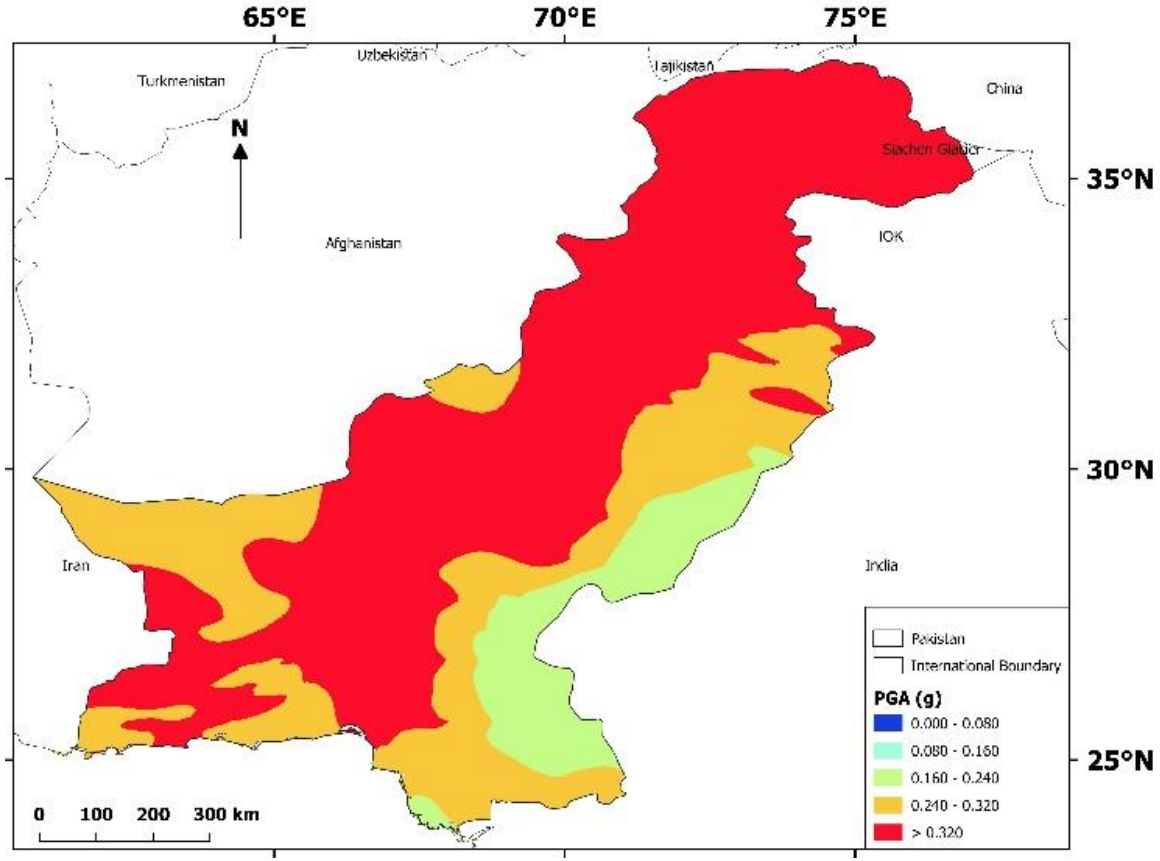
Current study

Comparison with previous studies

Comparison of Waseem et al. (2020) with current study (10% PE in 50 years)

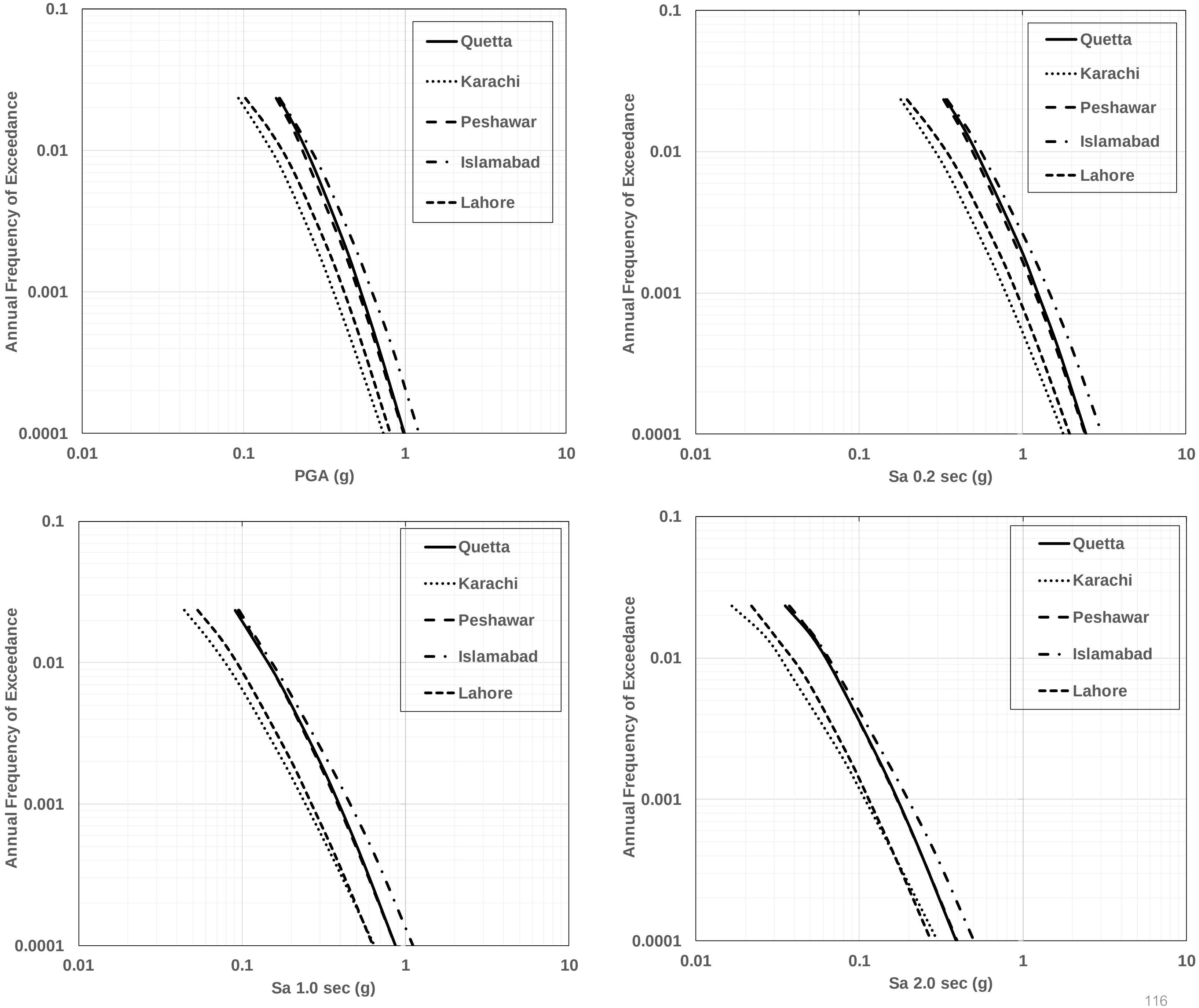


(Waseem et al. 2020)

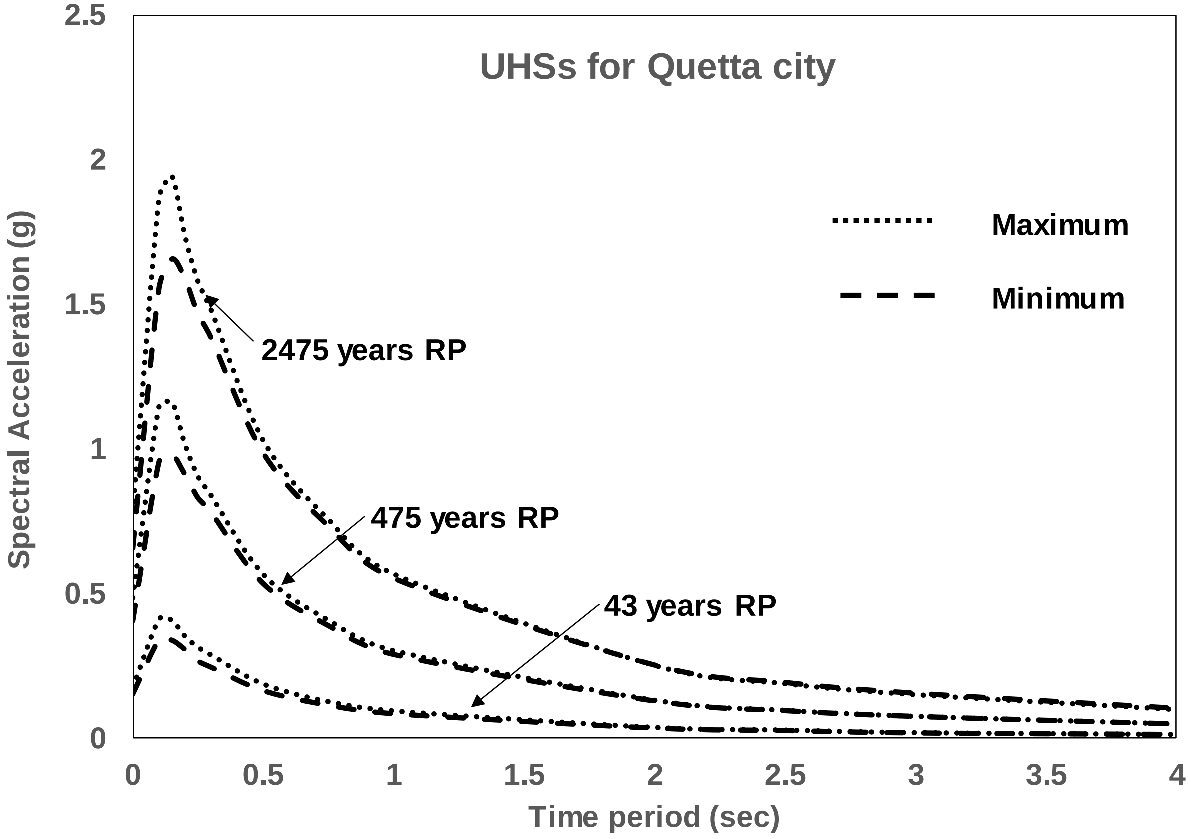


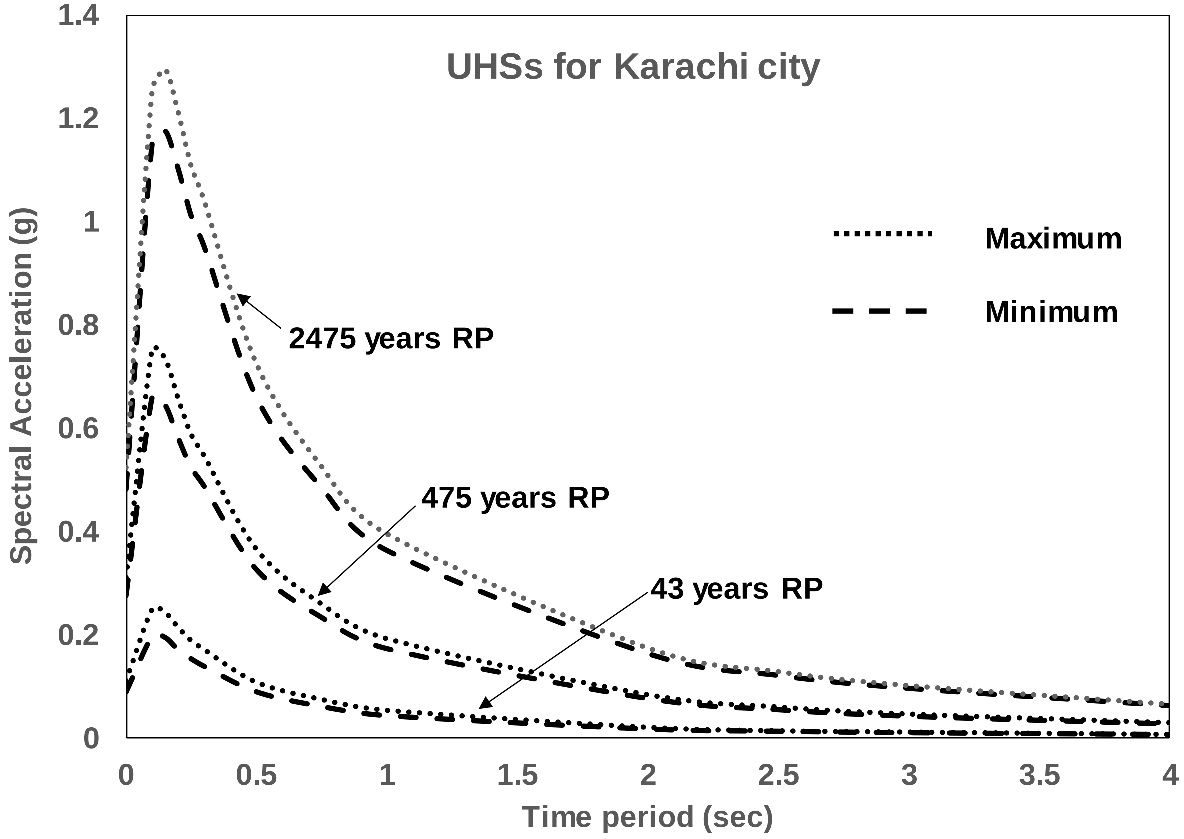
Current study

Hazard Curves for Major Cities in Pakistan

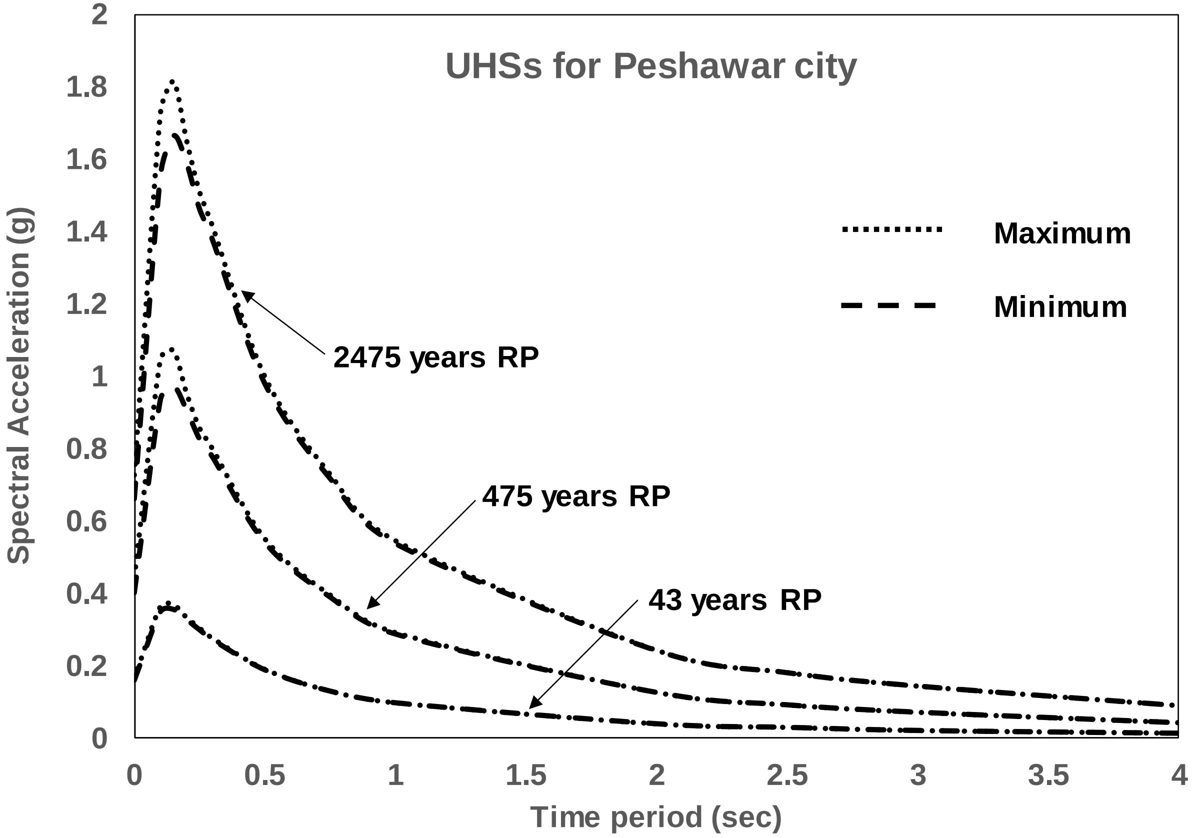


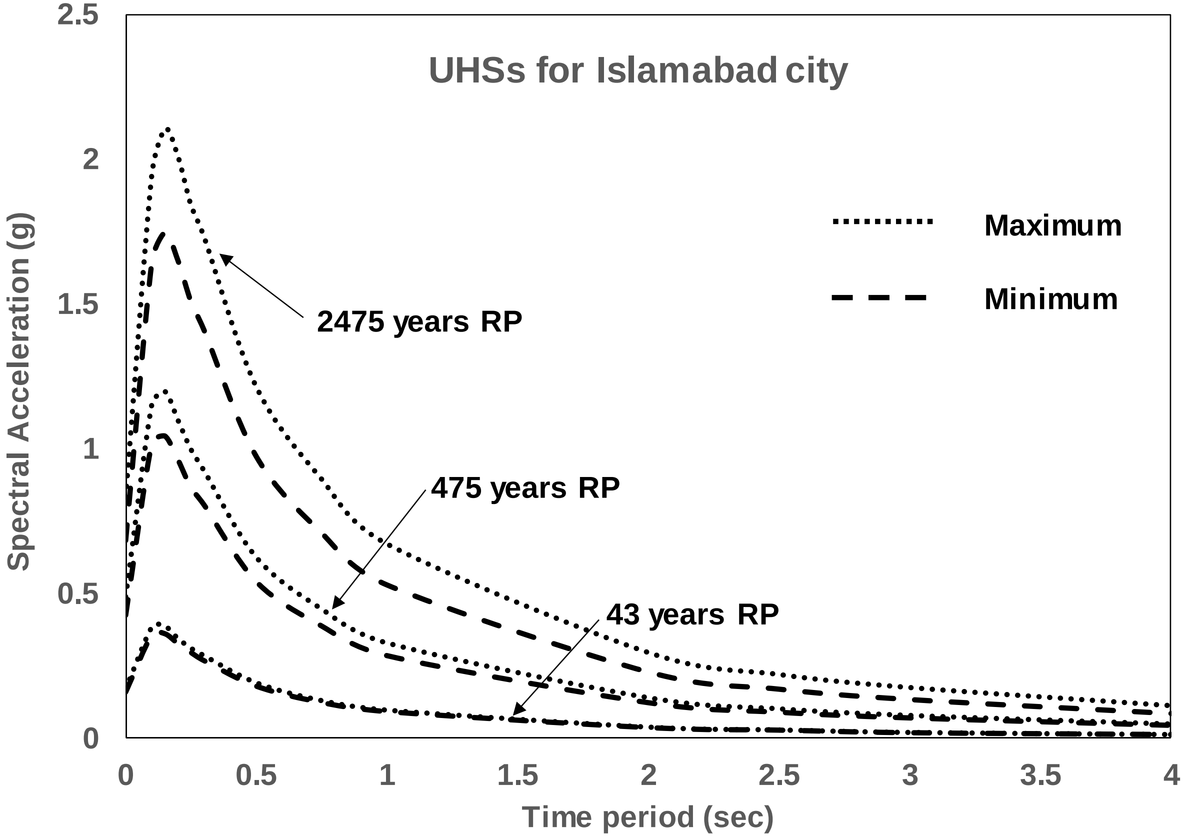
Uniform Hazard Spectra



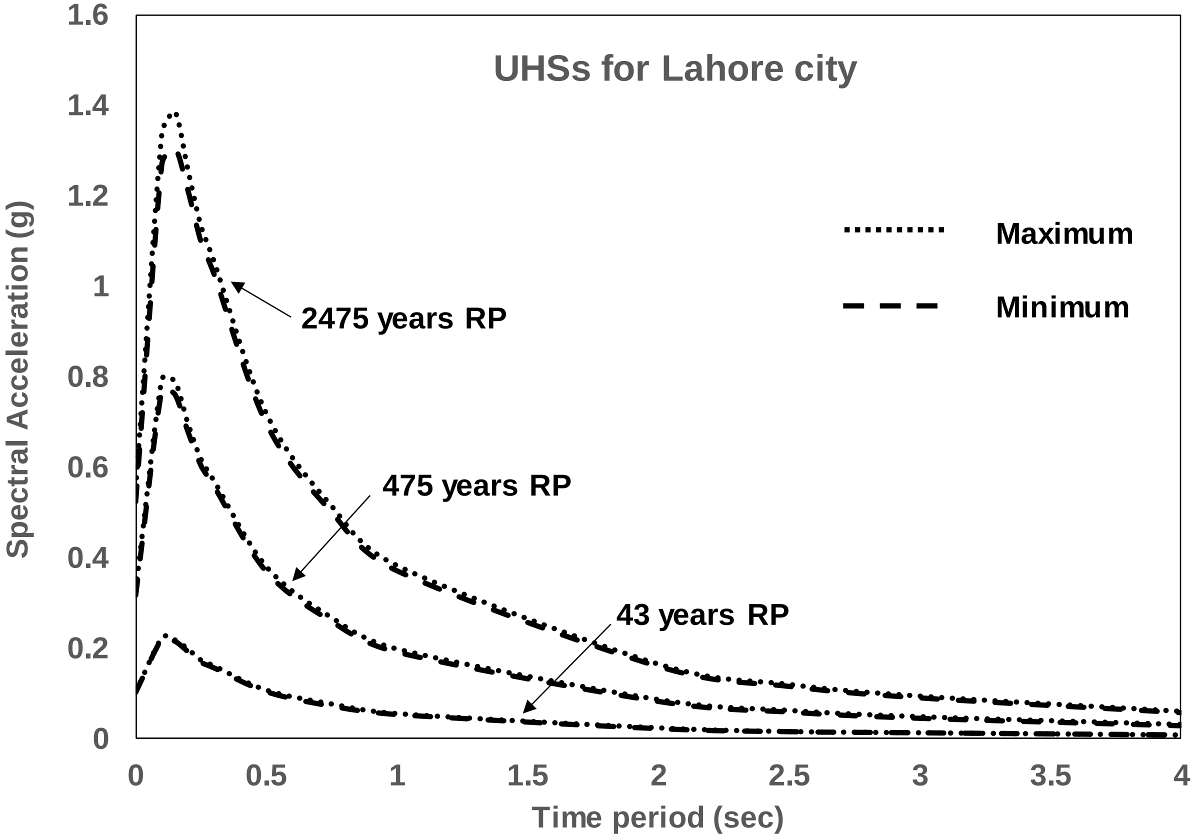


Uniform Hazard Spectra





Uniform Hazard Spectra



Updated National Seismic Hazard Maps for BCP 2021

Key Challenges:

- Updated national seismic hazard maps.
- Capacity building of the structural engineers to use modern tools.
- Improved seismic design procedure for new buildings.
- Retrofitting guidelines for existing non-engineered masonry buildings.
- A sound enforcement mechanism through provincial and district level regulations and byelaws enforced by local development authorities.

Pakistan Engineering Council (PEC) Taskforce to Develop

Updated National Seismic Hazard Maps

Thank you for your attention