Credits: 3 + 0
PG 2019
Spring 2020 Semester

Performance-based Seismic Design of Structures

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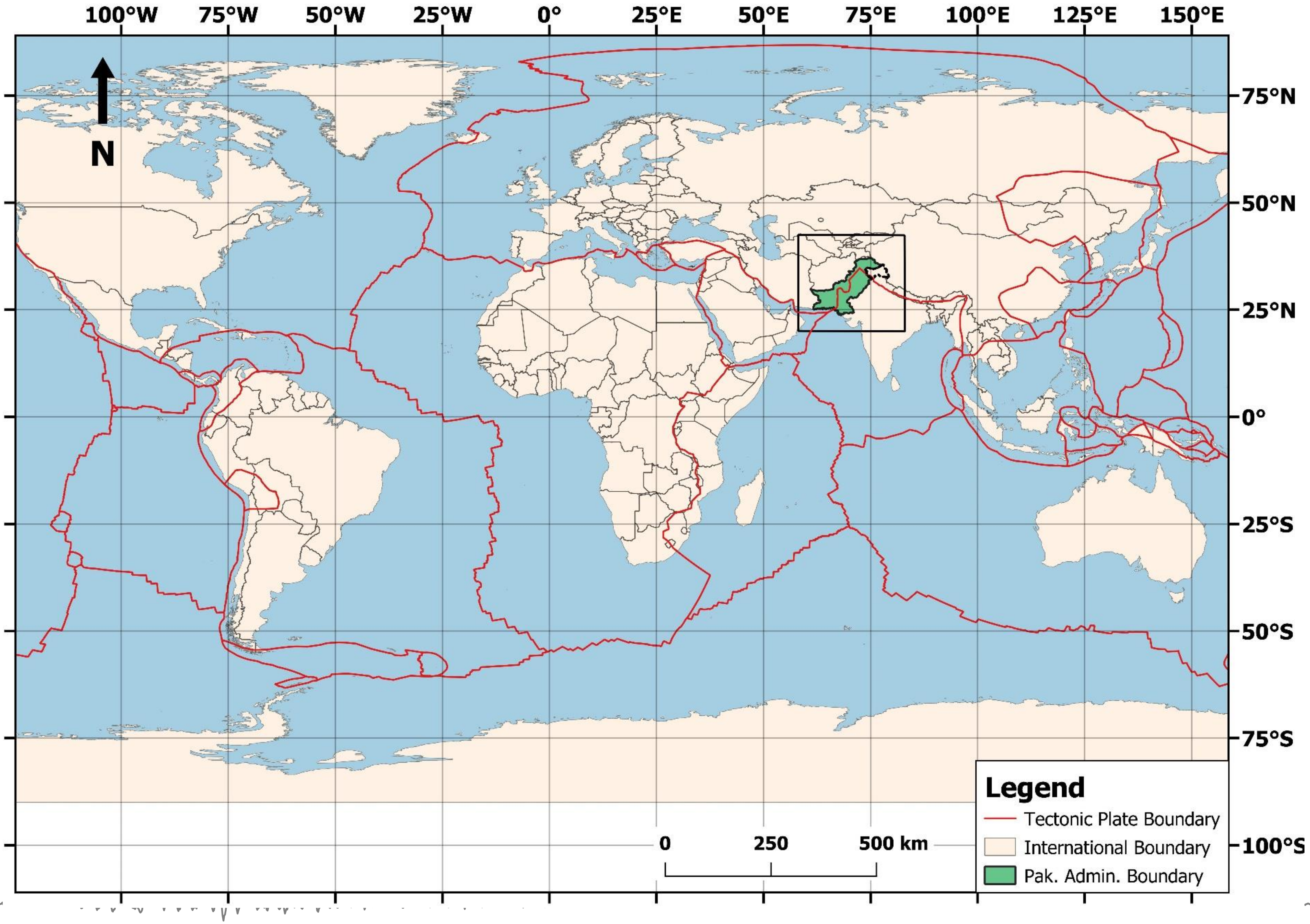
Lecture 2 (b): Probabilistic Seismic Hazard Assessment of Pakistan

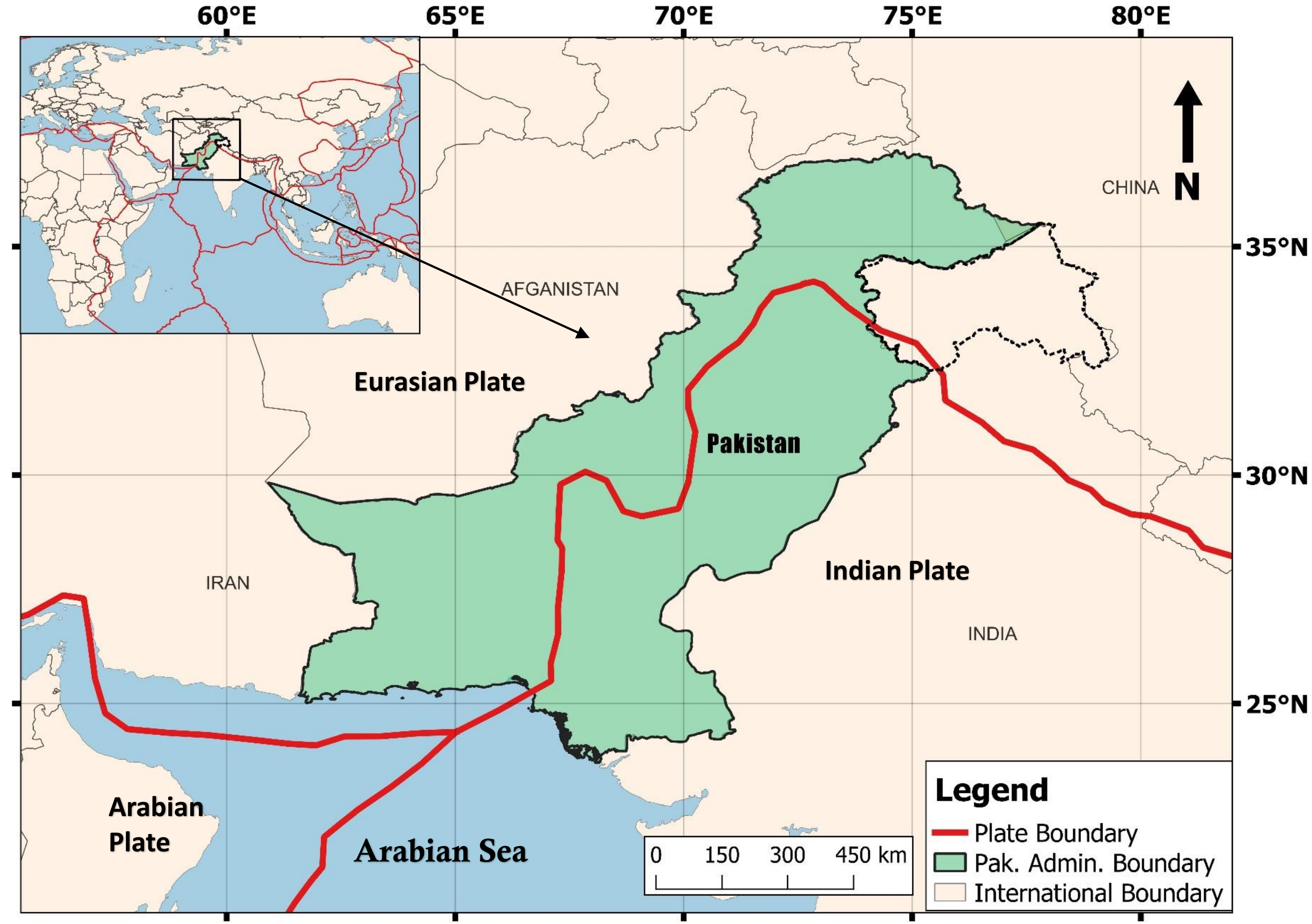
- Seismic Hazard Assessment of Pakistan (A Quick Review of Existing Studies)
- The 8th October 2005 Kashmir M 7.6 Event
- PSHA for BCP 2007
- PSHA of Pakistan using Spatially Smoothed Background Seismicity and Crustal Faults Model (Zaman and Warnitchai, 2016)
- Probabilistic Seismic Hazard and Deaggregation 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 (Asad, 2020)

SHA of Pakistan (A Quick Review of Existing Studies)

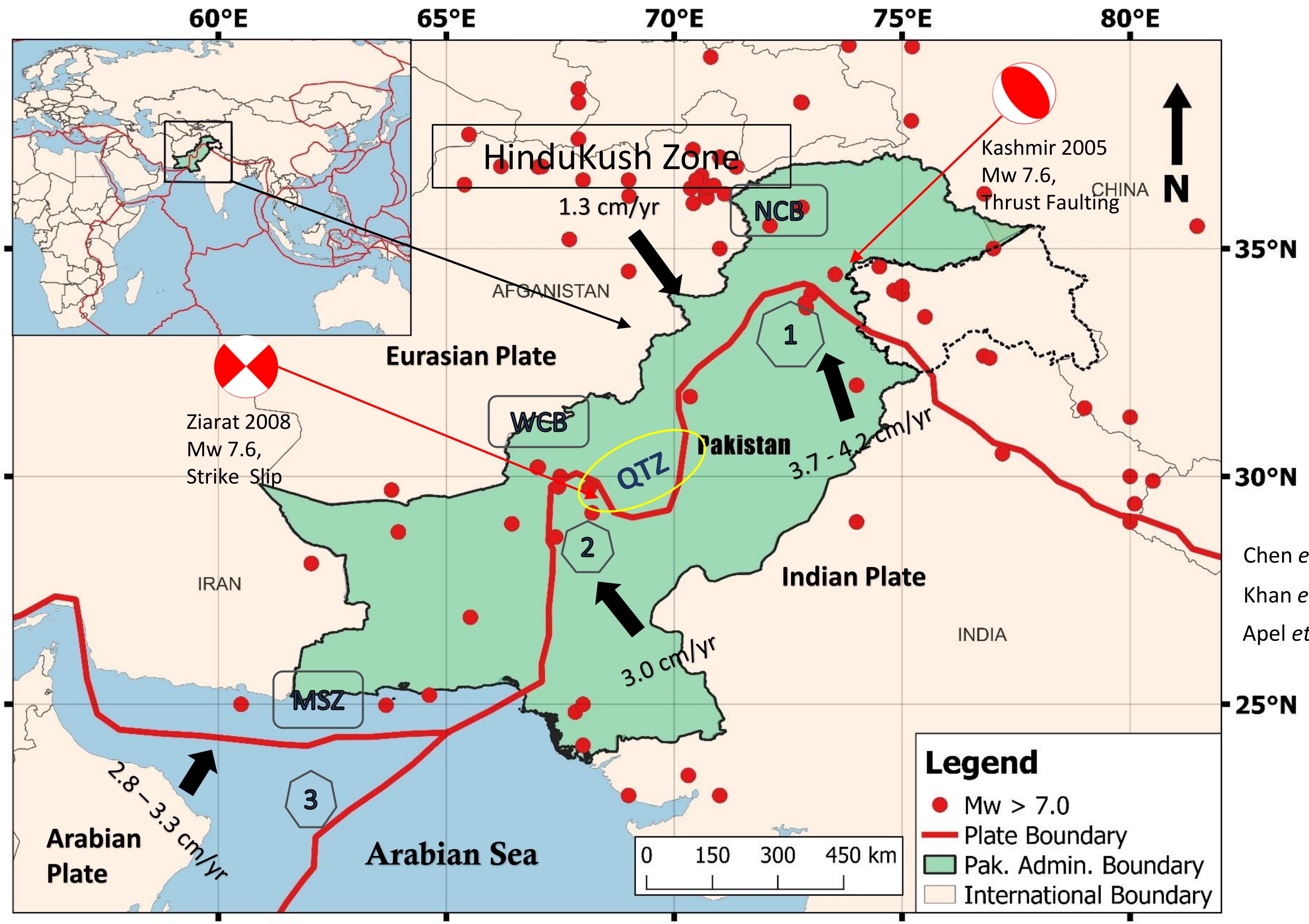
Location of Pakistan and the tectonic setting around



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

Why Seismic Hazard Assessment of Pakistan?

Absence of Accurate Picture of Seismic Hazard

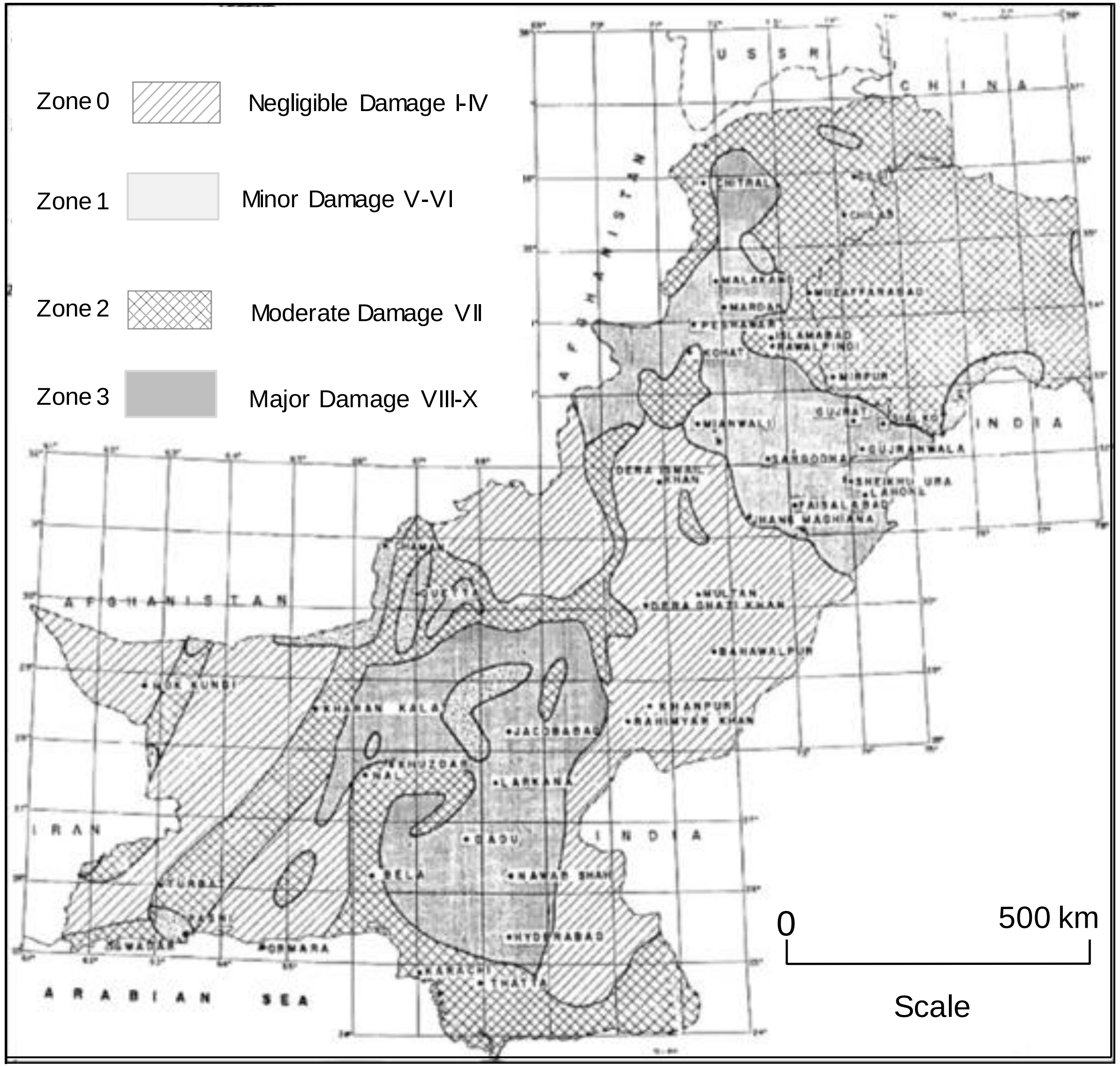
Non-Engineered Construction in Pakistan → Serious Threat to Property and lives of residents → Existing Zones Depict Low Seismic Hazard

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

Seismic Hazard Assessment of Pakistan

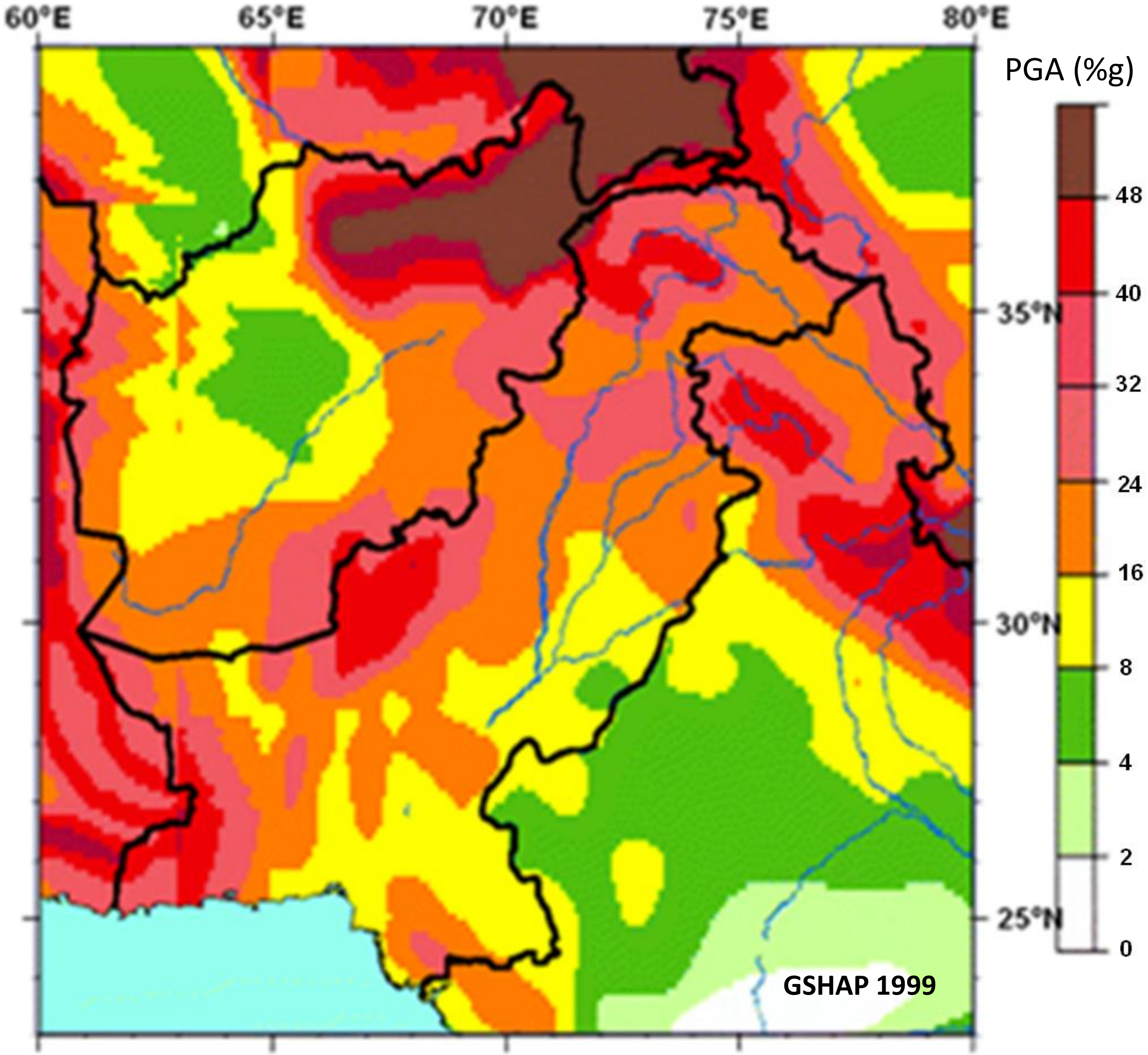
1) 1974 → Very first study by the Geological Survey of Pakistan. (Zaman, 2016)

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

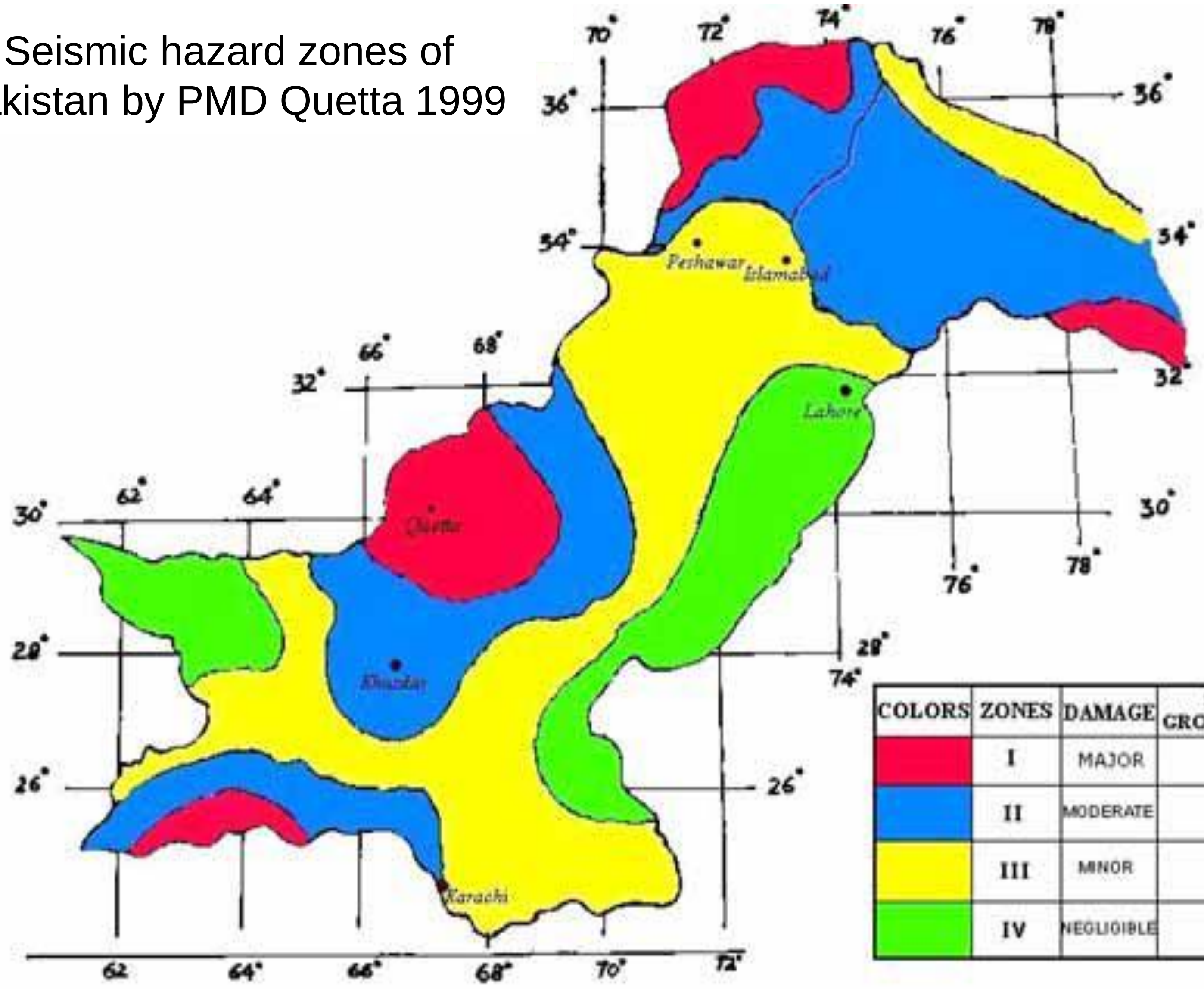
3) 1999 → Global Seismic Hazard Assessment Program (GSHAP). (Zhang et.al, 1999)



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

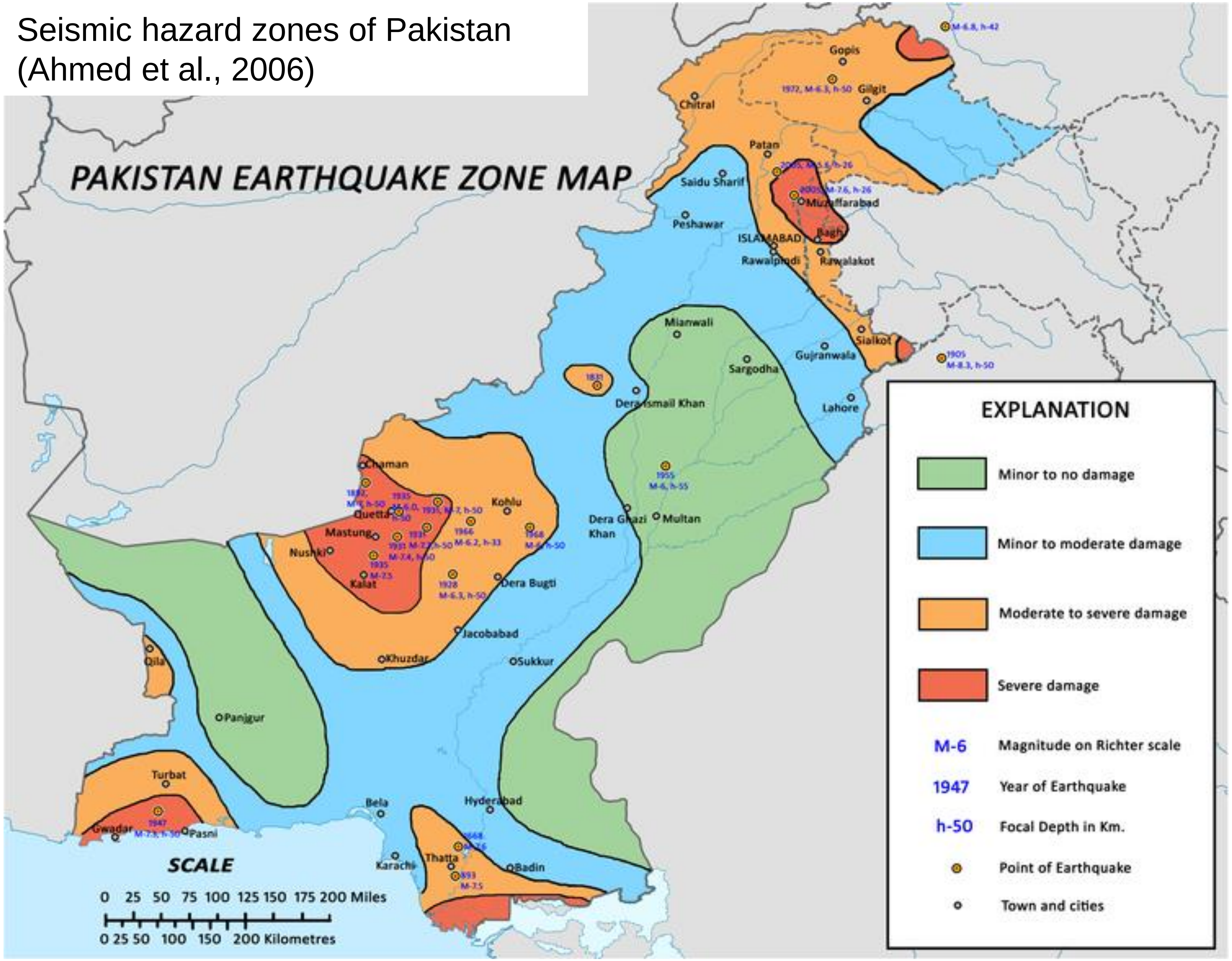
Seismic Hazard Assessment of Pakistan

Seismic hazard zones of
Pakistan by PMD Quetta 1999



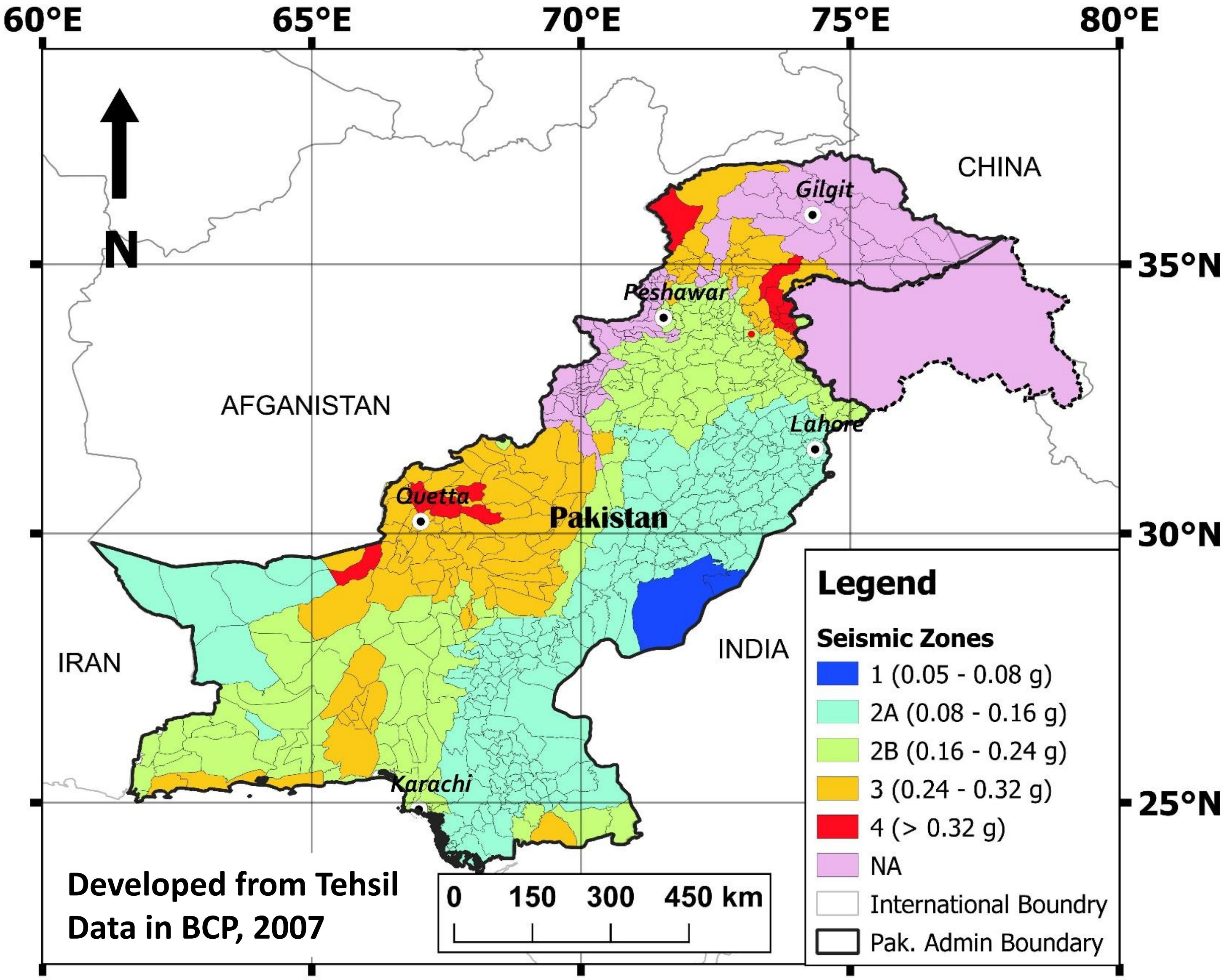
COLORS	ZONES	DAMAGE	SEISMIC FACTOR GROUND ACCELARATION
Red	I	MAJOR	g/5 to g/10
Blue	II	MODERATE	g/10 to g/15
Yellow	III	MINOR	g/15 to g/20
Green	IV	NEGLIGIBLE	g/20 or Less

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



Seismic Hazard Assessment of Pakistan

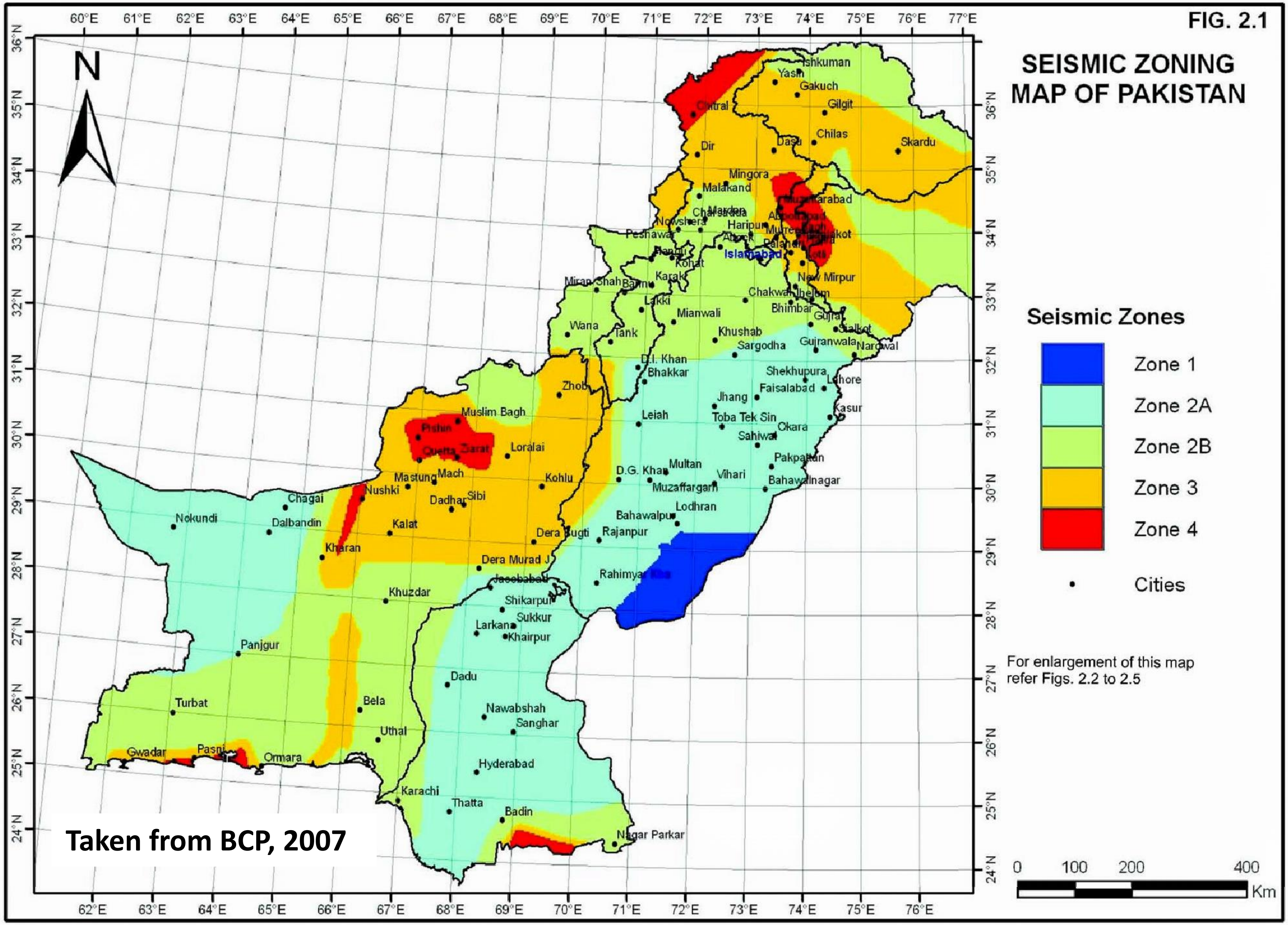
4) 2007 → NESPAK updated the Building Code of Pakistan. (BCP, 2007)



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

Seismic Hazard Assessment of Pakistan

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

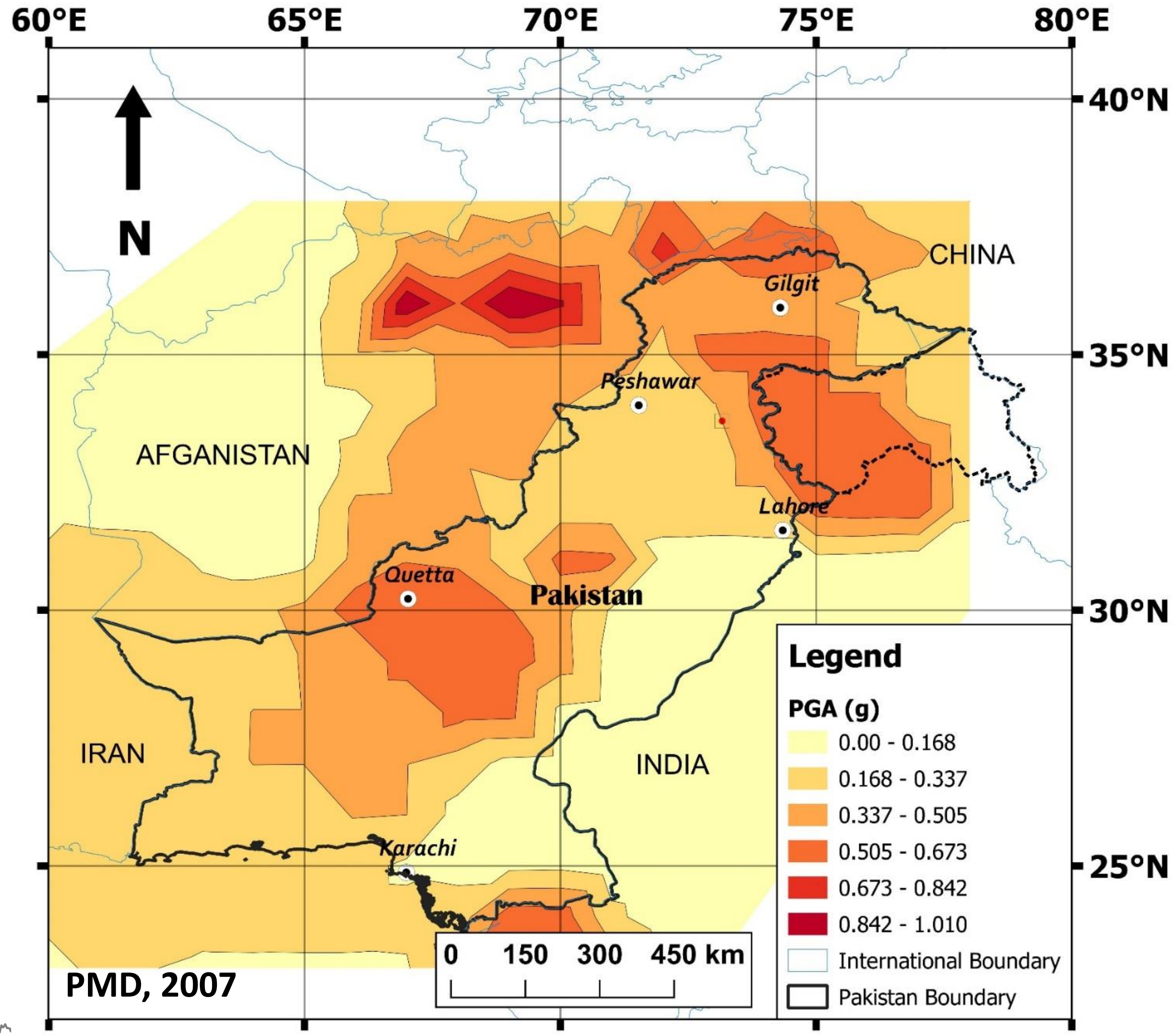


Taken from BCP, 2007

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

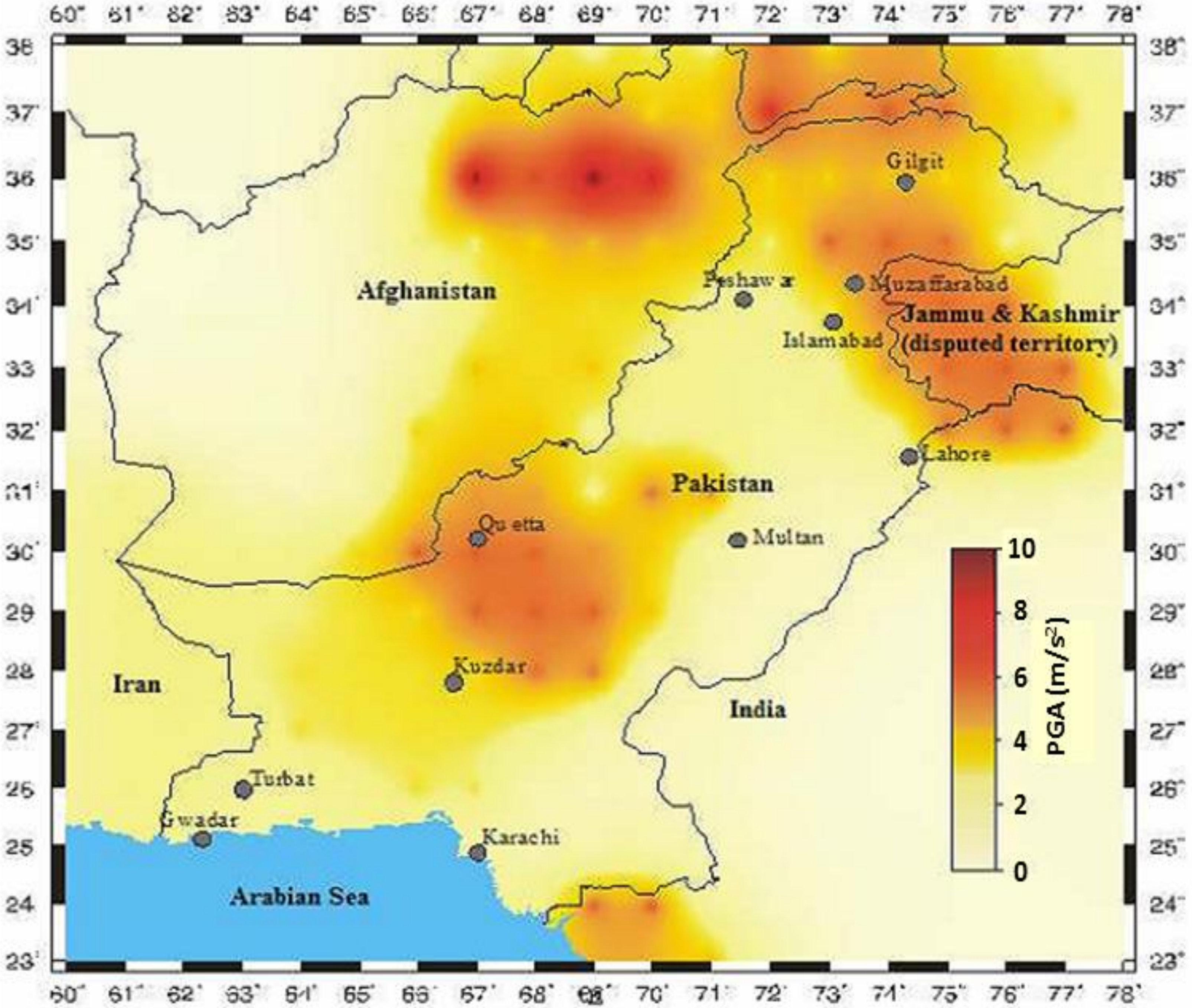
Seismic Hazard Assessment of Pakistan

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



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

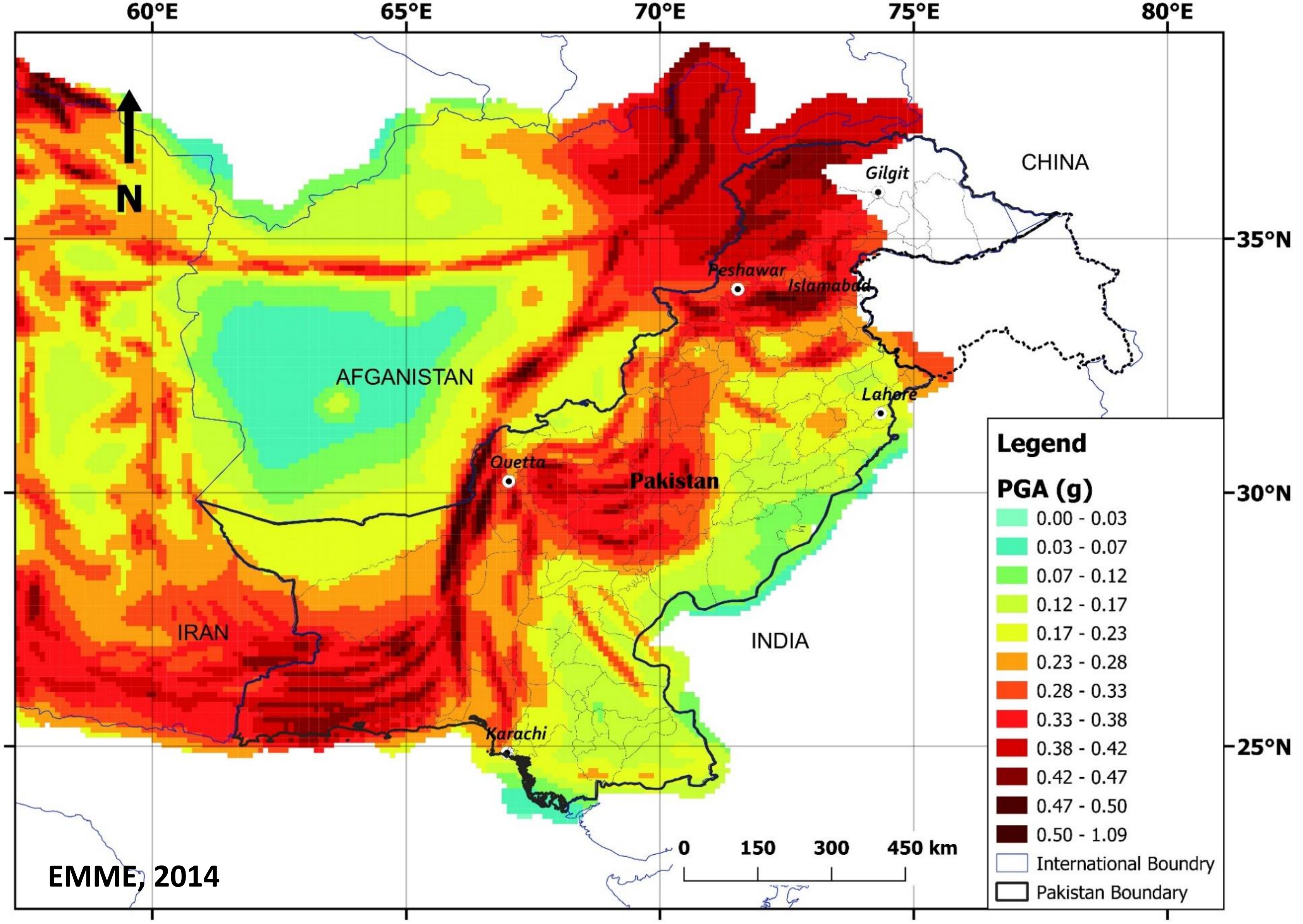
Seismic hazard map of Pakistan for PGA for 475 years return period (Modified from PMD-NORSAR 2007)



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

Seismic Hazard Assessment of Pakistan

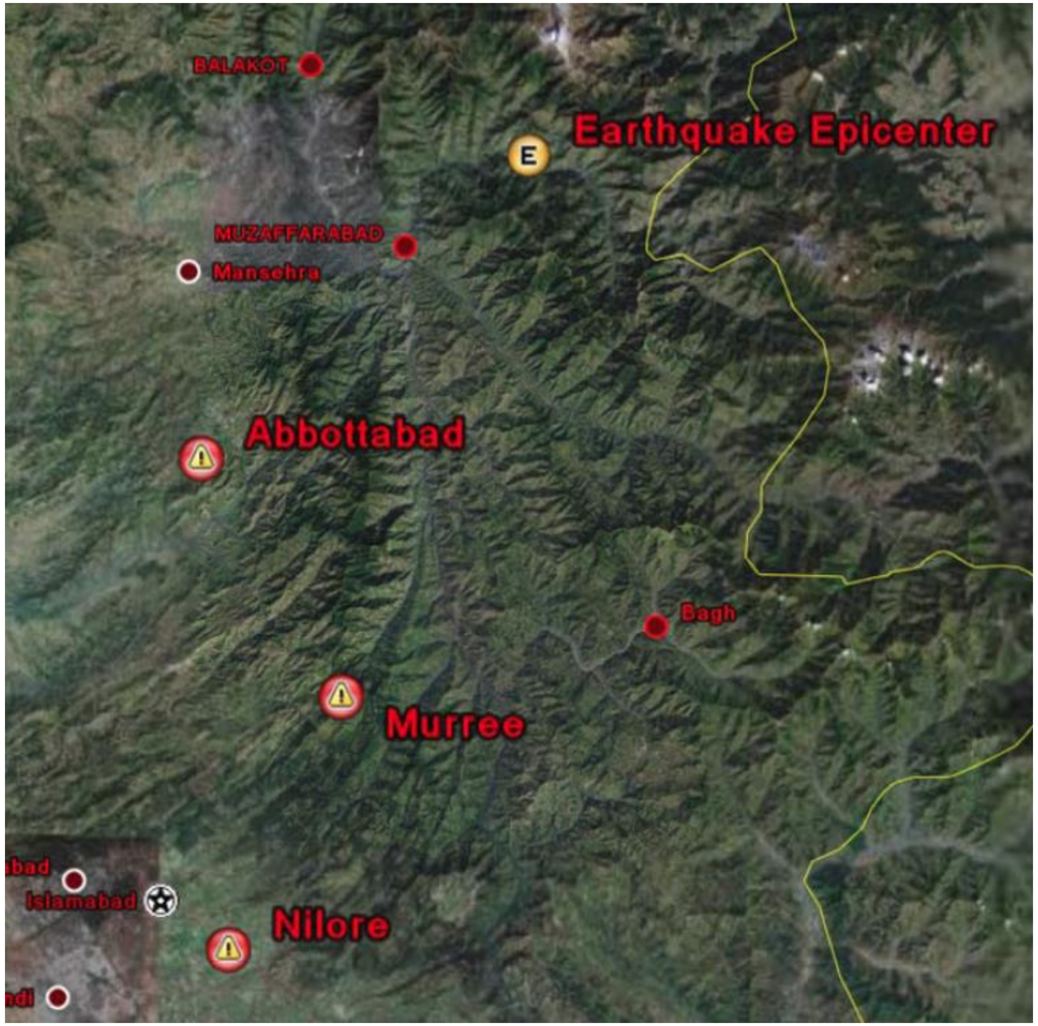
6) 2014 → Earthquake Model of Middle East (EMME 2014). (Sesetyan et.al, 2014)

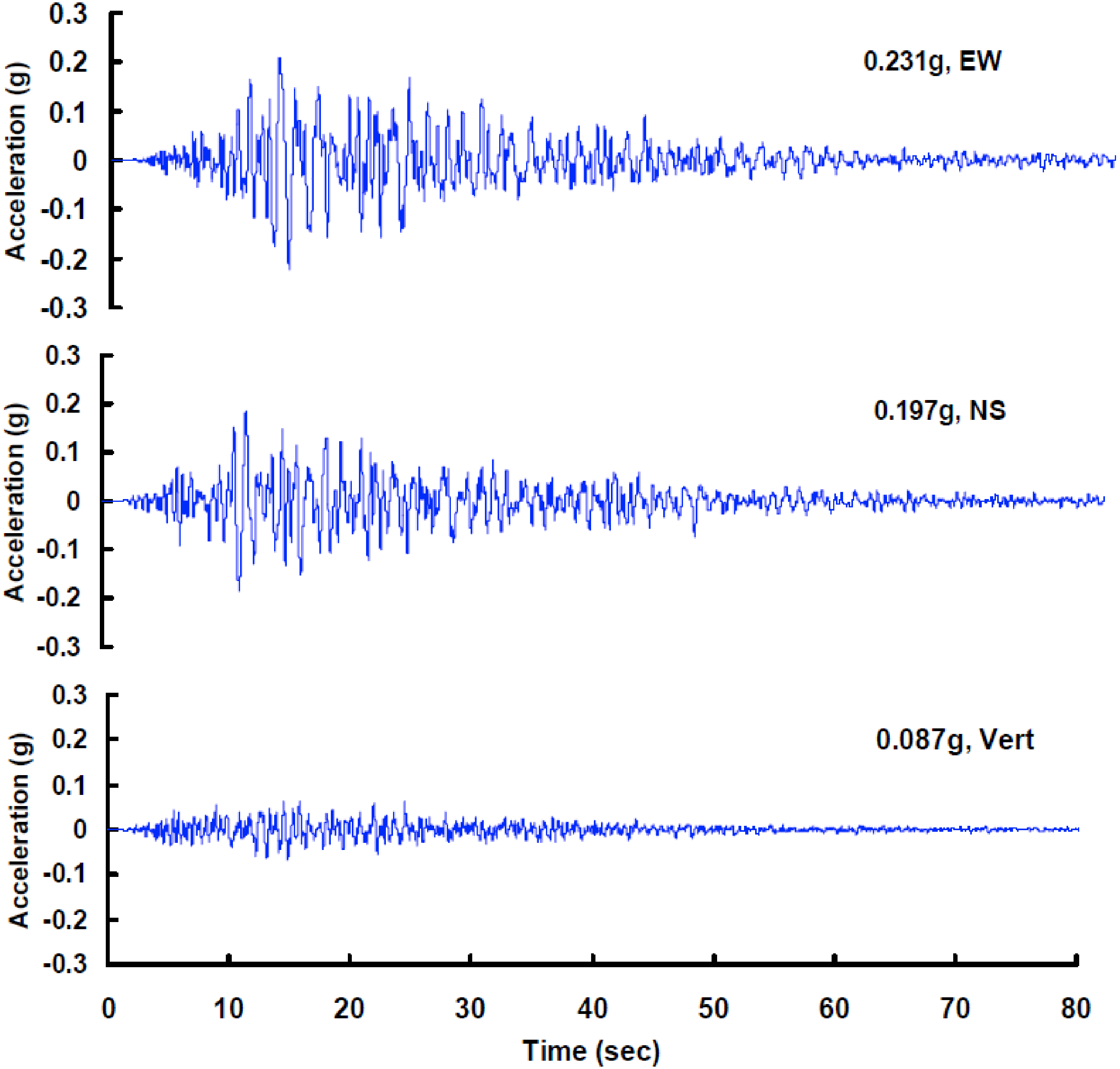


PGA: Peak Ground Acceleration
(10% Probability of Exceedance in 50 yrs)

The 8th October 2005 Kashmir M 7.6 Event

Abbottabad, 8th October 2005

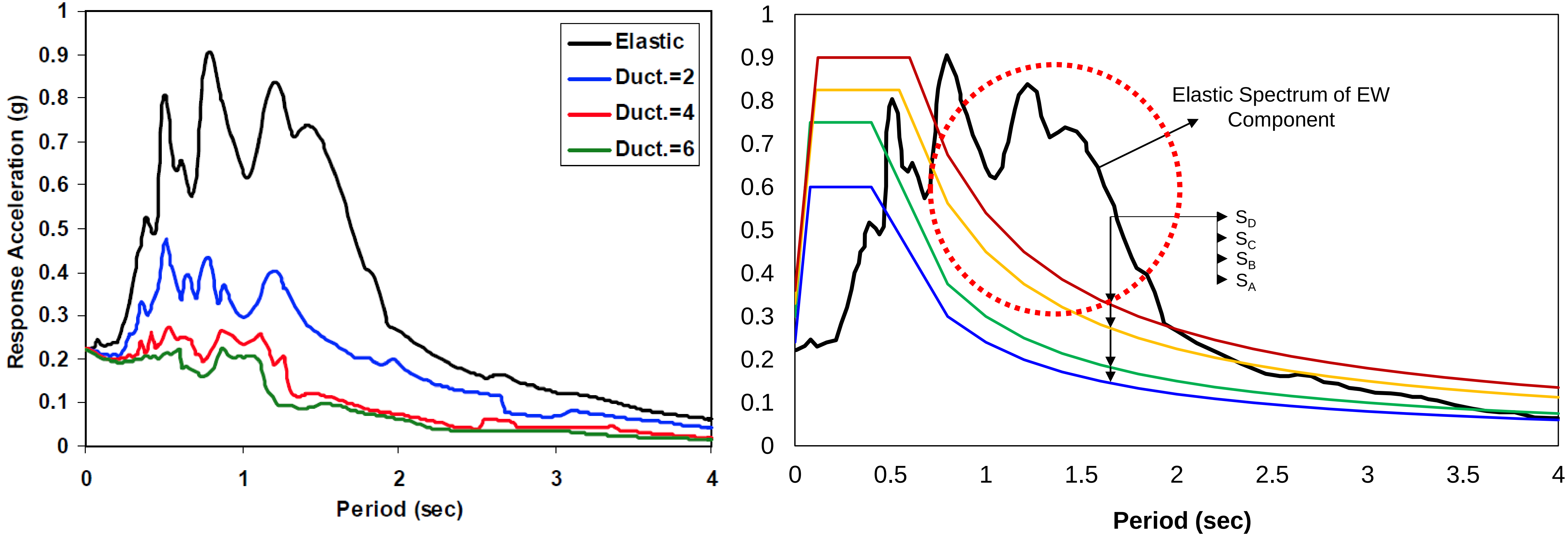




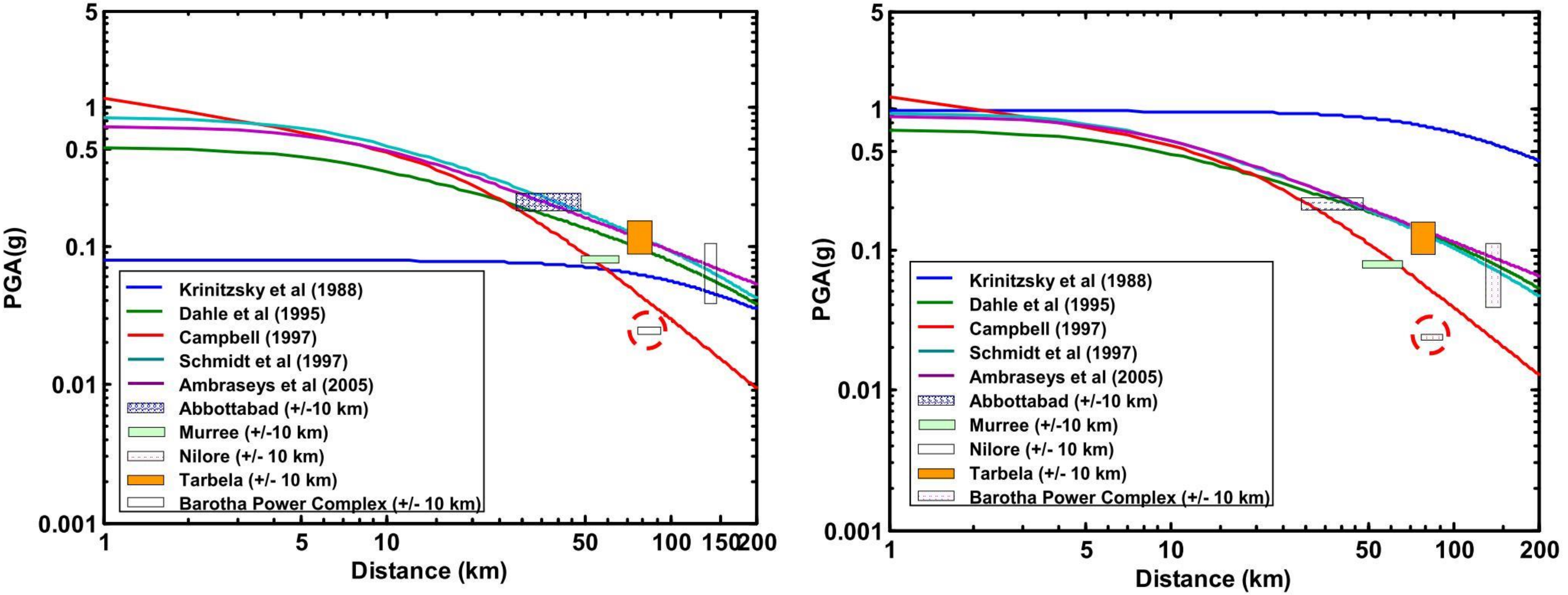
Source: Durrani et al., (2005) Kashmir earthquake of 8th October 2005 – A quick look report

How much we understand?

Abbottabad, 8th October 2005



Source: Durrani et al., (2005) Kashmir earthquake of 8th October 2005 – A quick look report



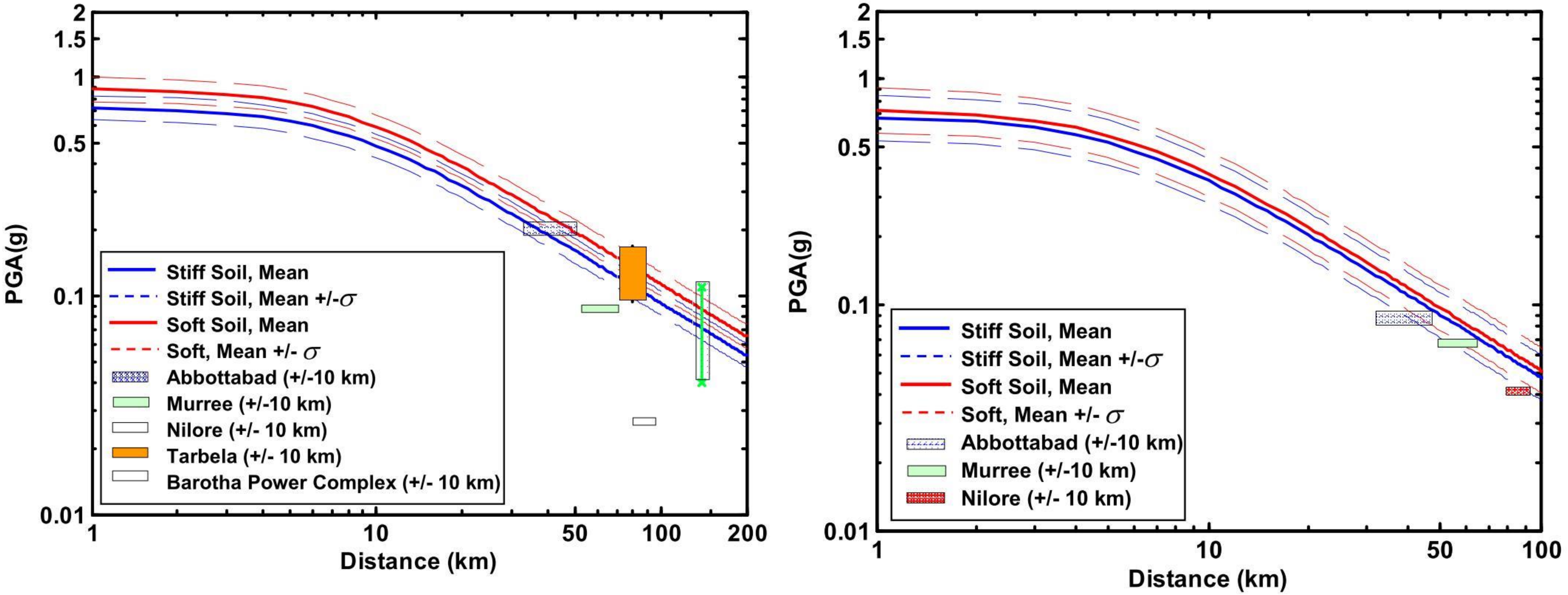
(a) PGA prediction for stiff soil

(b) PGA prediction for soft soil

Figure 3.10 Prediction of horizontal peak ground acceleration (bracketed value is suspect)

Note: Record at Nilore (red circle) is response of raft foundation

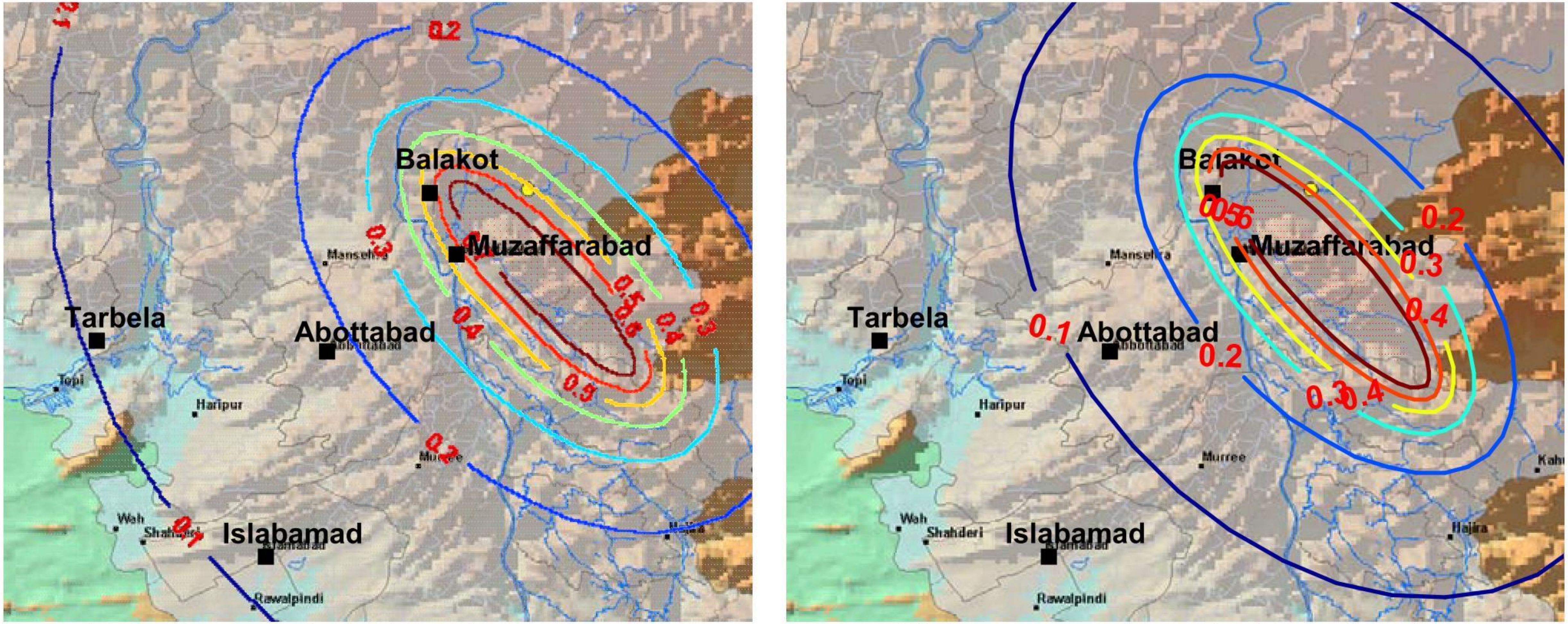
Source: Durrani et al., (2005) Kashmir earthquake of 8th October 2005 – A quick look report



(a) PGA prediction for horizontal ground motion (b) PGA prediction for vertical ground motion

Figure 3.11 Prediction of peak ground acceleration using equation by Ambraseys and Douglas (2005)

Source: Durrani et al., (2005) Kashmir earthquake of 8th October 2005 – A quick look report



(a) Contour map for horizontal ground motion (b) Contour map for vertical ground motion

Figure 3.12 PGA Contour maps for the affected region (on the fault trace, accelerations of 1g or higher are possible)

Source: Durrani et al., (2005) Kashmir earthquake of 8th October 2005 – A quick look report

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

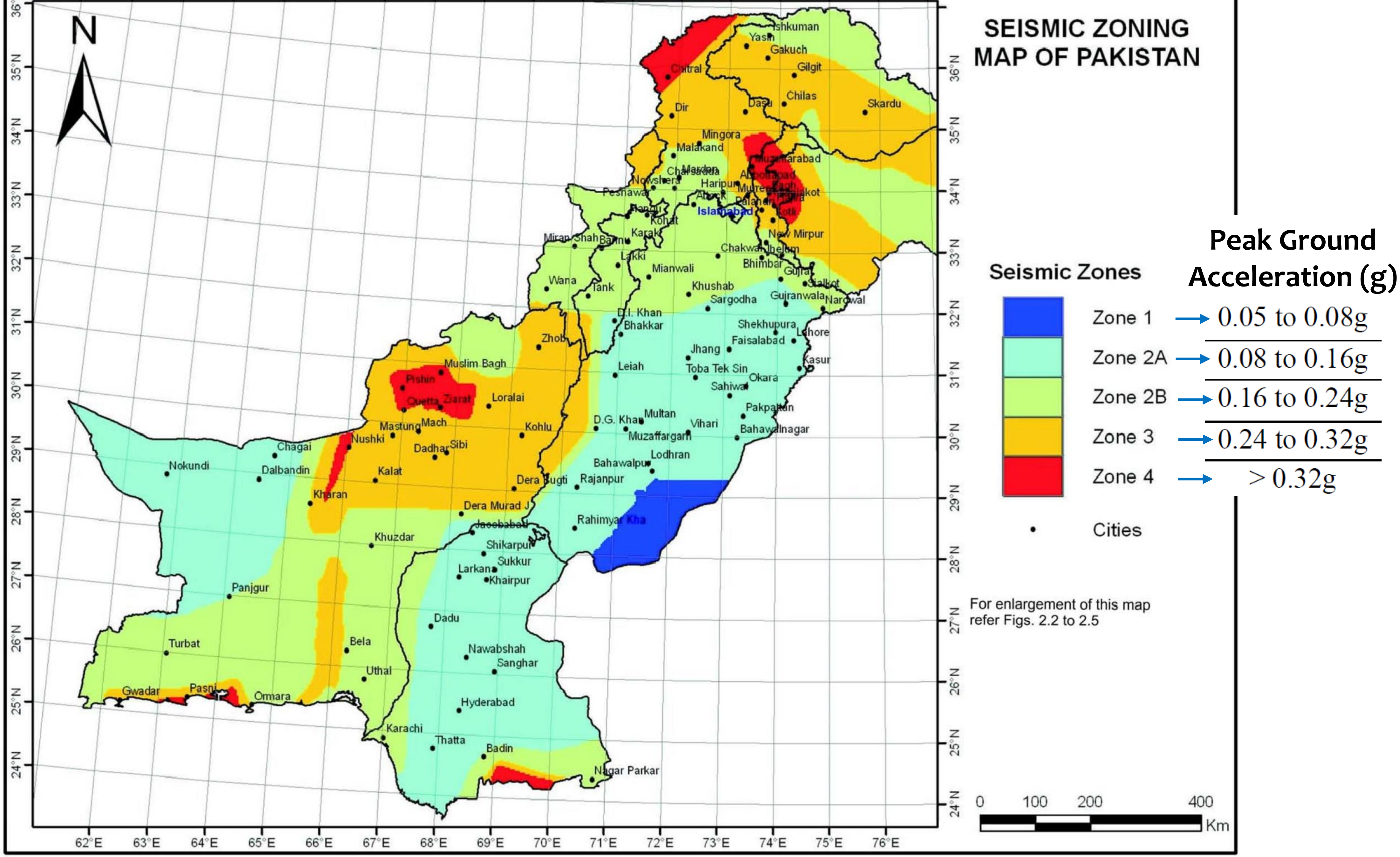
Major active faults of Pakistan and surrounding areas that strongly influence the seismic hazard are listed below:

- 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
N
Seismic Zones
Zone 1
Zone 2A
Zone 2B
Zone 3
Zone 4
Cities
Peak Ground Acceleration (g)
0.05 to 0.08g
0.08 to 0.16g
0.16 to 0.24g
0.24 to 0.32g
> 0.32g
For enlargement of this map refer Figs. 2.2 to 2.5
0 100 200 400 Km
Ishkuman
Yasin
Gakuch
Gilgit
Chitral
Chilas
Dasu
Skardu
Dir
Mingora
Malakand
Muzaffarabad
Charsadda
Mardan
Nowshera
Abbottabad
Haripur
Peshawar
Murree
Attock
Bagh
Kotli
Islamabad
Kohat
Hangu
Karak
Miran Shah
Bannu
New Mirpur
Chakwal
Jhelum
Lakki
Bhimbar
Mianwali
Gujrat
Wana
Tank
Khushab
Sialkot
Gujranwala
Narowal
Sargodha
D.I. Khan
Bhakkar
Shekhupura
Lahore
Faisalabad
Zhob
Jhang
Kasur
Muslim Bagh
Leiah
Toba Tek Sin
Okara
Pishin
Sahiwal
Loralai
Quetta
Ziarat
Pakpattan
Mastung
Mach
D.G. Khan
Multan
Vihari
Kohlu
Muzaffargarh
Bahawalnagar
Nushki
Sibi
Chagai
Dadhar
Nokundi
Lodhran
Dalbandin
Kalat
Bahawalpur
Dera Bugti
Rajanpur
Kharan
Dera Murad J
Jacobabad
Rahimyar Kha
Khuzdar
Shikarpur
Sukkur
Larkana
Khairpur
Panjgur
Dadu
Nawabshah
Sanghar
Turbat
Bela
Uthal
Gwadar
Pasni
Ormara
Hyderabad
Karachi
Thatta
Badin
Nagar Parkar

FIG. 2.2

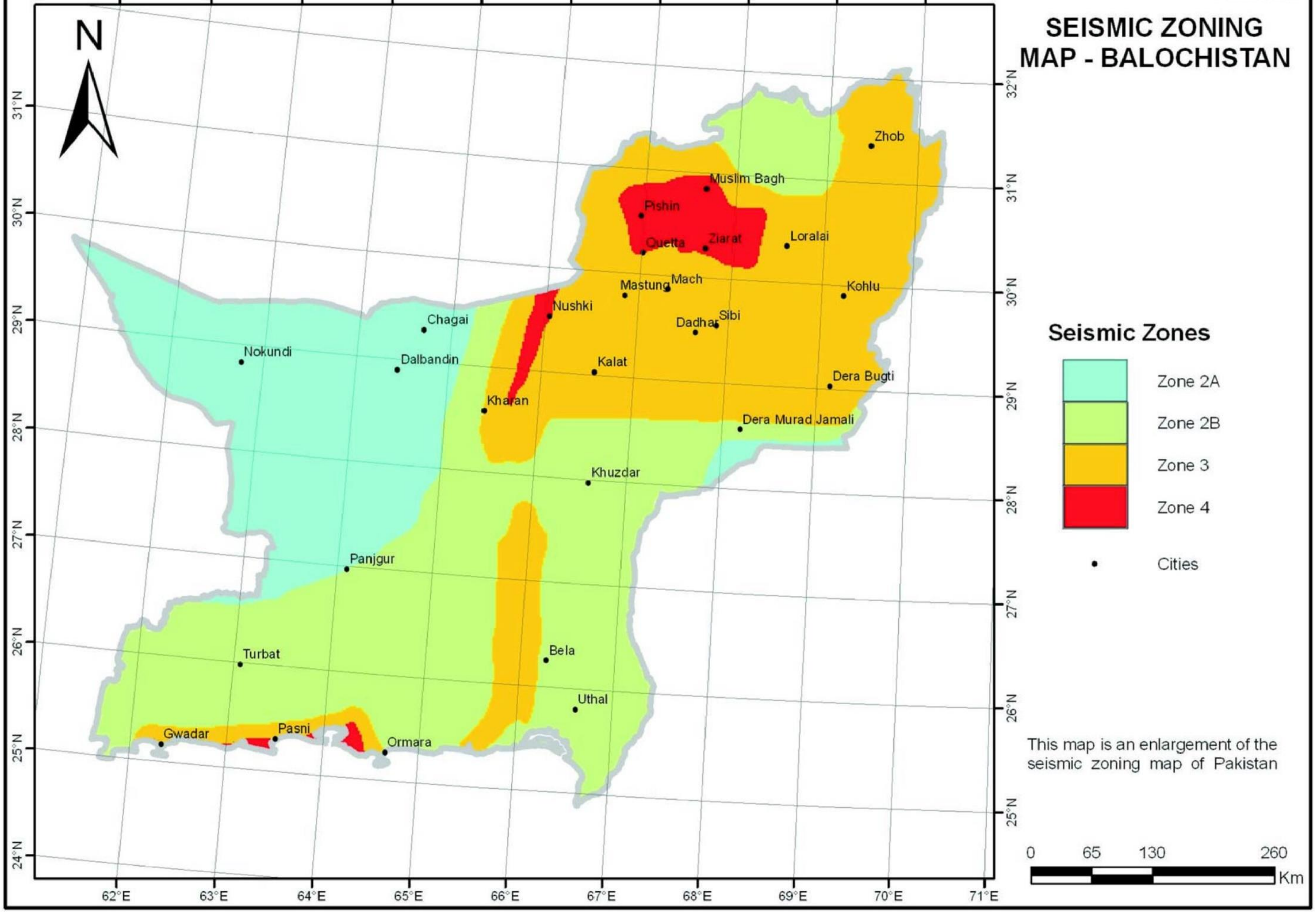
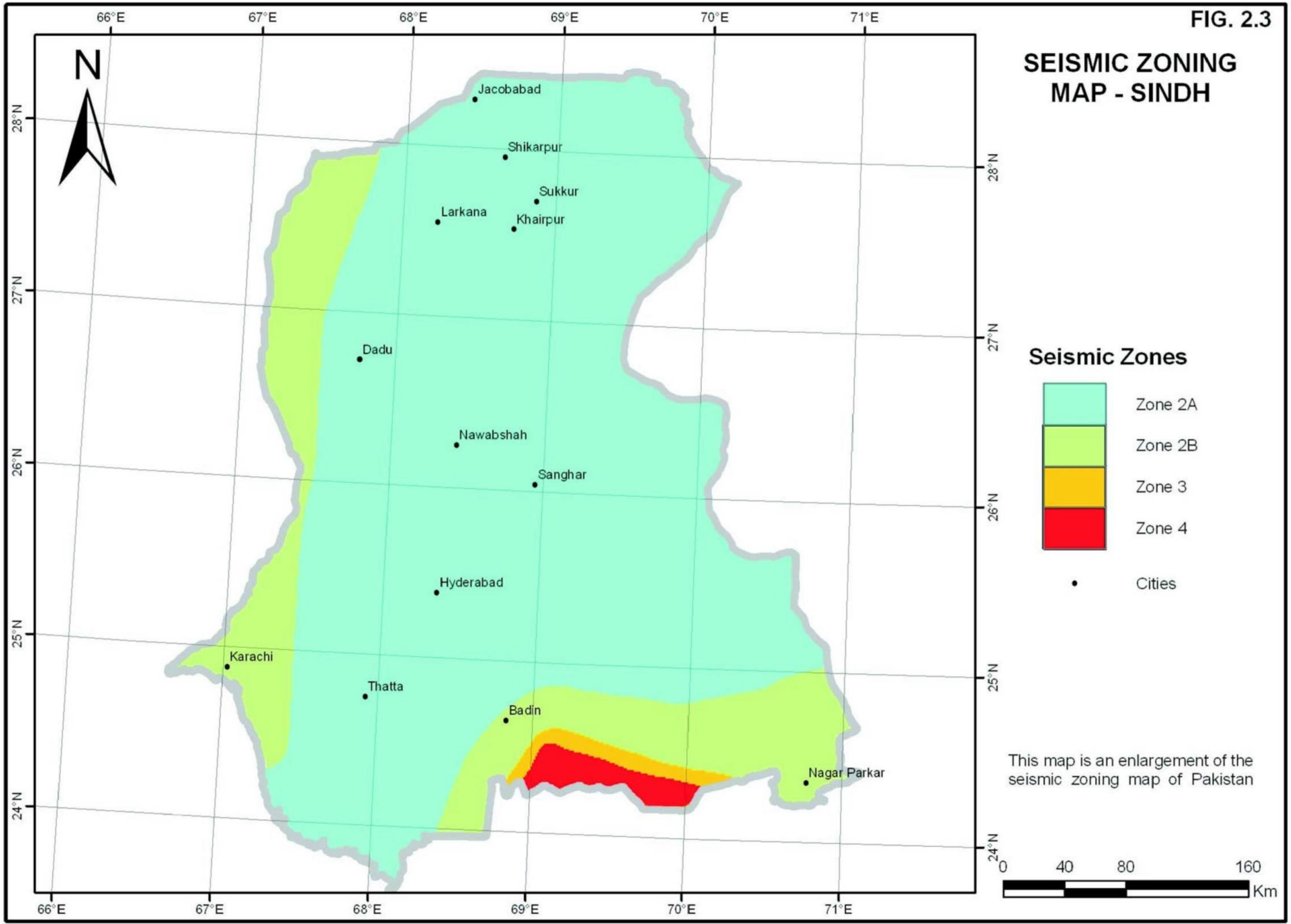

SEISMIC ZONING
MAP - BALOCHISTAN
N
Seismic Zones
Zone 2A
Zone 2B
Zone 3
Zone 4
Cities
This map is an enlargement of the seismic zoning map of Pakistan
0
65
130
260
Km
Zhob
Muslim Bagh
Pishin
Quetta
Ziarat
Loralai
Mastung
Mach
Kohlu
Nushki
Dadhar
Sibi
Chagai
Nokundi
Dalbandin
Kalat
Dera Bugti
Kharan
Dera Murad Jamali
Khuzdar
Panjgur
Turbat
Bela
Uthal
Gwadar
Pasni
Ormara
61°E
62°E
63°E
64°E
65°E
66°E
67°E
68°E
69°E
70°E
71°E
24°N
25°N
26°N
27°N
28°N
29°N
30°N
31°N
32°N

FIG. 2.3


SEISMIC ZONING
MAP - SINDH
N
Jacobabad
Shikarpur
Sukkur
Larkana
Khairpur
Dadu
Nawabshah
Sanghar
Hyderabad
Karachi
Thatta
Badin
Nagar Parkar
66°E
67°E
68°E
69°E
70°E
71°E
24°N
25°N
26°N
27°N
28°N
Seismic Zones
Zone 2A
Zone 2B
Zone 3
Zone 4
Cities
This map is an enlargement of the seismic zoning map of Pakistan
0
40
80
160
Km

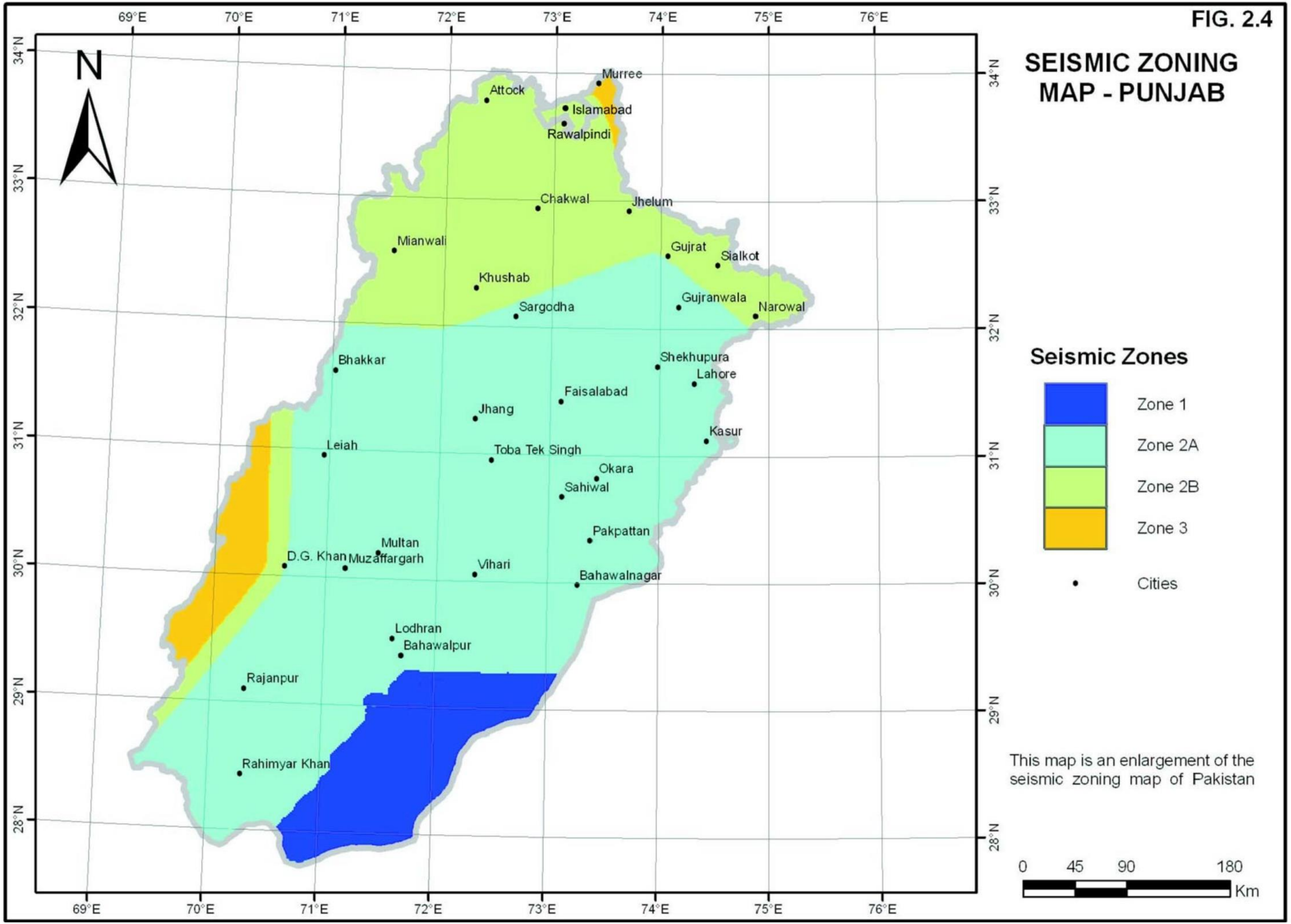


FIG. 2.4

SEISMIC ZONING MAP - PUNJAB

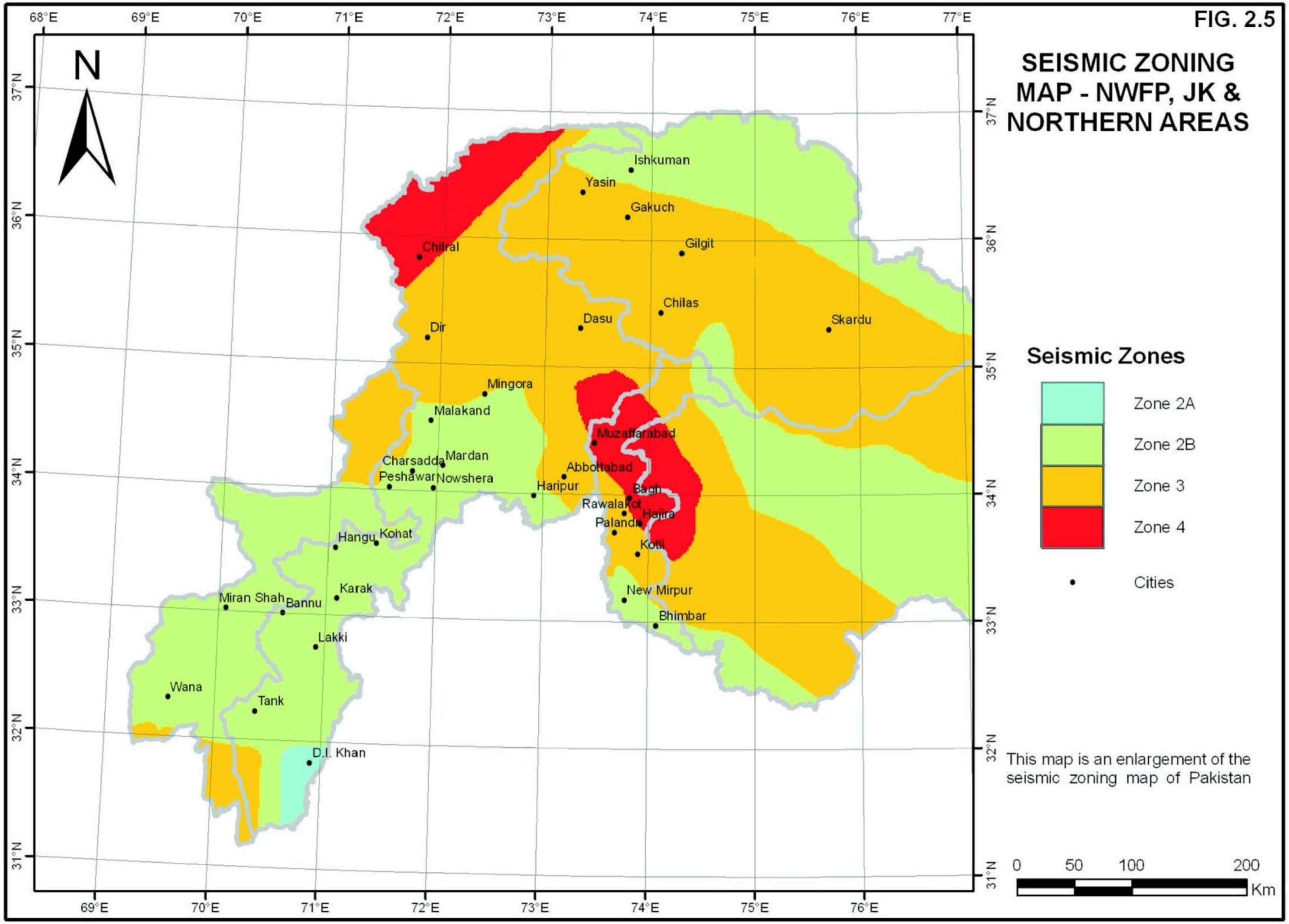
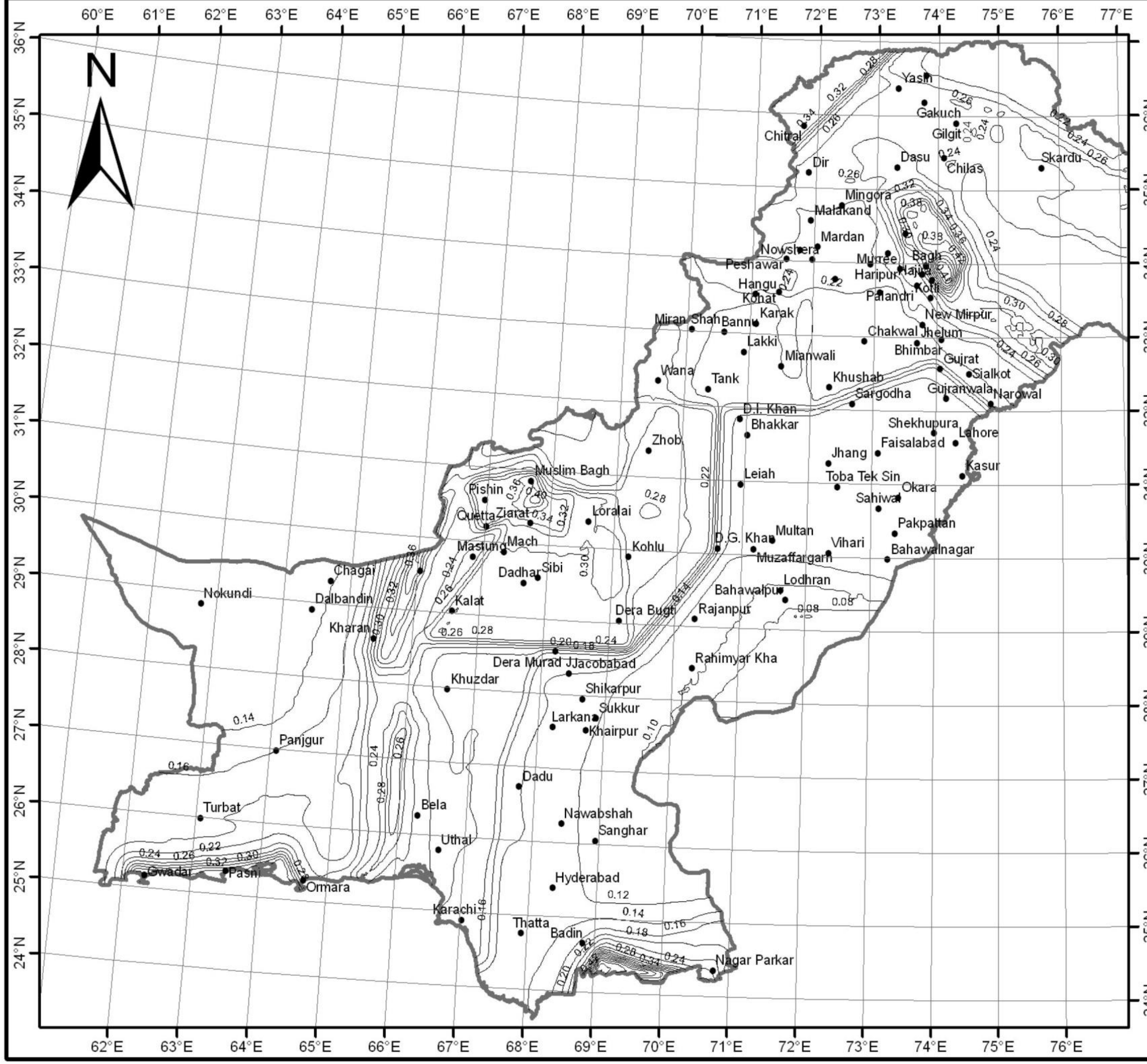


FIG. 2.5

SEISMIC ZONING MAP - NWFP, JK & NORTHERN AREAS

FIG. A-1



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

PGA Contour Interval = 0.02g

0 100 200 400 Km

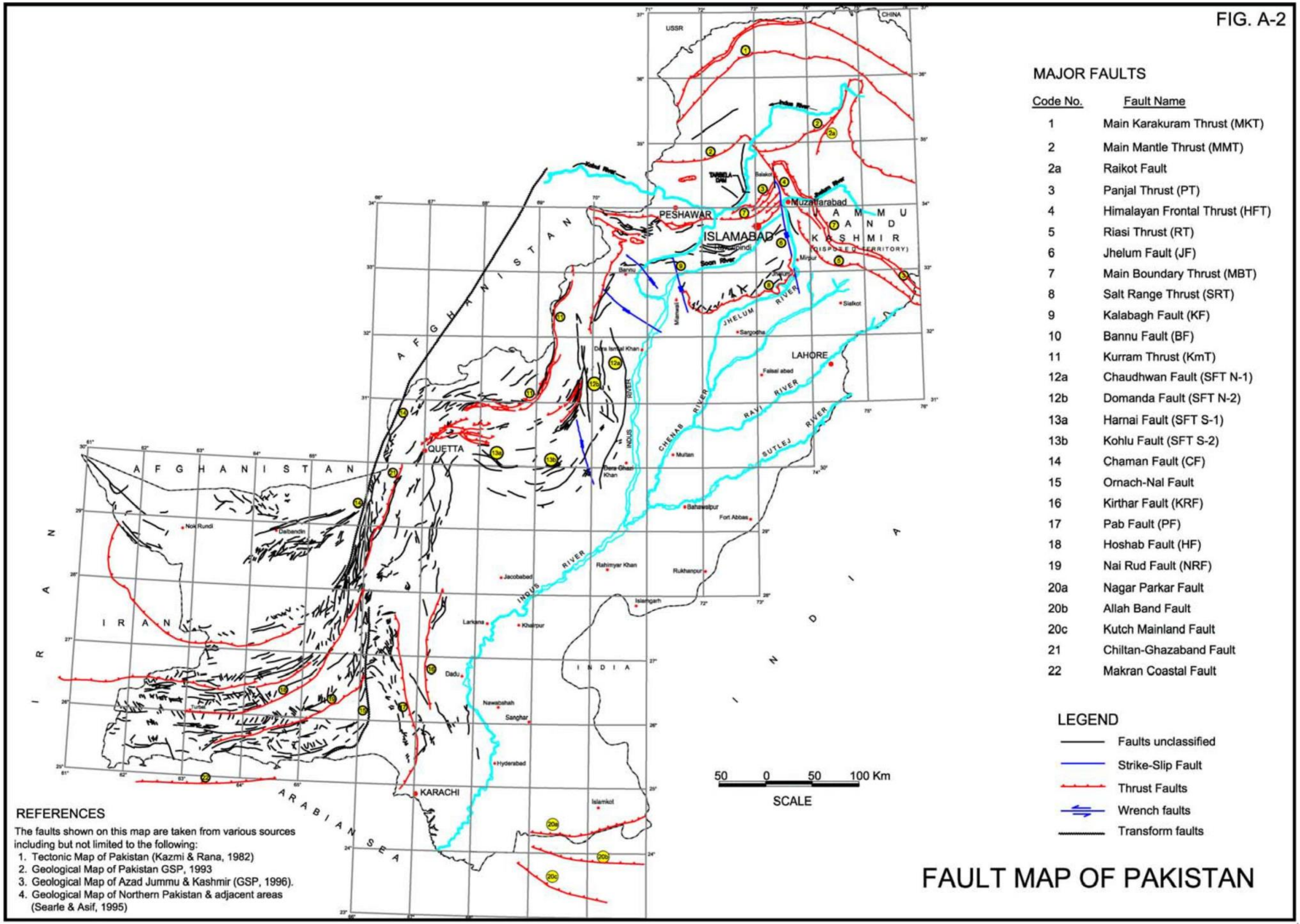
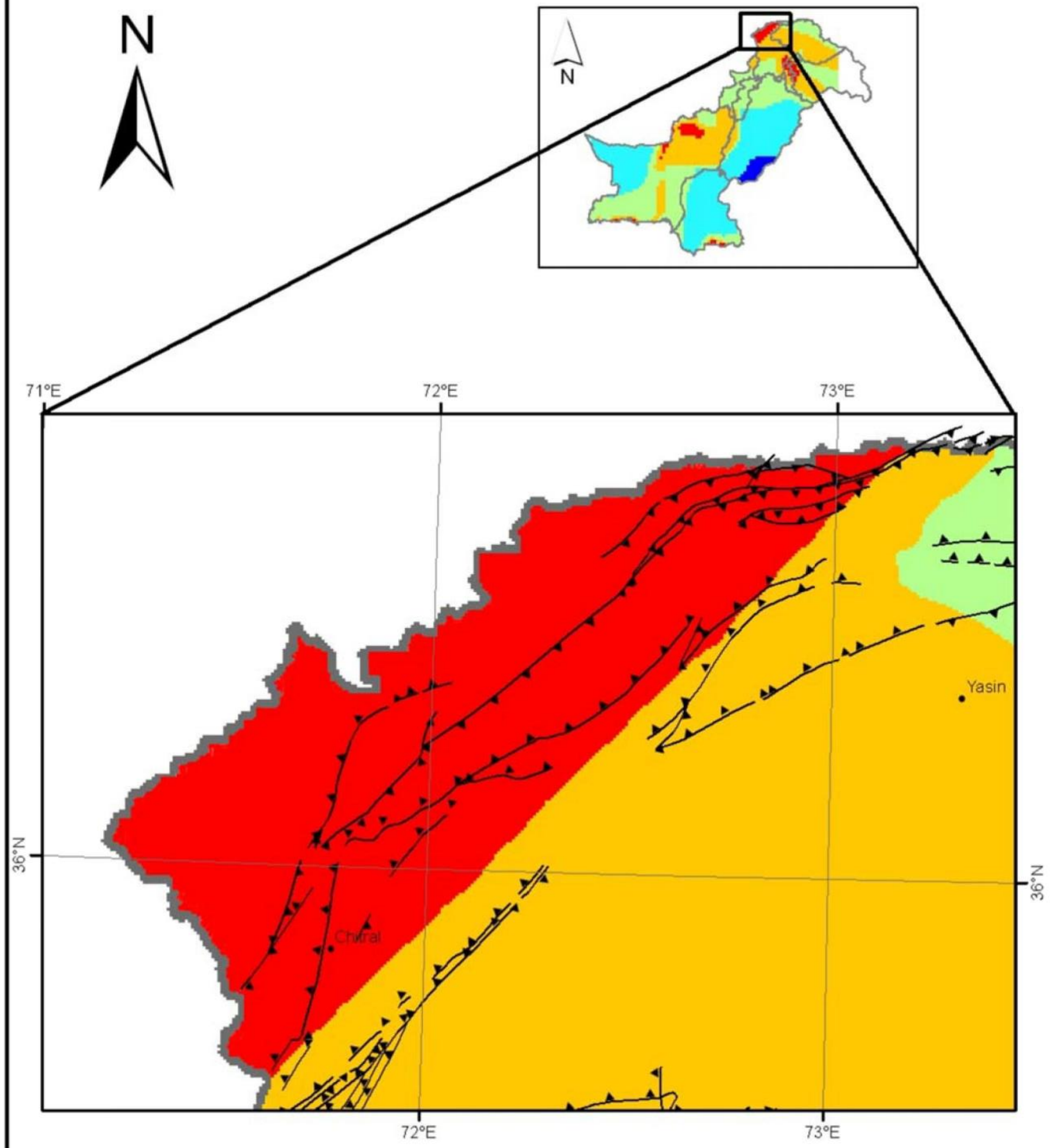


FIG. A-2
MAJOR FAULTS
Code No. Fault Name
1 Main Karakuram Thrust (MKT)
2 Main Mantle Thrust (MMT)
2a Raikot Fault
3 Panjal Thrust (PT)
4 Himalayan Frontal Thrust (HFT)
5 Riasi Thrust (RT)
6 Jhelum Fault (JF)
7 Main Boundary Thrust (MBT)
8 Salt Range Thrust (SRT)
9 Kalabagh Fault (KF)
10 Bannu Fault (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
50 0 50 100 Km
SCALE
FAULT MAP OF PAKISTAN
AFGHANISTAN
IRAN
INDIA
ARABIAN SEA
JAMMU AND KASHMIR (DISPUTED TERRITORY)
ISLAMABAD
PESHAWAR
Muzaffarabad
QUETTA
KARACHI
LAHORE
CHINA
USSR
INDUS RIVER
JHELUM RIVER
CHENAB RIVER
RAVI RIVER
SUTLEJ RIVER
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)

FIG. A-3a

DETAILS OF FAULTS IN ZONE 4



Seismic Zones

- Zone 1
- Zone 2A
- Zone 2B
- Zone 3
- Zone 4
- • Cities

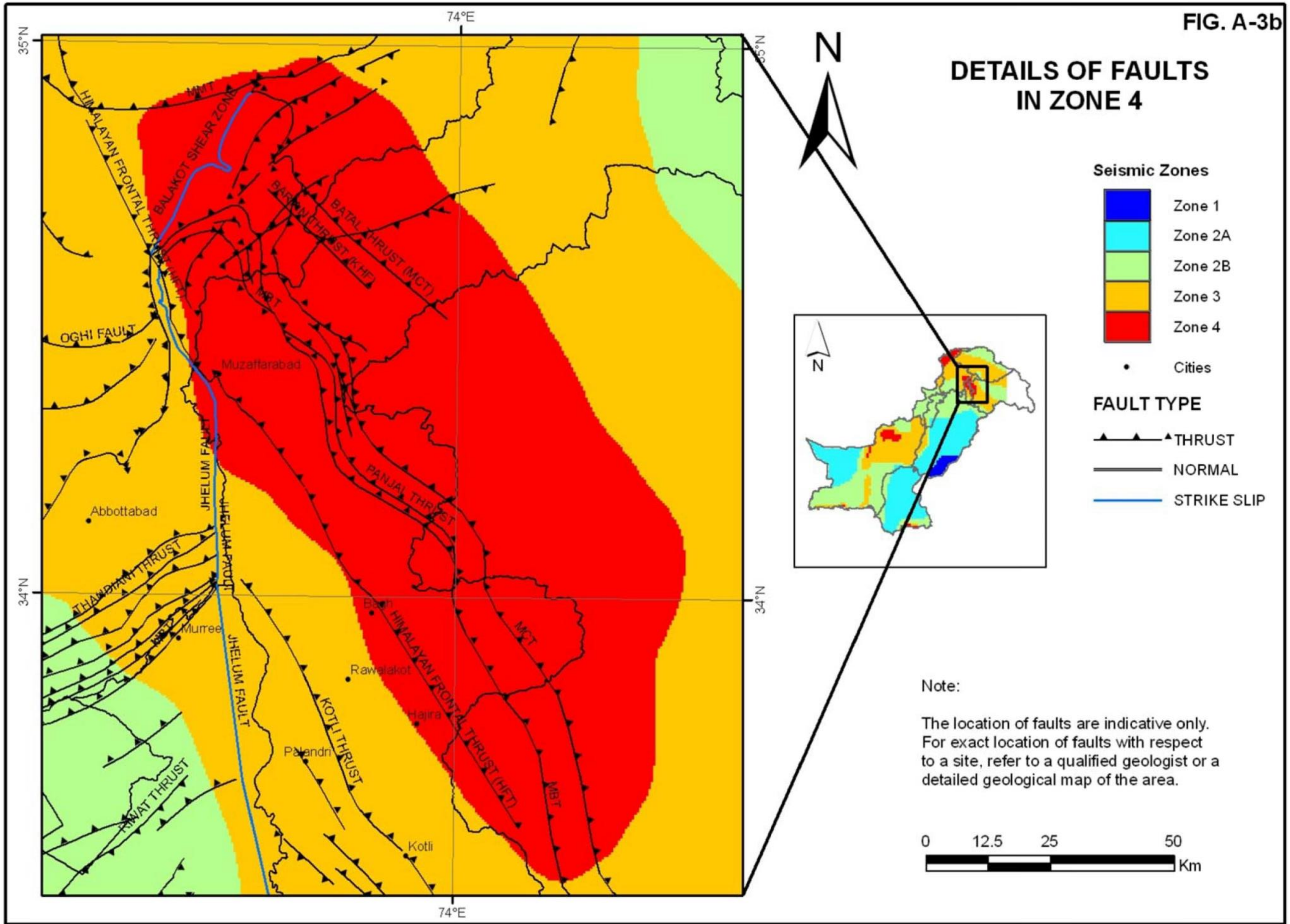
FAULT TYPE

- THRUST
- NORMAL
- STRIKE SLIP

Note:

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.

0 15 30 60 Km



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.

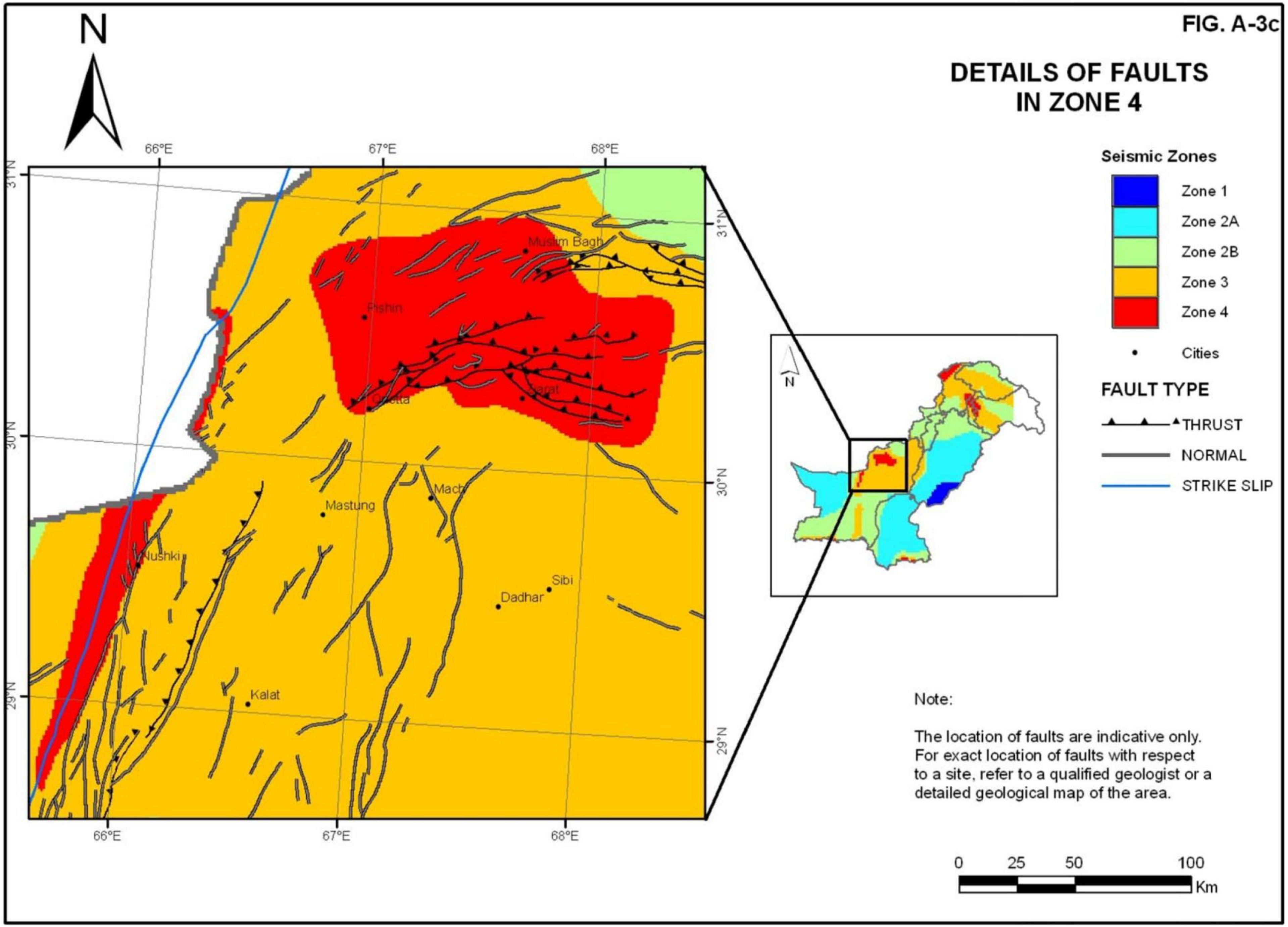
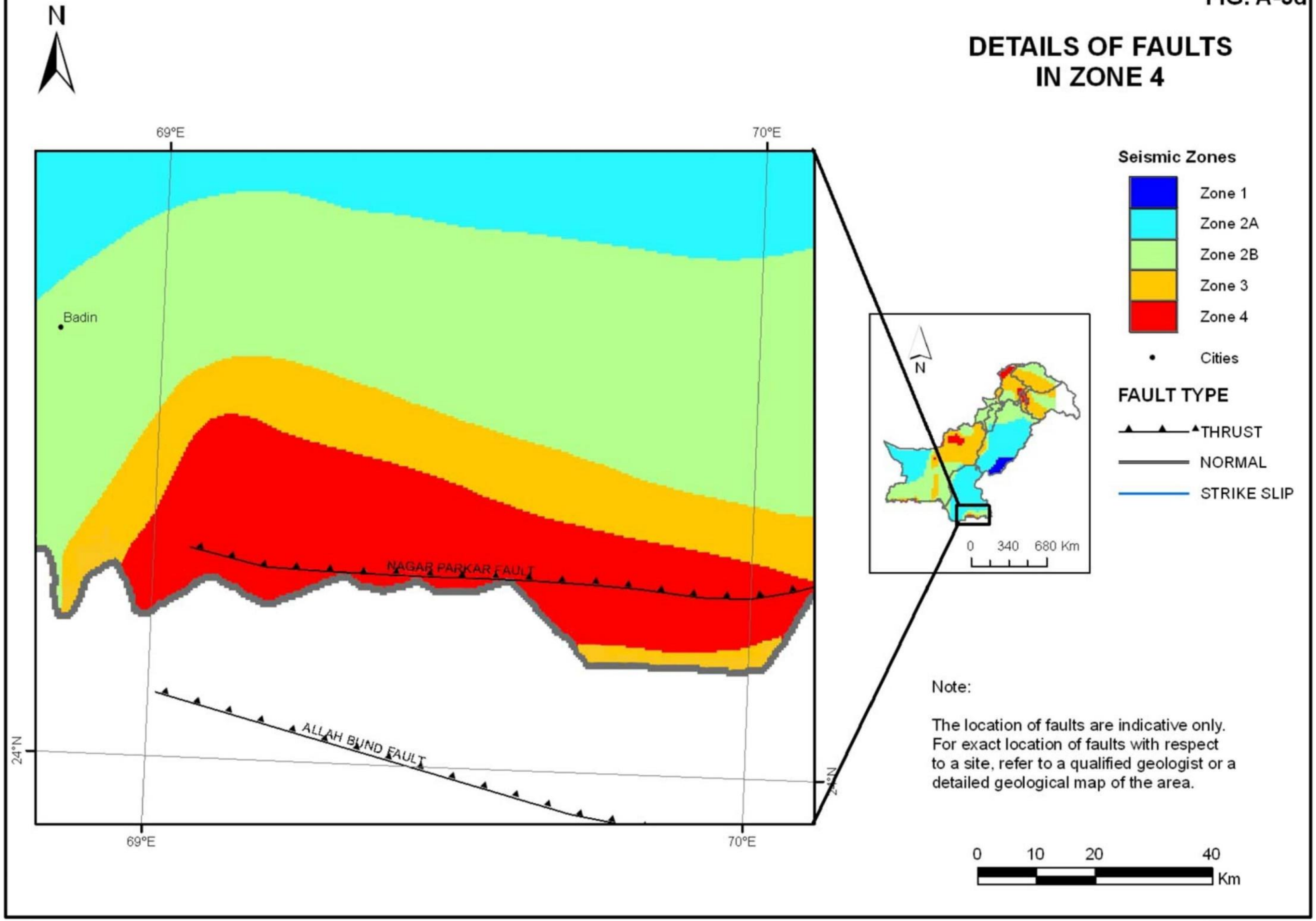


FIG. A-3c
DETAILS OF FAULTS
IN ZONE 4
N
66°E
67°E
68°E
31°N
30°N
29°N
Muslim Bagh
Pishin
Quetta
Ziarat
Mastung
Mach
Nushki
Sibi
Dadhar
Kalat
Seismic Zones
Zone 1
Zone 2A
Zone 2B
Zone 3
Zone 4
Cities
FAULT TYPE
THRUST
NORMAL
STRIKE SLIP
Note:
The location of faults are indicative only.
For exact location of faults with respect
to a site, refer to a qualified geologist or a
detailed geological map of the area.
0
25
50
100
Km

FIG. A-3d

DETAILS OF FAULTS IN ZONE 4

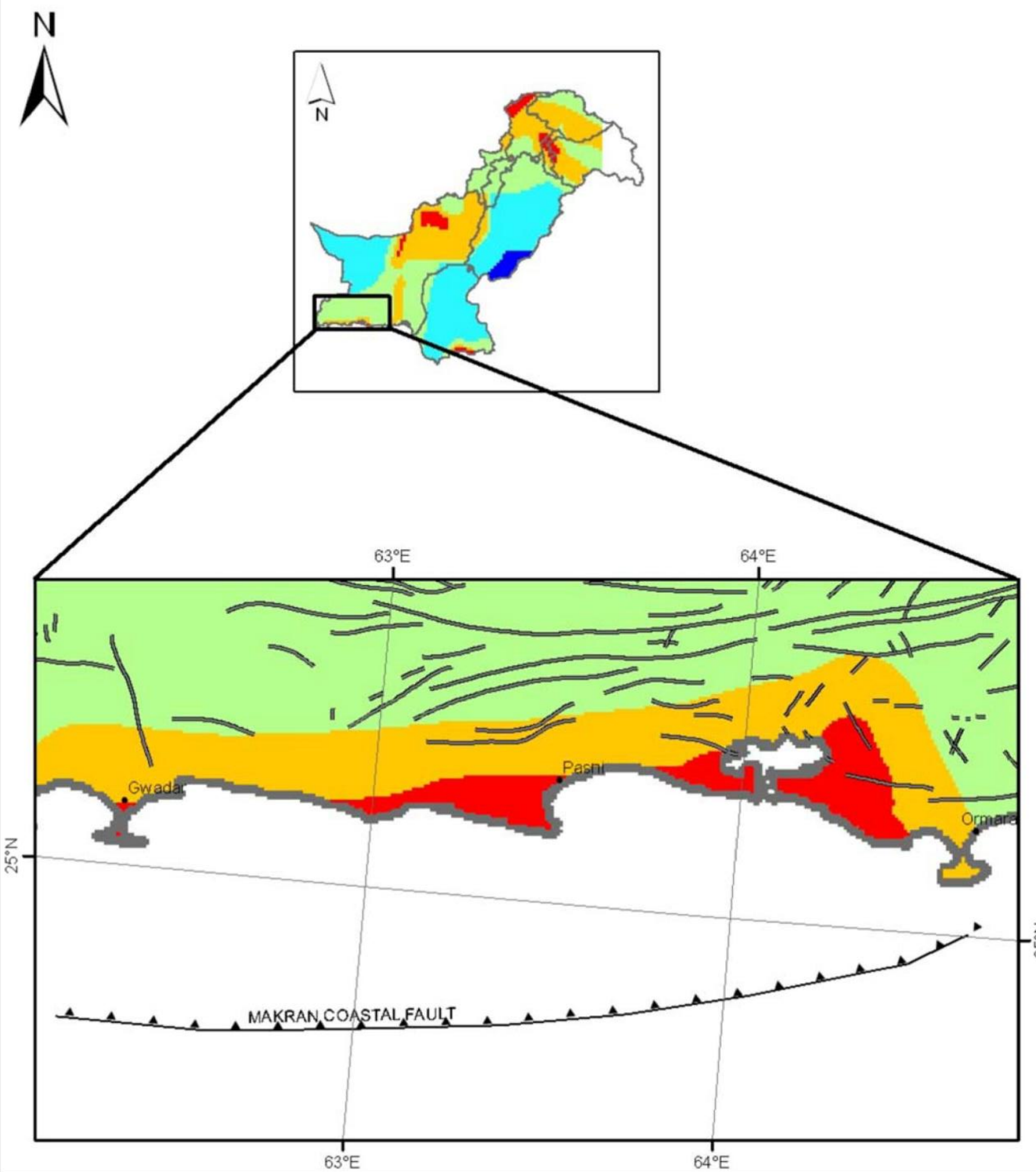


Note:

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-3e

DETAILS OF FAULTS IN ZONE 4



Seismic Zones

- Zone 1
- Zone 2A
- Zone 2B
- Zone 3
- Zone 4
- • Cities

FAULT TYPE

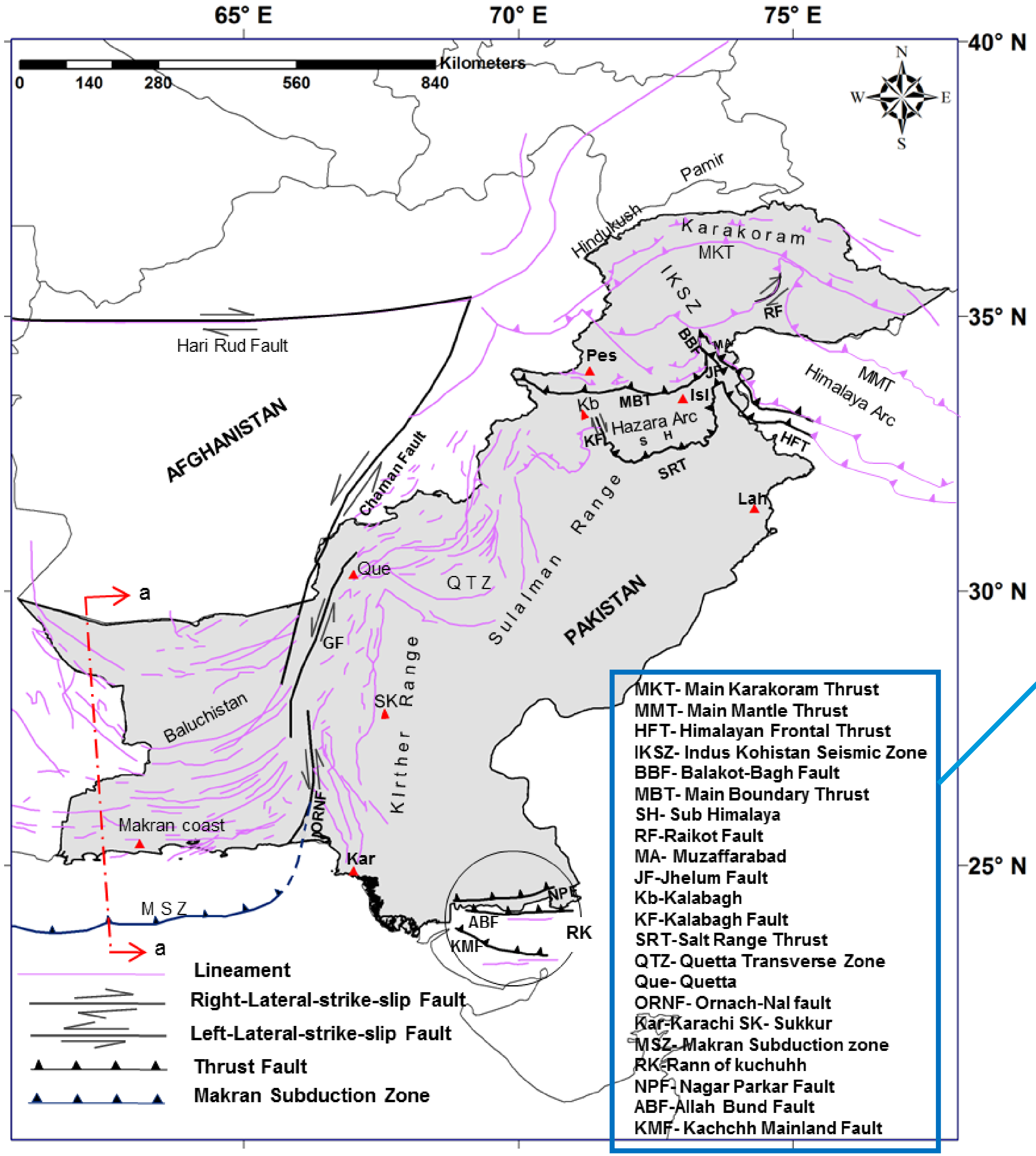
- THRUST
- NORMAL
- STRIKE SLIP

Note:

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.

0 20 40 80 Km

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

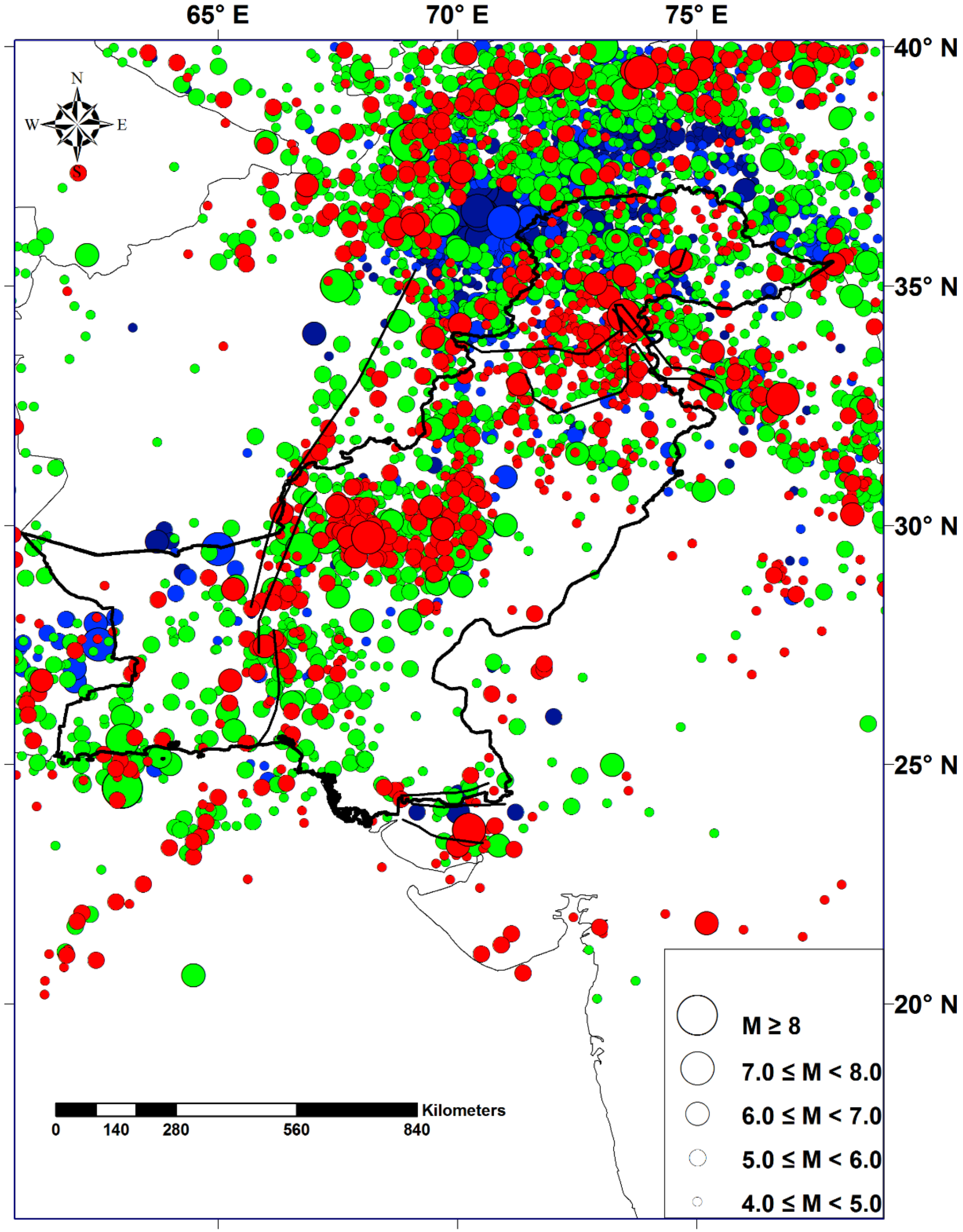


Regional tectonic setting of Pakistan

- 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

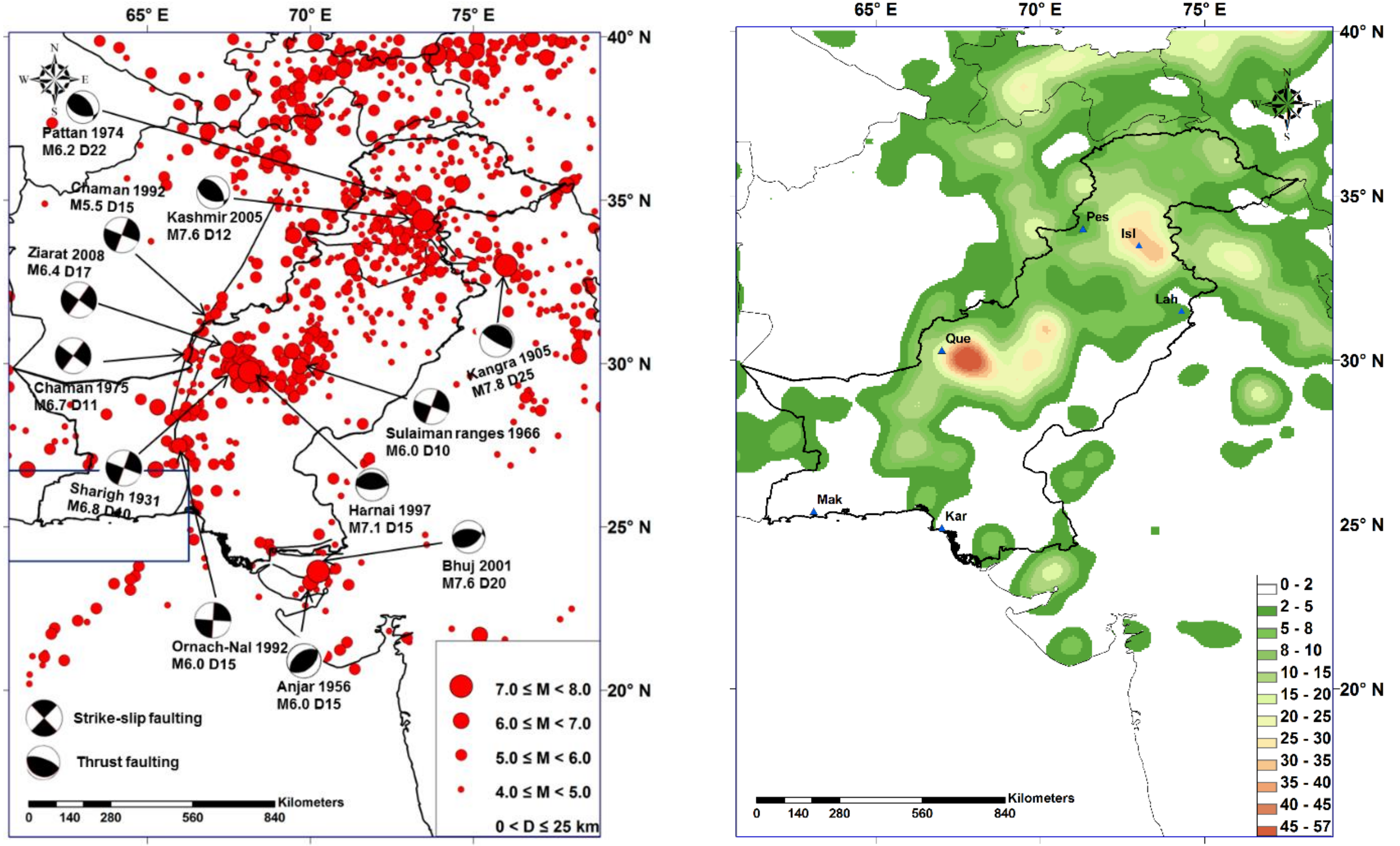
(Modified from Sarwar et al., 1979)

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



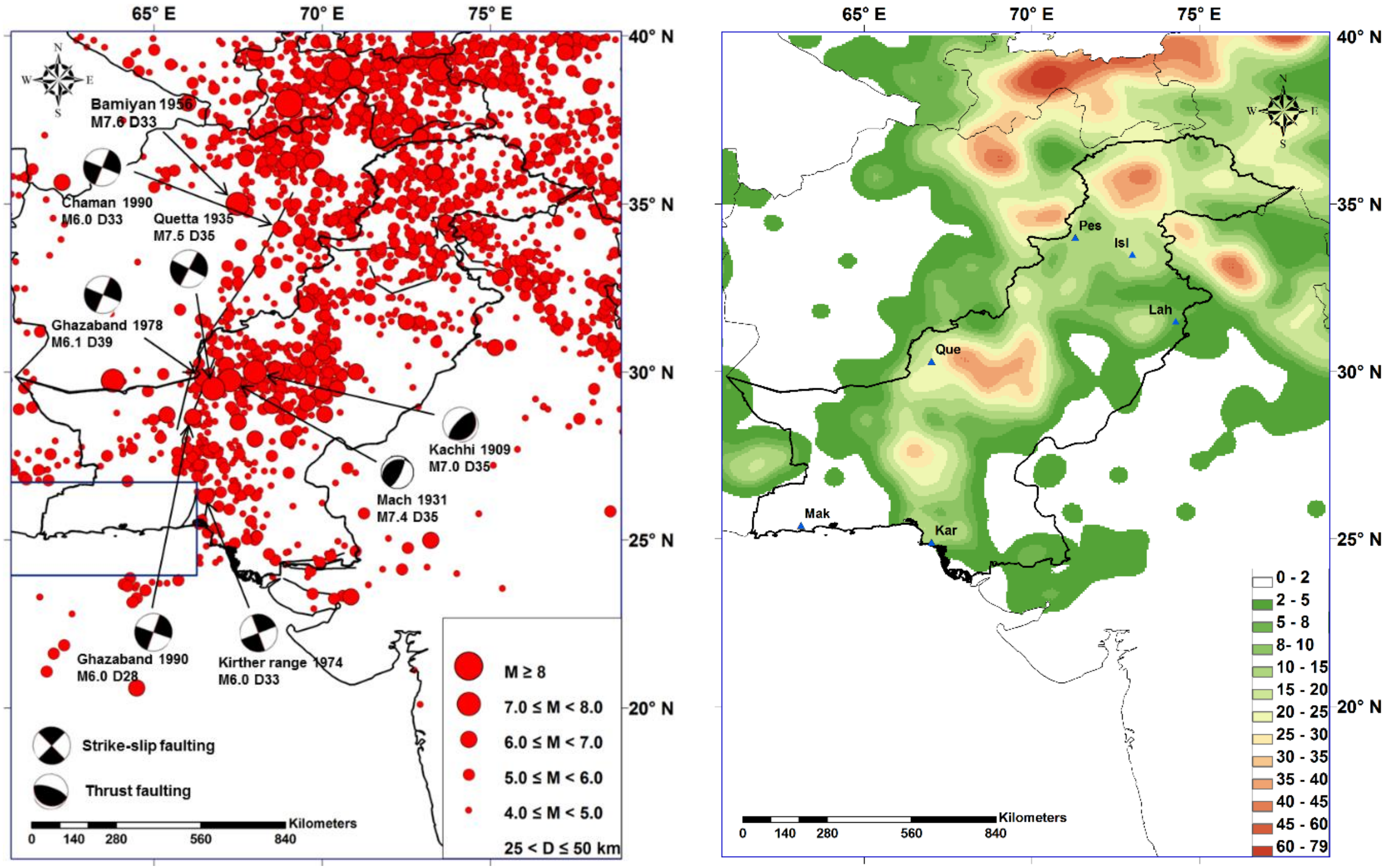
Pakistan and its surrounding seismicity from 1902 to 2009; red: 0-25 km depth, green: 25-50 km depth, blue: 50-100 km depth, and dark blue: 100-250 km depth

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



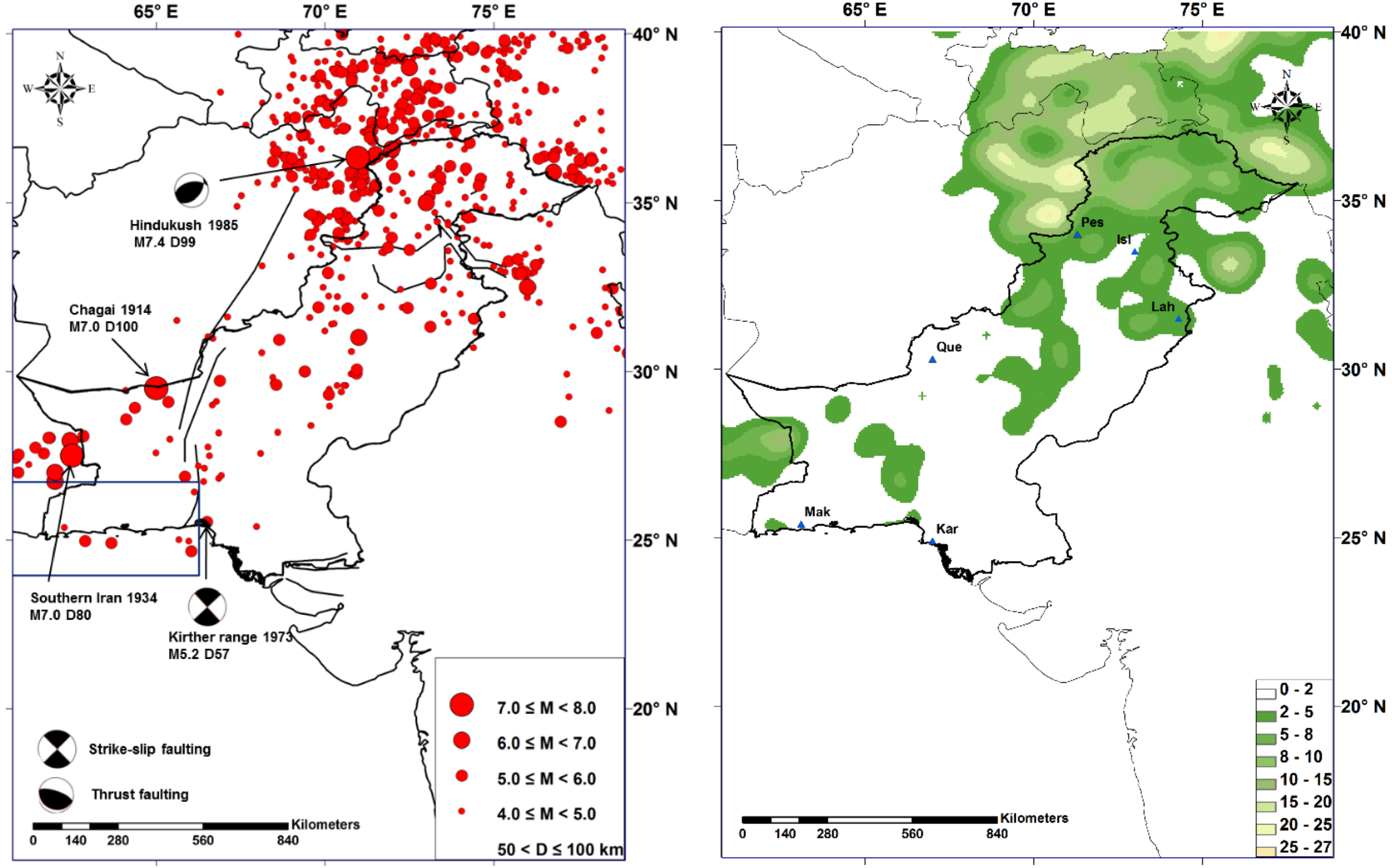
(a) Seismicity and (b) smoothed activity rate 10^a value derived for seismicity from 0-25 km depth

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



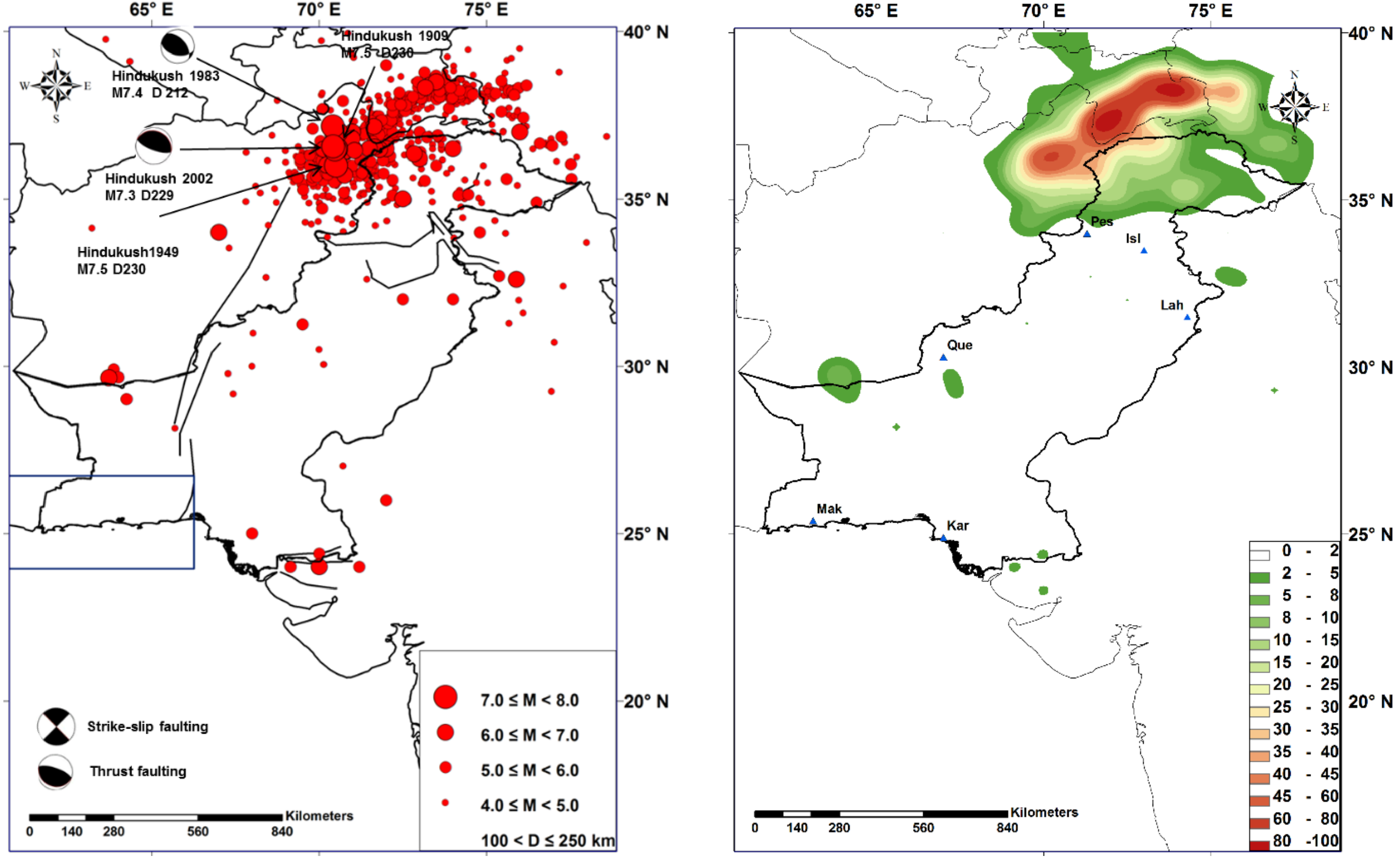
(a) Seismicity and (b) smoothed activity rate 10^a value derived for seismicity from 25-50 km depth

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



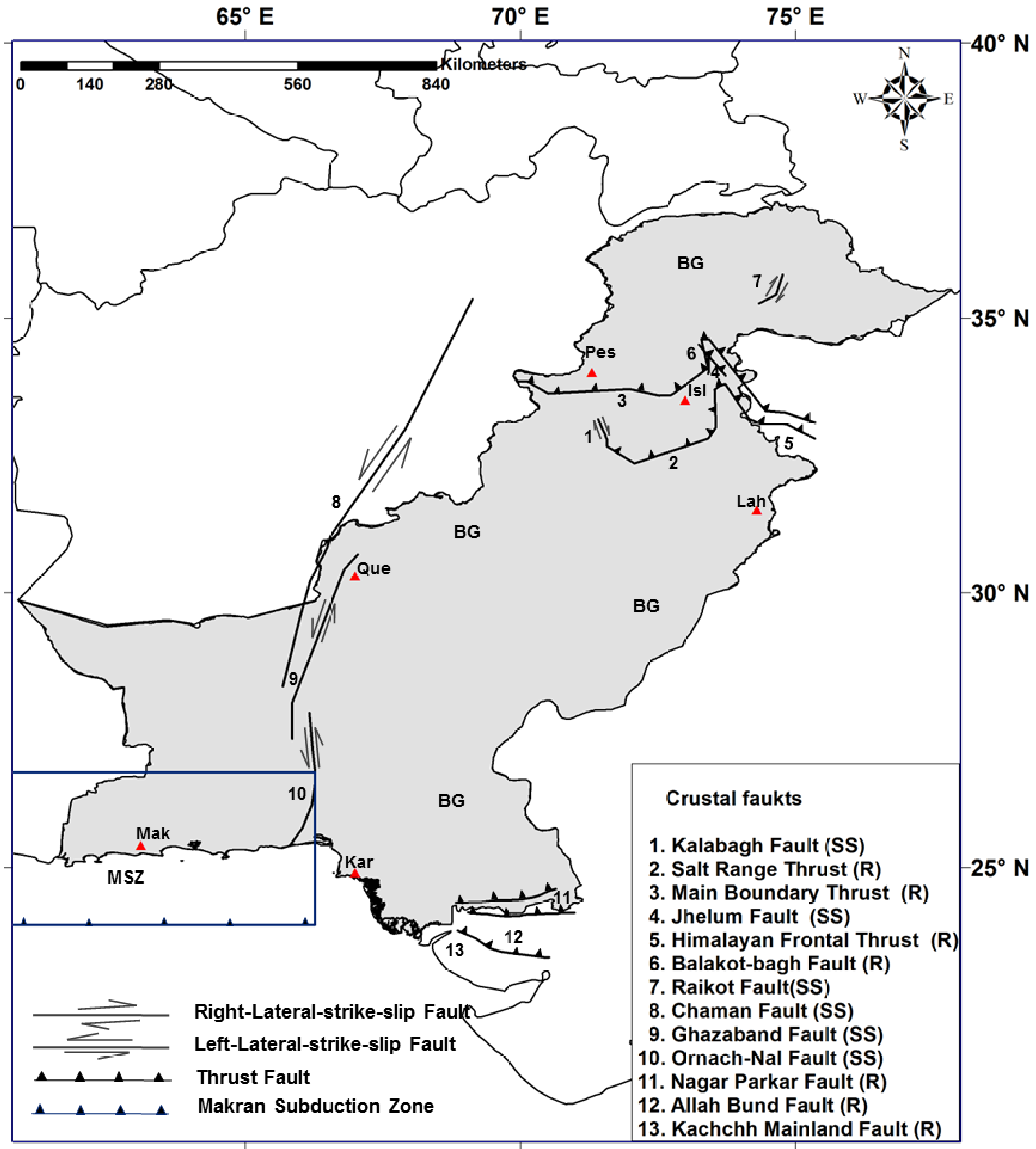
(a) Seismicity and (b) smoothed activity rate 10^a value derived for seismicity from 50-100 km depth

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



(a) Seismicity and (b) smoothed activity rate 10^a 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:

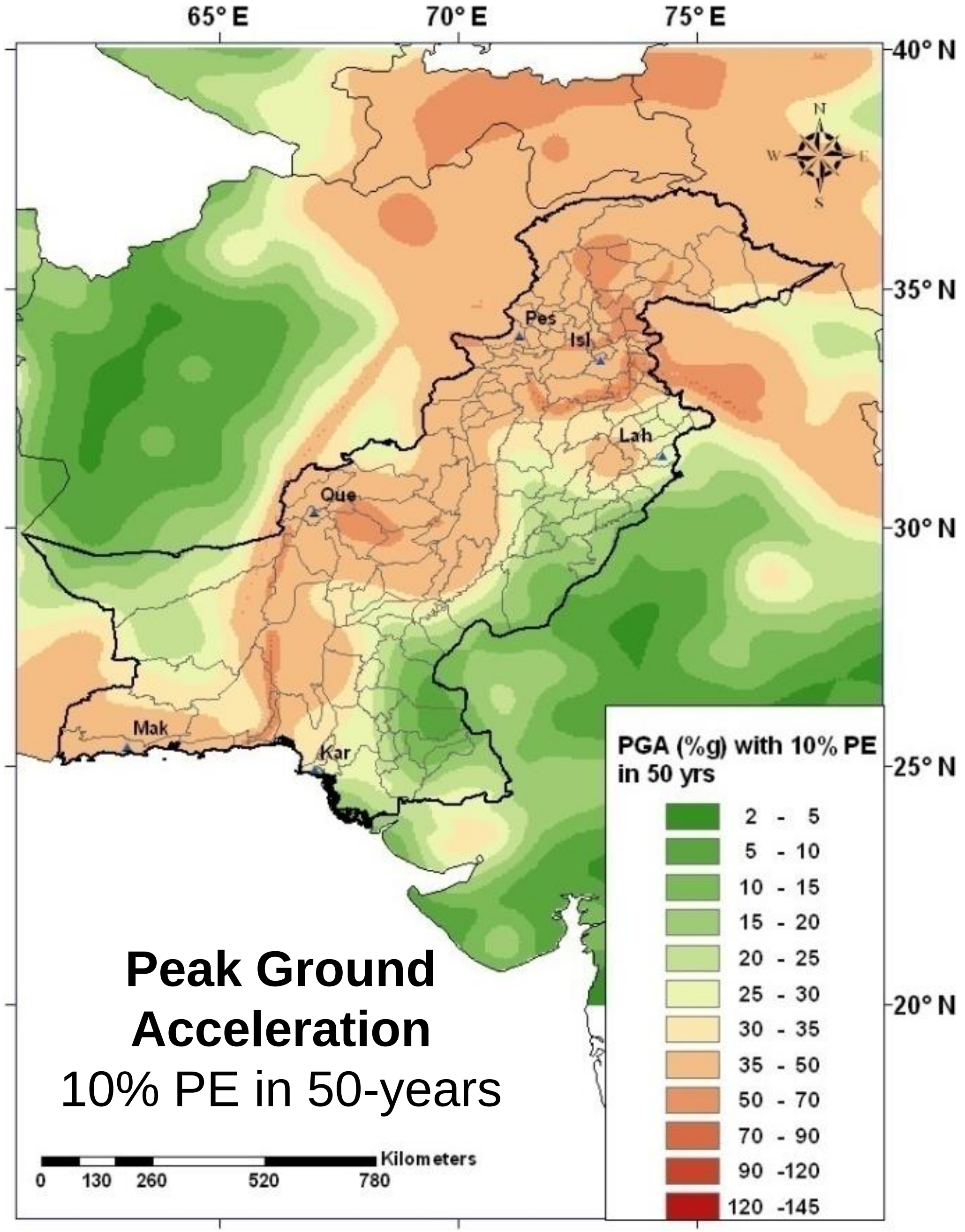
a) Background seismicity zone (BG)

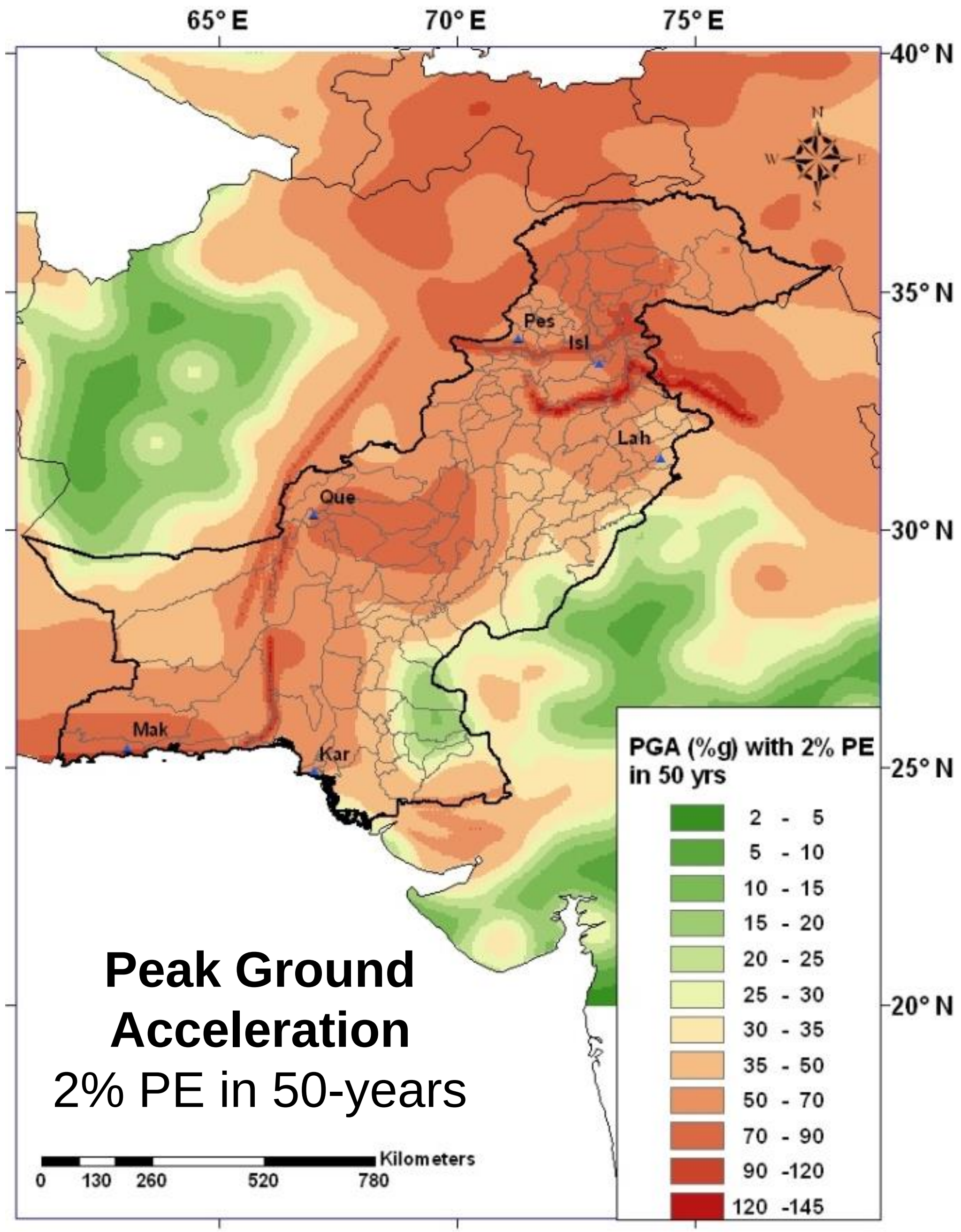
b) Crustal faults (1-13) SS: Strike-Slip fault, R: Reverse fault), and

c) Makran subduction zone (MSZ)

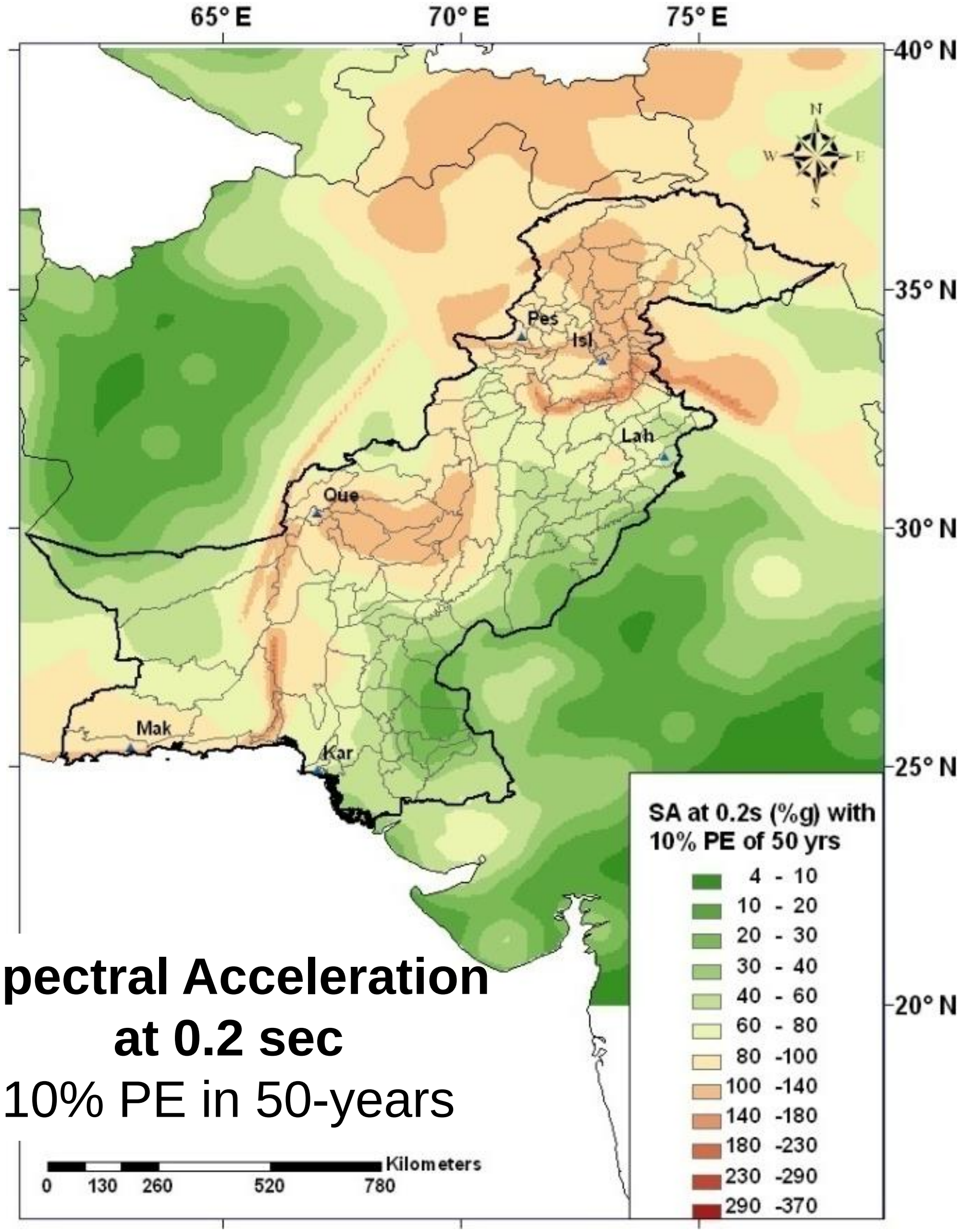
Red Triangle shows major cities of Pakistan that is Peshawar (Pes), Islamabad (Isl), Lahore (Lah), Quetta (Que), Karachi (Kar), and Makran (Mak)

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

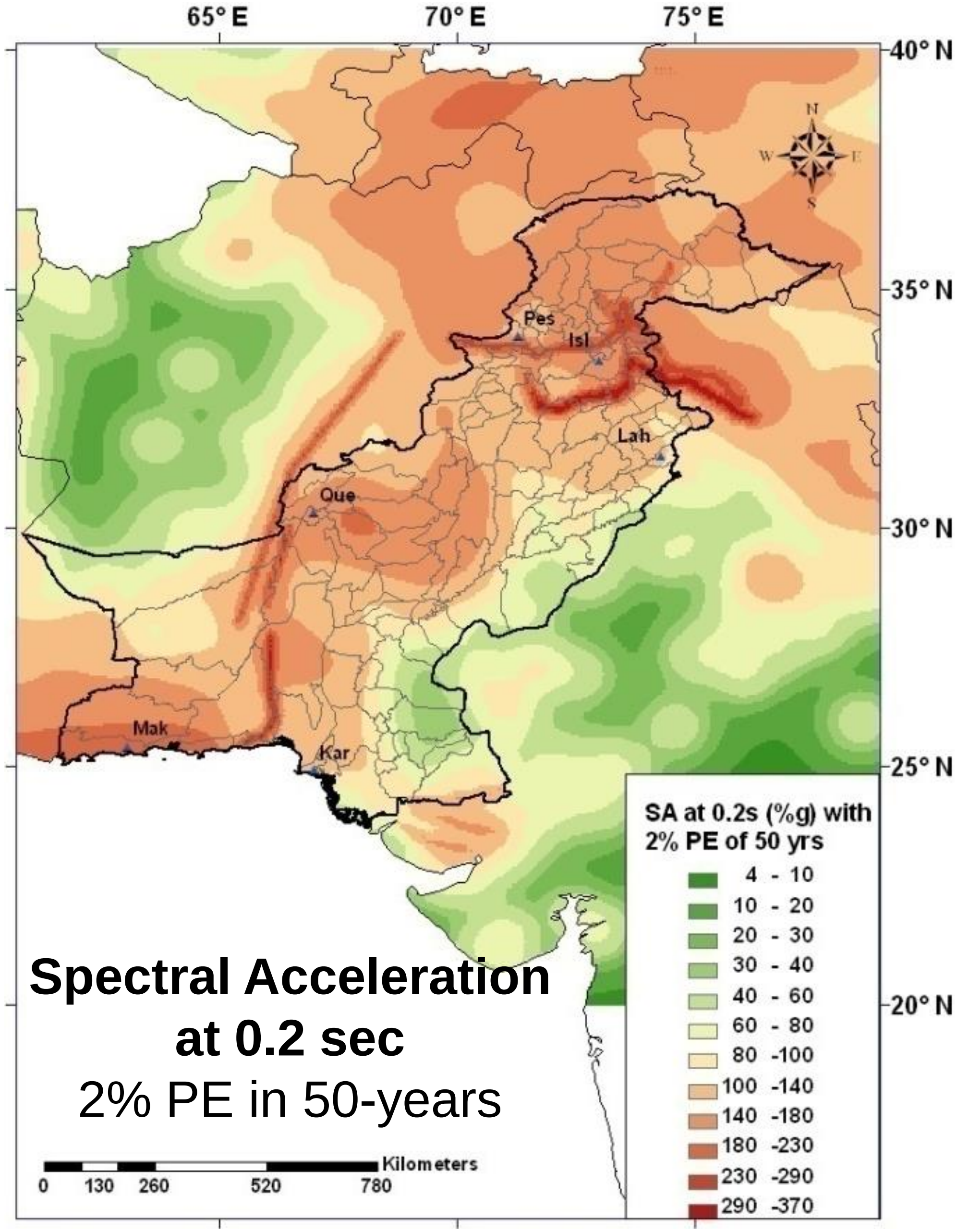




Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan

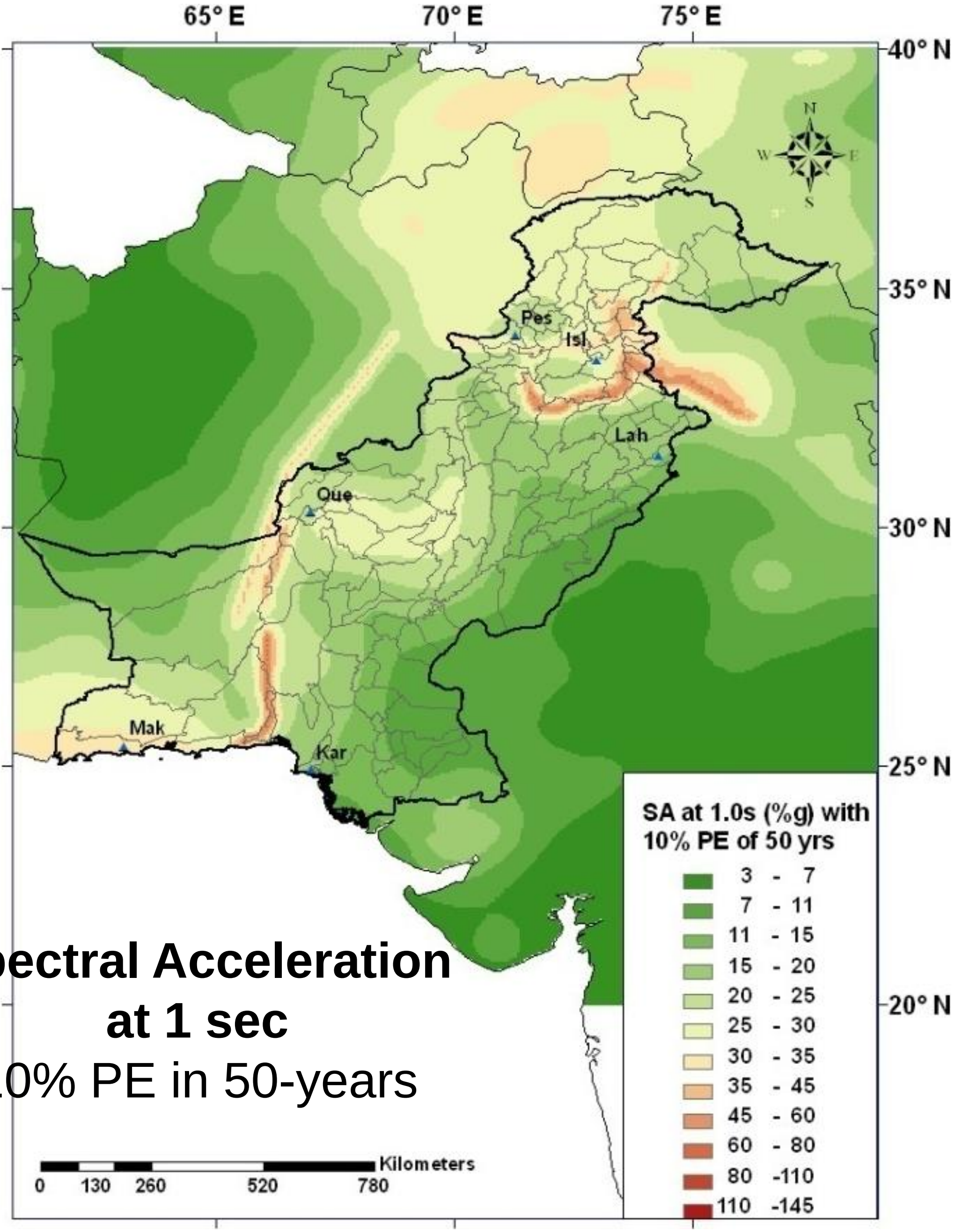


Spectral Acceleration at 0.2 sec
10% PE in 50-years



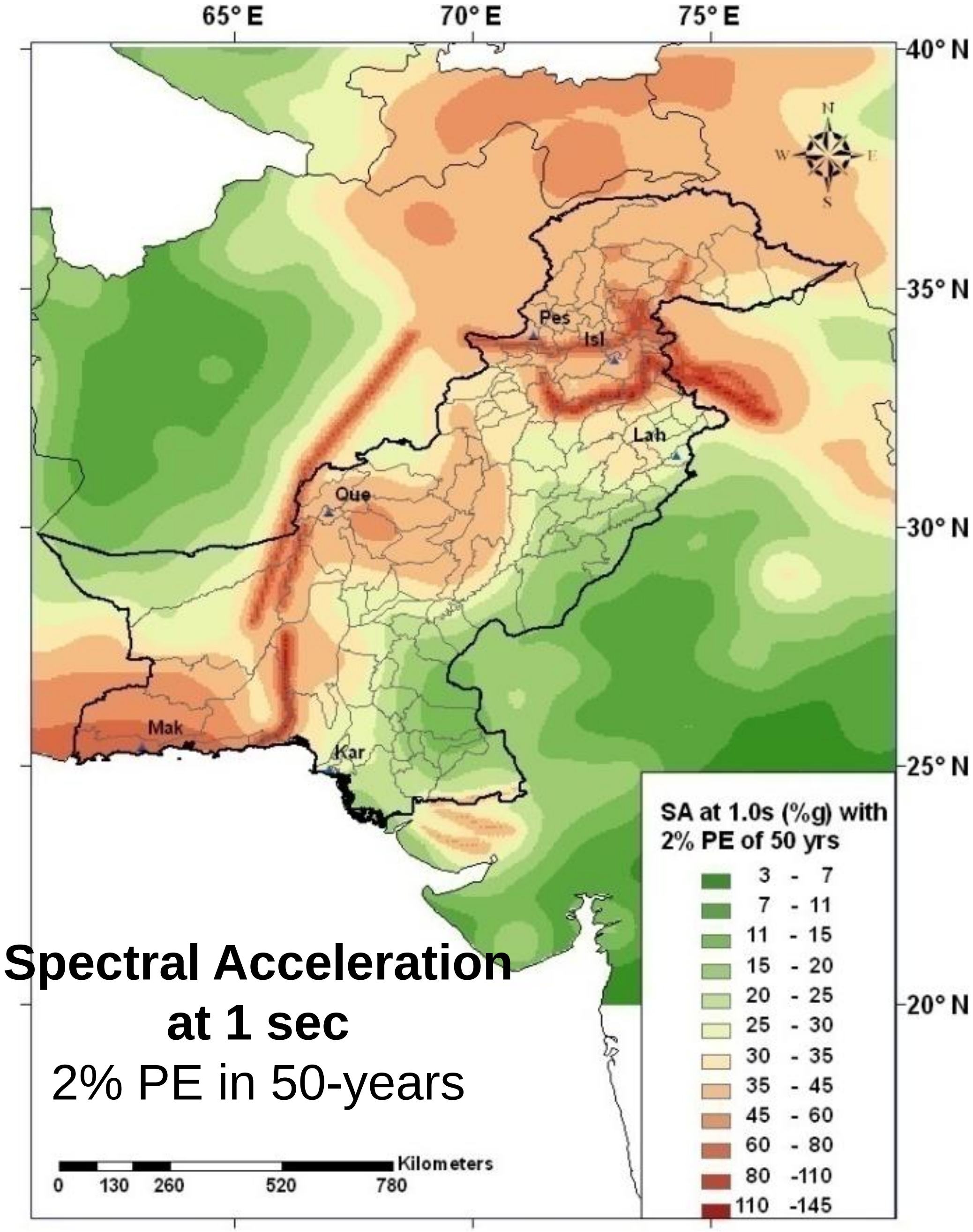
Spectral Acceleration at 0.2 sec
2% PE in 50-years

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



Spectral Acceleration at 1 sec

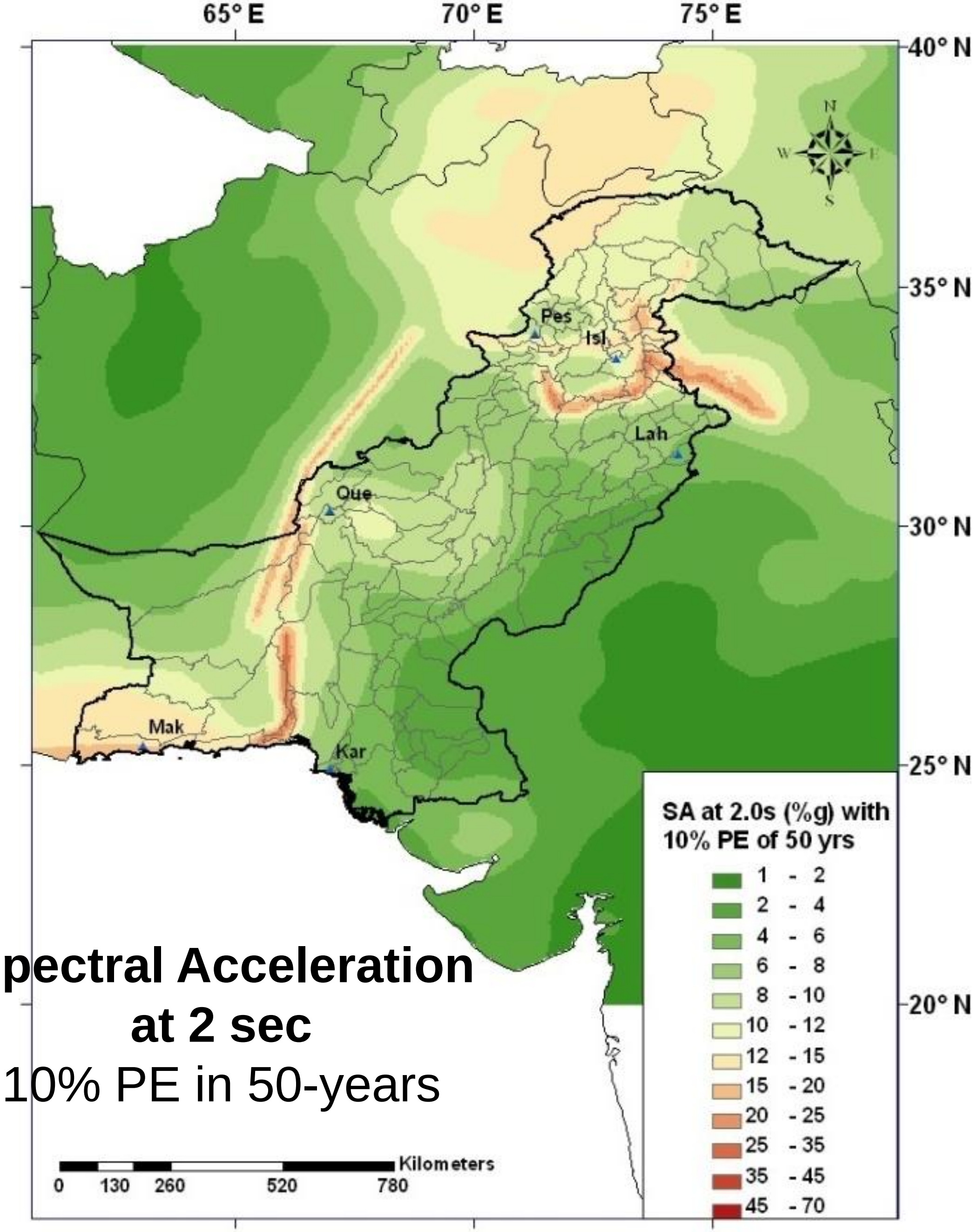
10% PE in 50-years



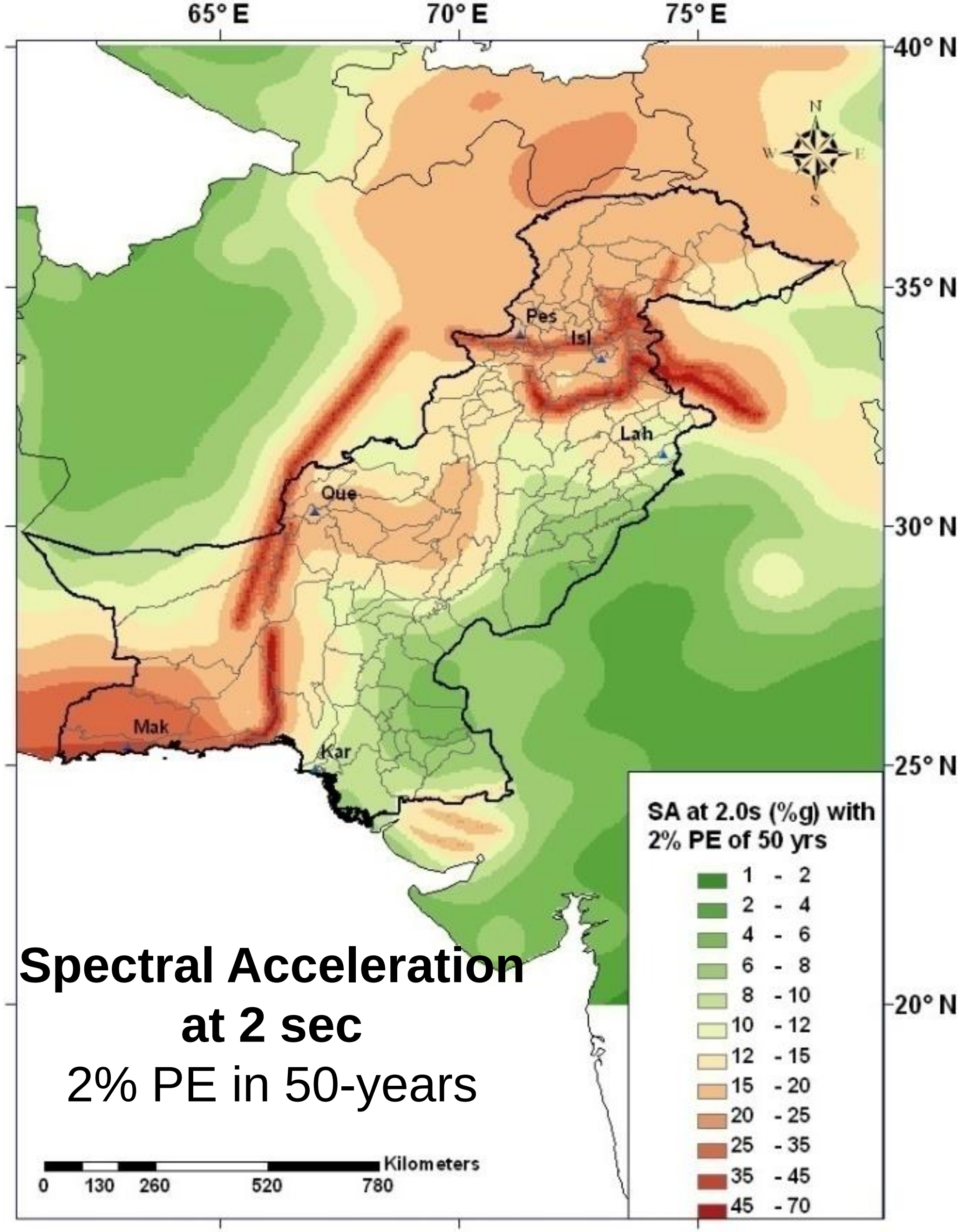
Spectral Acceleration at 1 sec

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

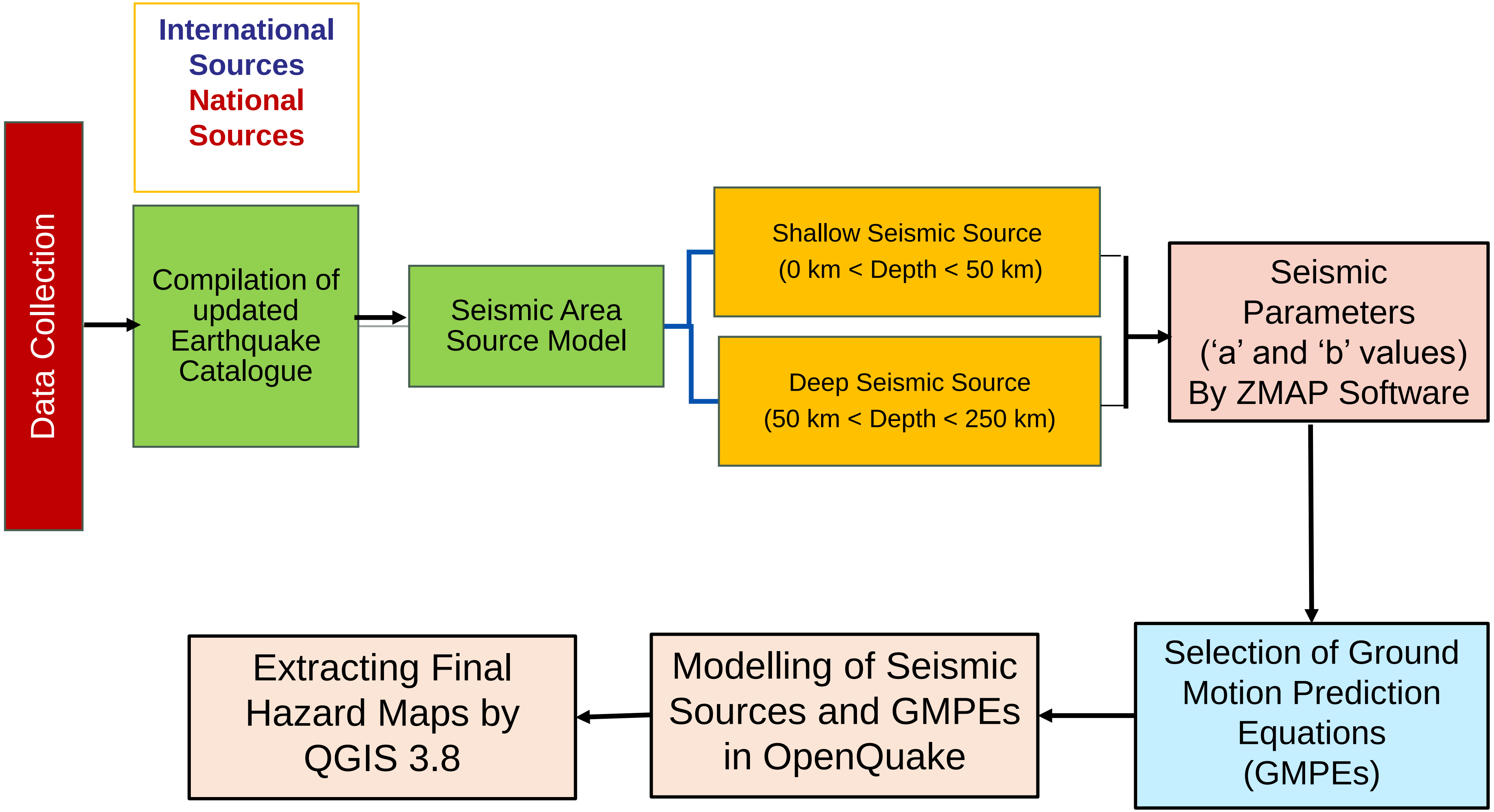
Source: Zaman S. (2016) Probabilistic Seismic Hazard Assessment and Site-Amplification Mapping for Pakistan

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

Atif Rasheed

MS Structural Engineering (2017)

Methodology



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)

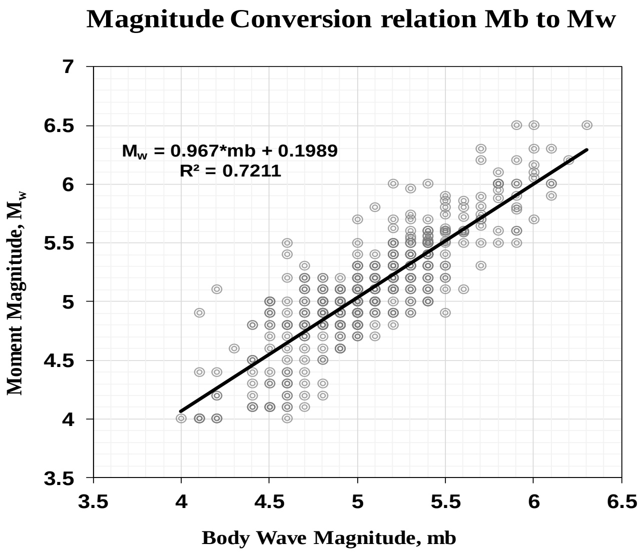
❑ A total of **71,759** events are collected for period of AD 10 to 2018 CE

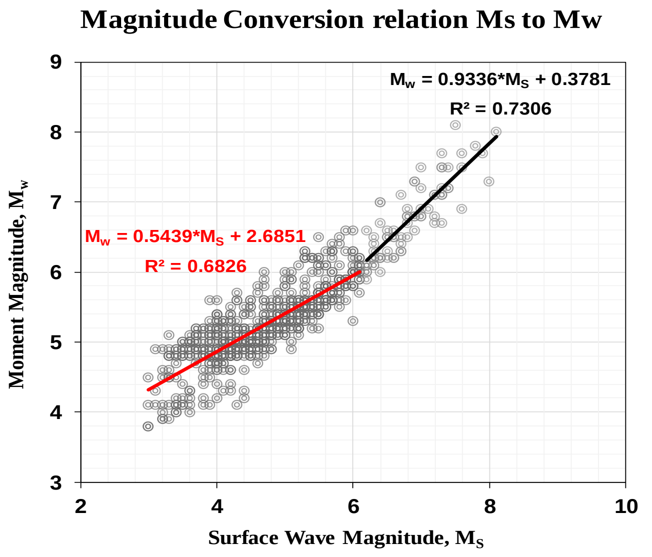
Methodology - Compilation of Earthquake Catalogue

➢ Magnitude Homogenization

- Empirical Equations are developed
- Body wave magnitude

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





- Surface wave magnitude

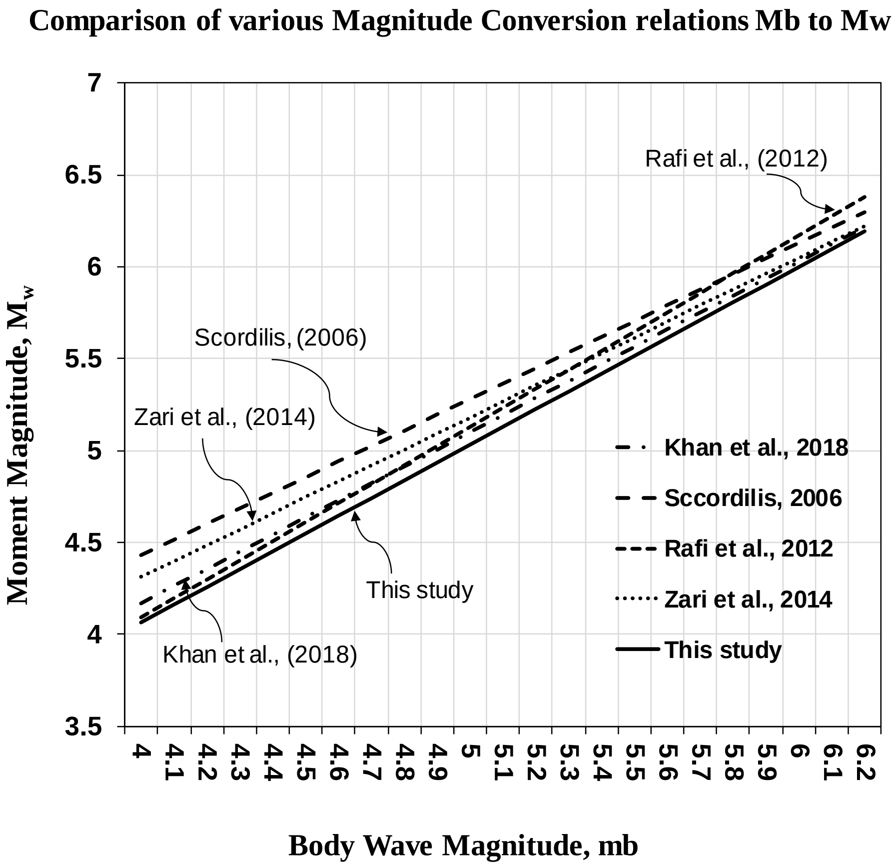
$$M_w = 0.5396 * M_S + 2.7051 \qquad 3.0 \leq M_S \leq 6.1$$

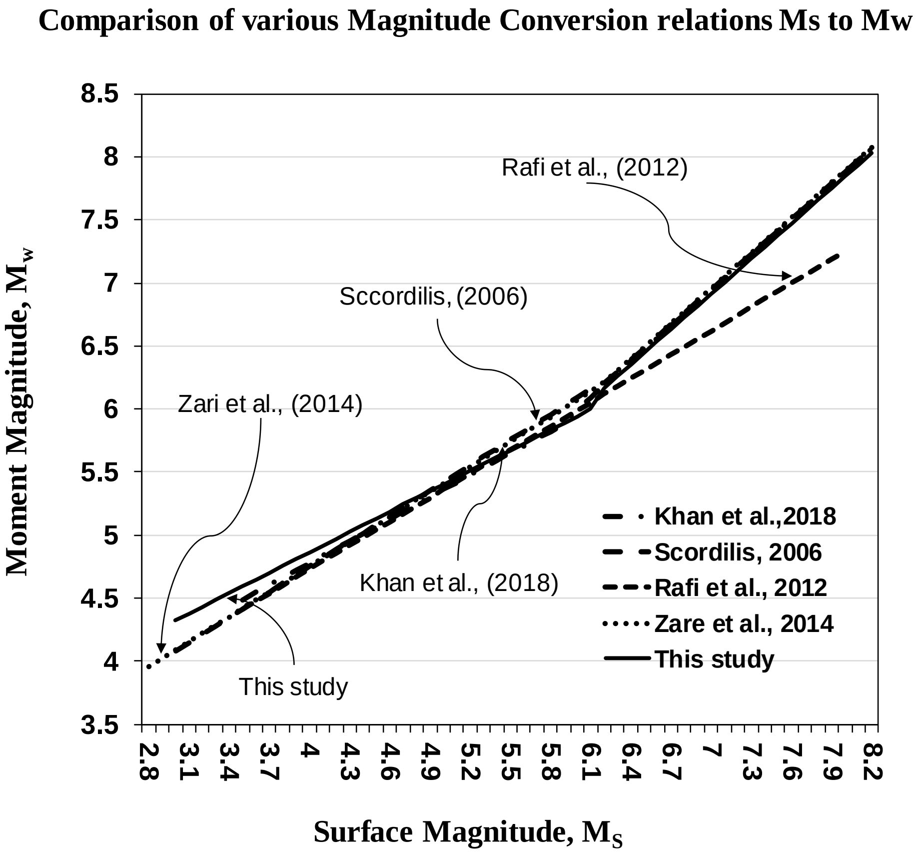
$$M_w = 0.9336 * M_S + 0.3781 \qquad 6.2 \leq M_S \leq 8.2$$

Methodology - Compilation of Earthquake Catalogue

Magnitude Homogenization

Comparison of developed empirical relations with previous studies





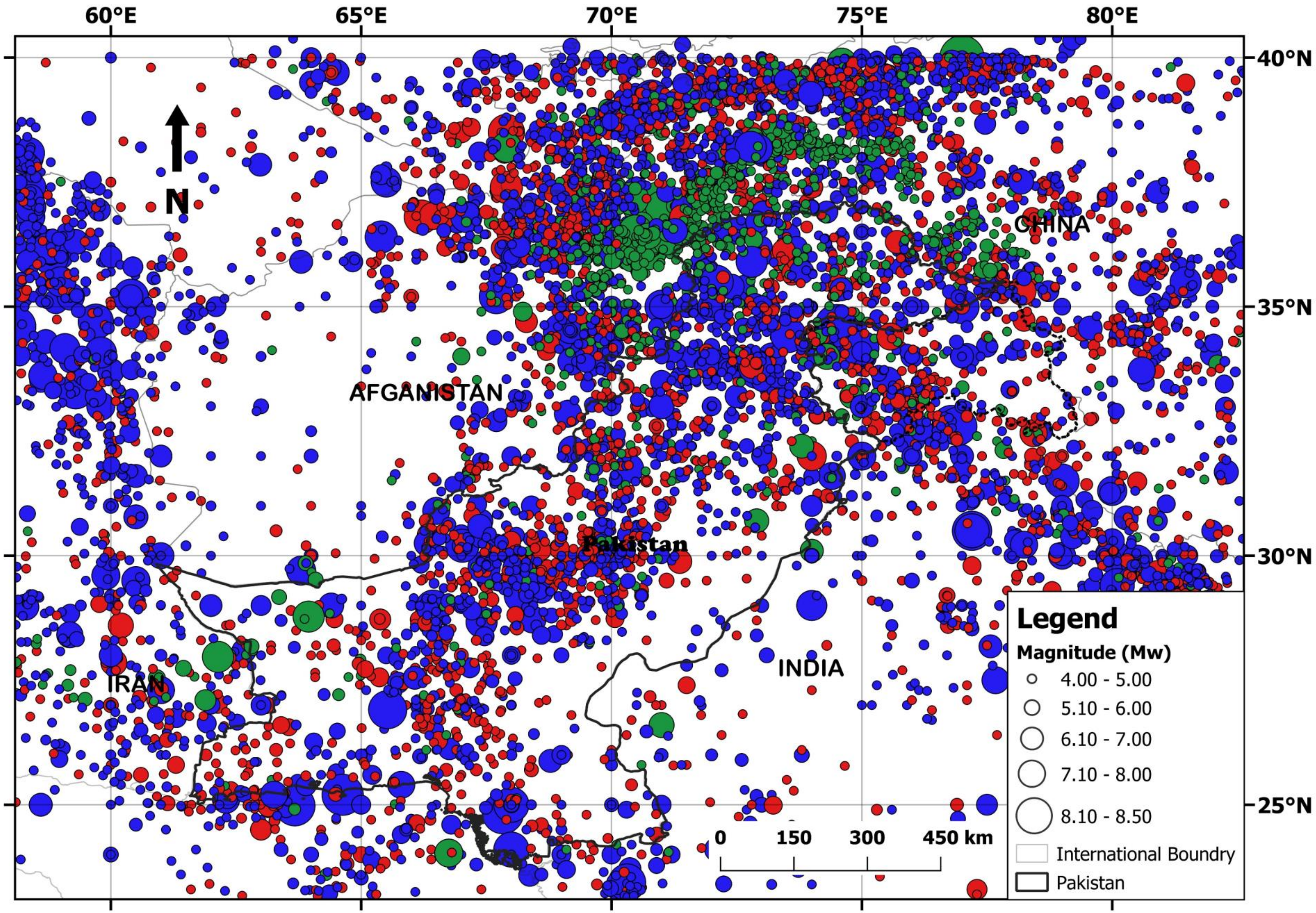
Methodology - Compilation of Earthquake Catalogue (Data Processing)

- 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.



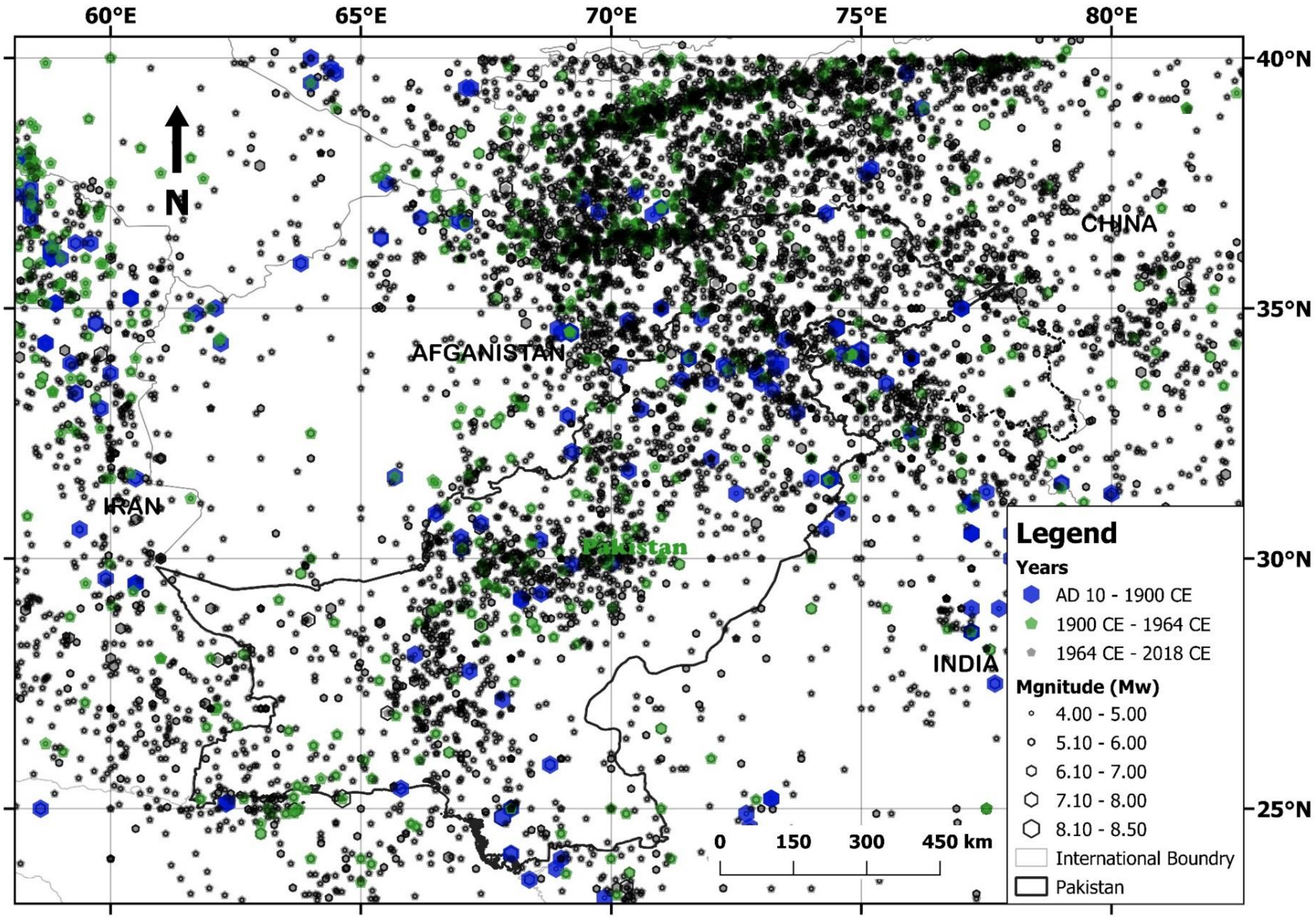
Blue 0 – 25 km **Red** 25 – 50 km **Green** 50 – 250 km

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
AFGANISTAN
IRAN
CHINA
INDIA
Pakistan
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;

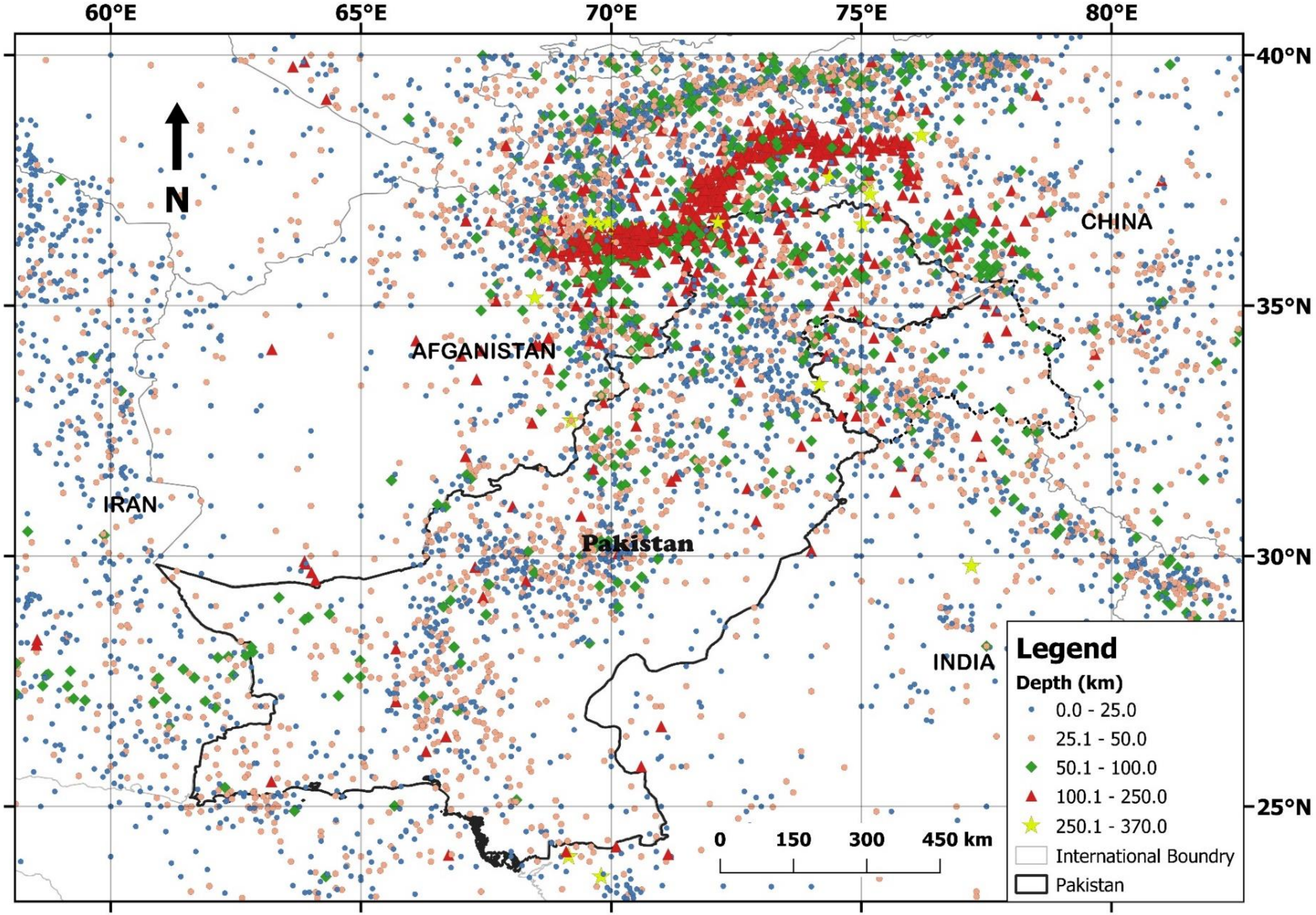
a) Visual Cumulative Method (CUVI)

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

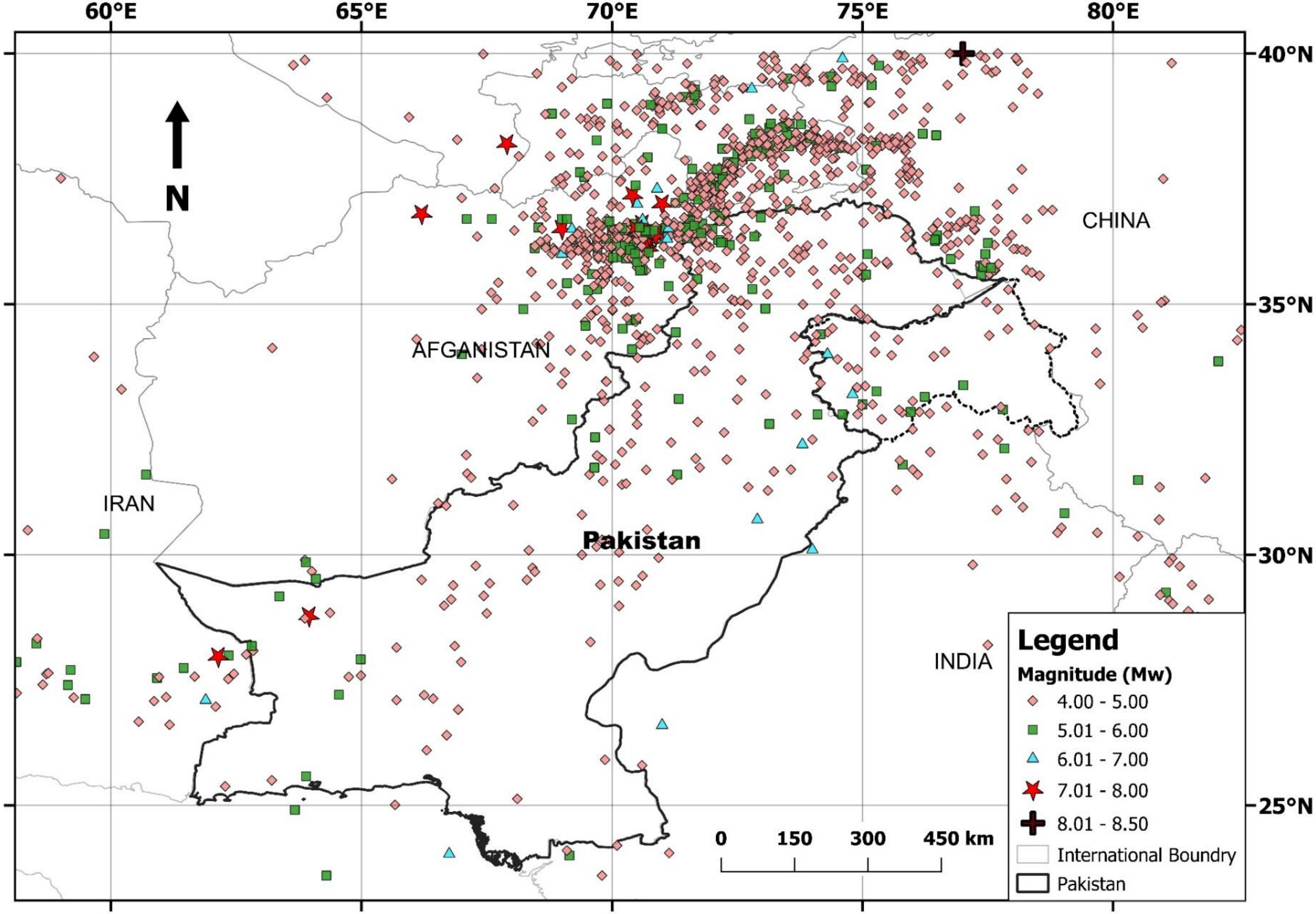
Magnitude class	Completeness period
M_w **≥ 4.0**	1990 – 2018 = 28
M_w **≥ 4.5**	1975 – 2018 = 43
M_w **≥ 5.0**	1951 – 2018 = 67
M_w **≥ 5.5**	1926 – 2018 = 92
M_w **≥ 6.0**	1900 – 2018 = 118
M_w **≥ 6.5**	1900 – 2018 = 118
M_w **≥ 7.0**	1900 – 2018 = 118
M_w **≥ 7.5**	1884 – 2018 = 134
M_w **≥ 8.0**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

Seismogenic Depths

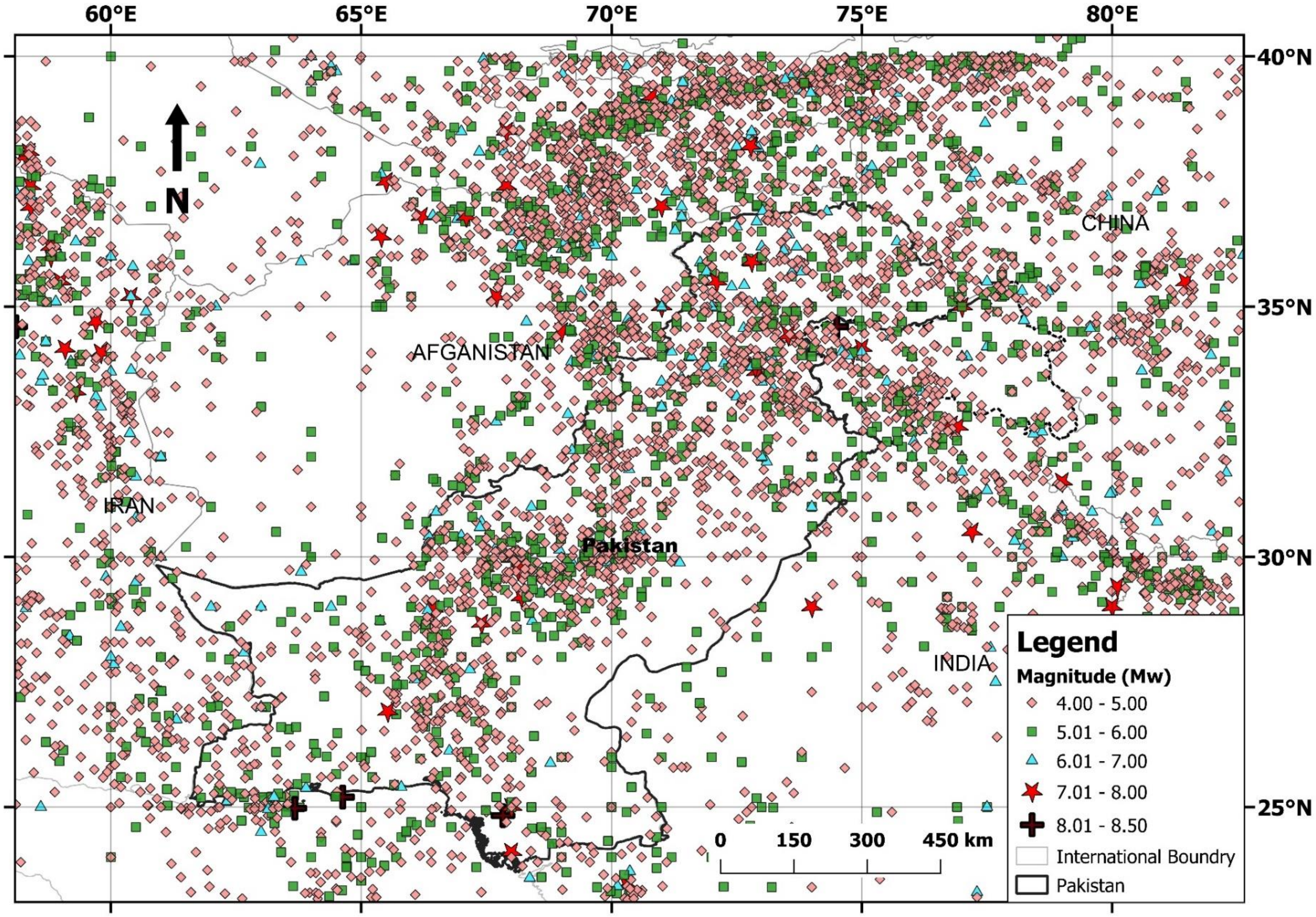
Determination of focal depths of earthquakes is extremely important (Maggi, Priestley and Jackson, 2002)



Deep Earthquakes
$(Depth > 50\ km)$

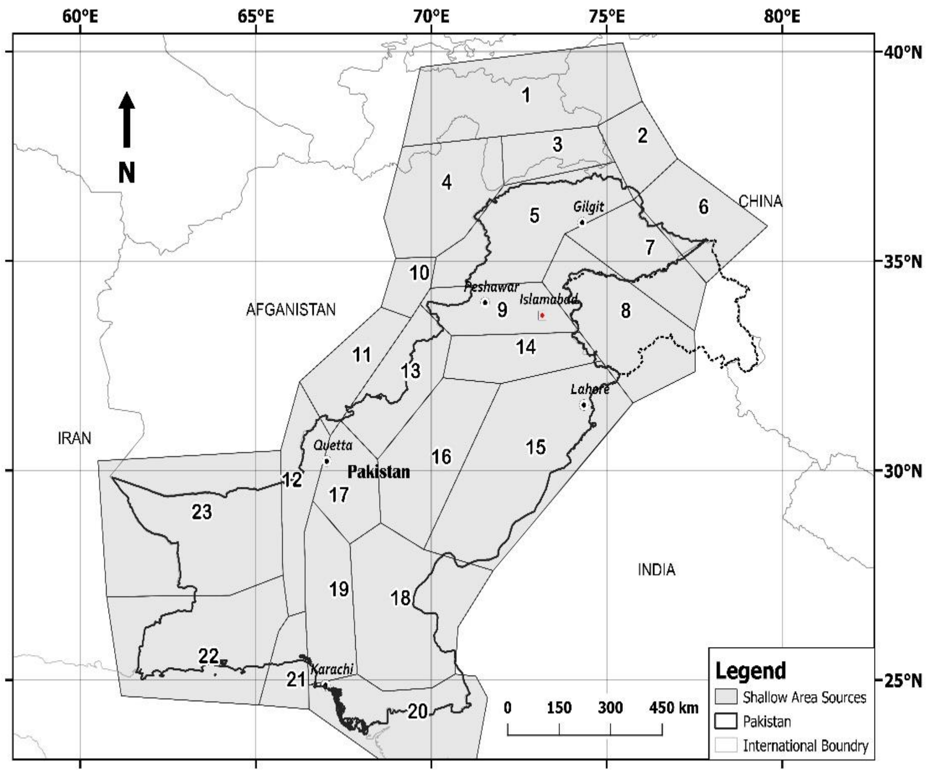


Shallow Earthquakes
$(Depth < 50\ km)$



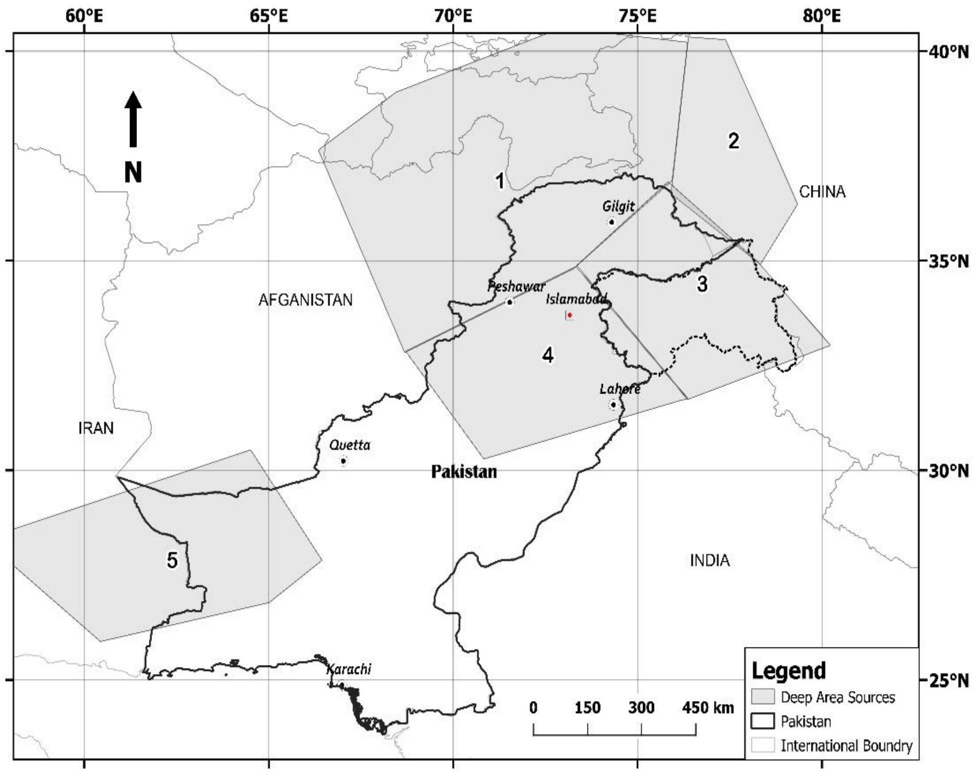
Seismic Area Source Model - Delineation of Seismic Area Sources

Shallow Area Sources (23)



4823 Earthquake Events

Deep Area Sources (5)

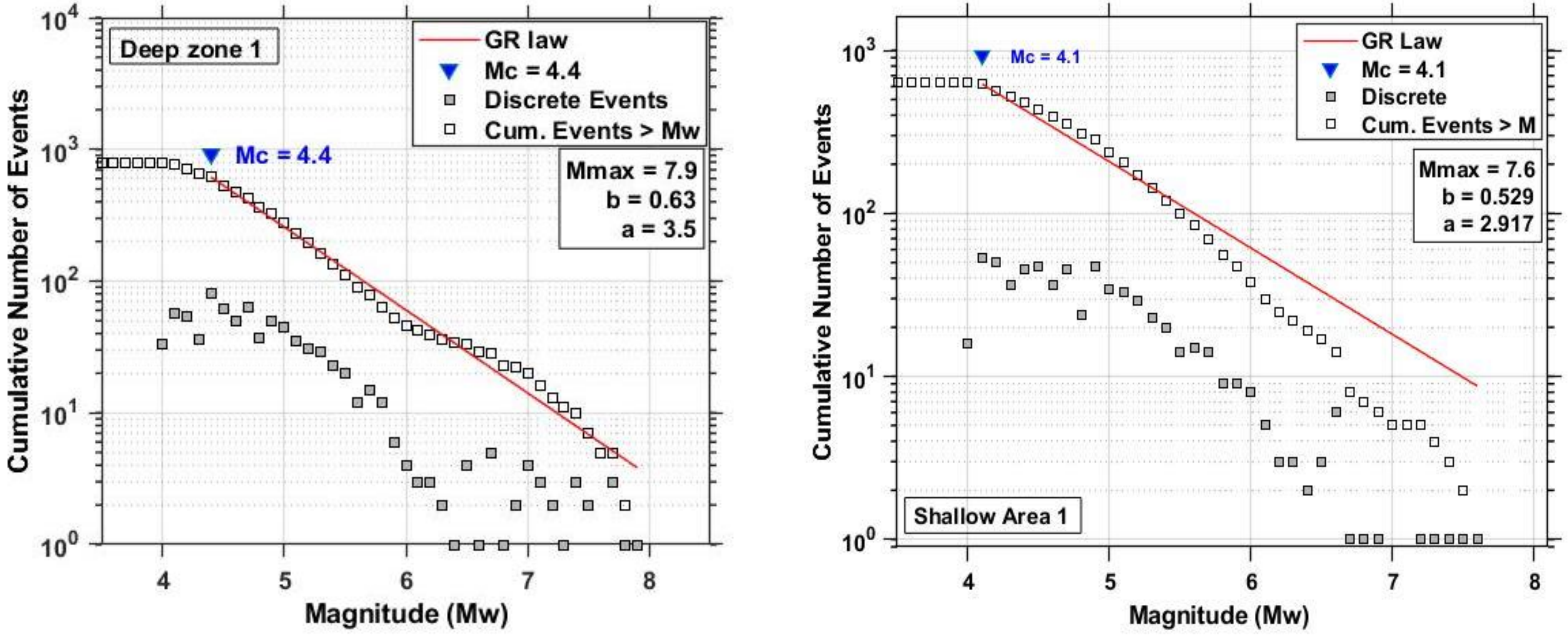


1457 Earthquake Events

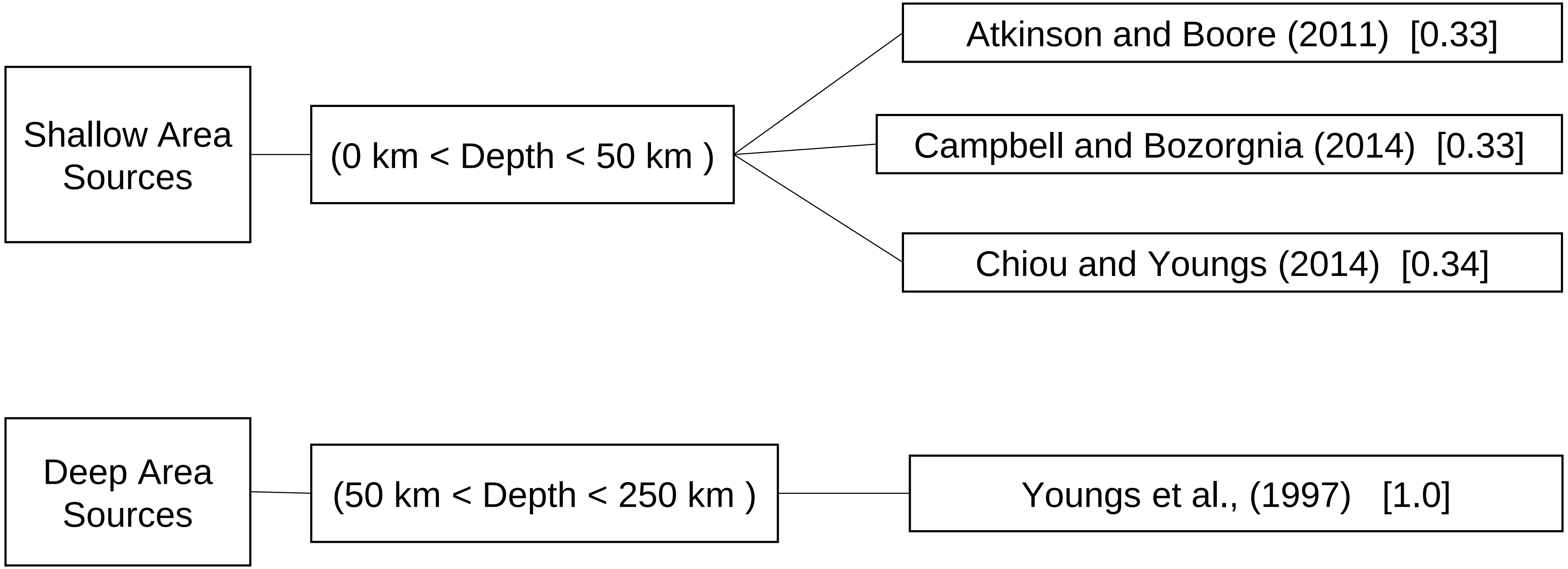
Recurrence Models and Seismicity Parameters

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

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



Ground Motion Prediction Equations (GMPEs)



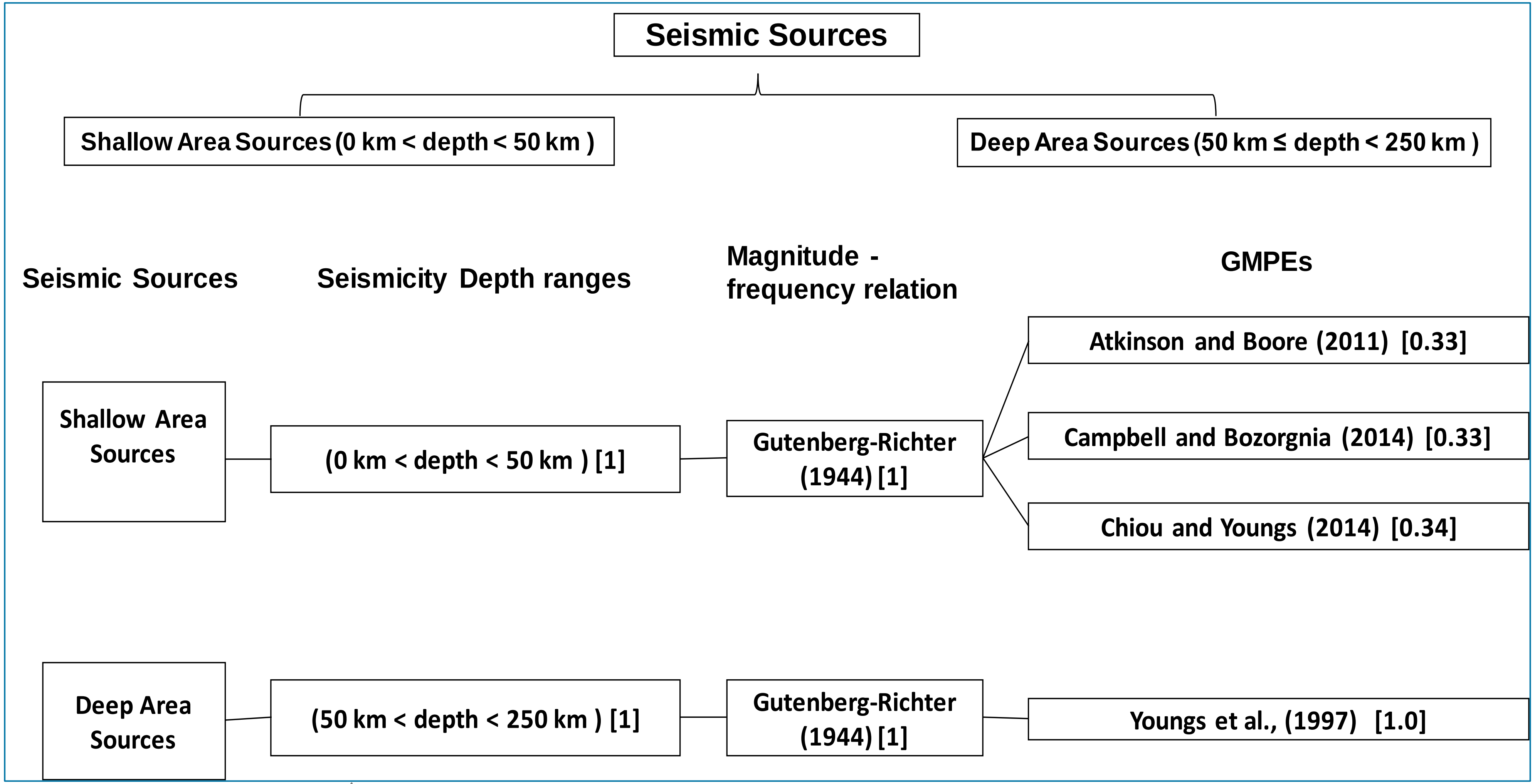
Waseem et.al, Natural Hazards (2018)

Zaman, PhD Thesis (2016)

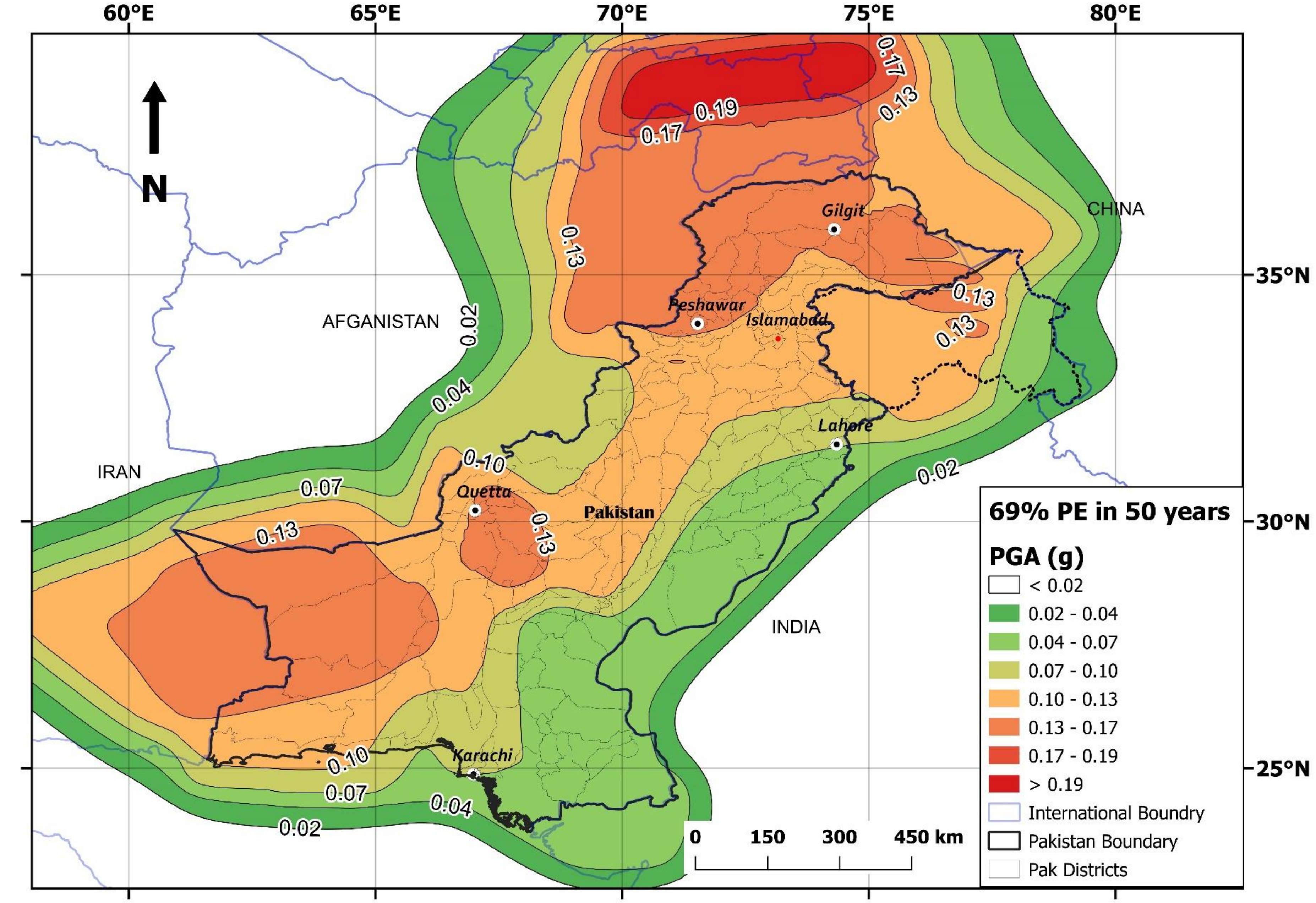
Nath et.al, Seismological Research Letters (2018)

Probabilistic Seismic Hazard Analysis (PSHA)

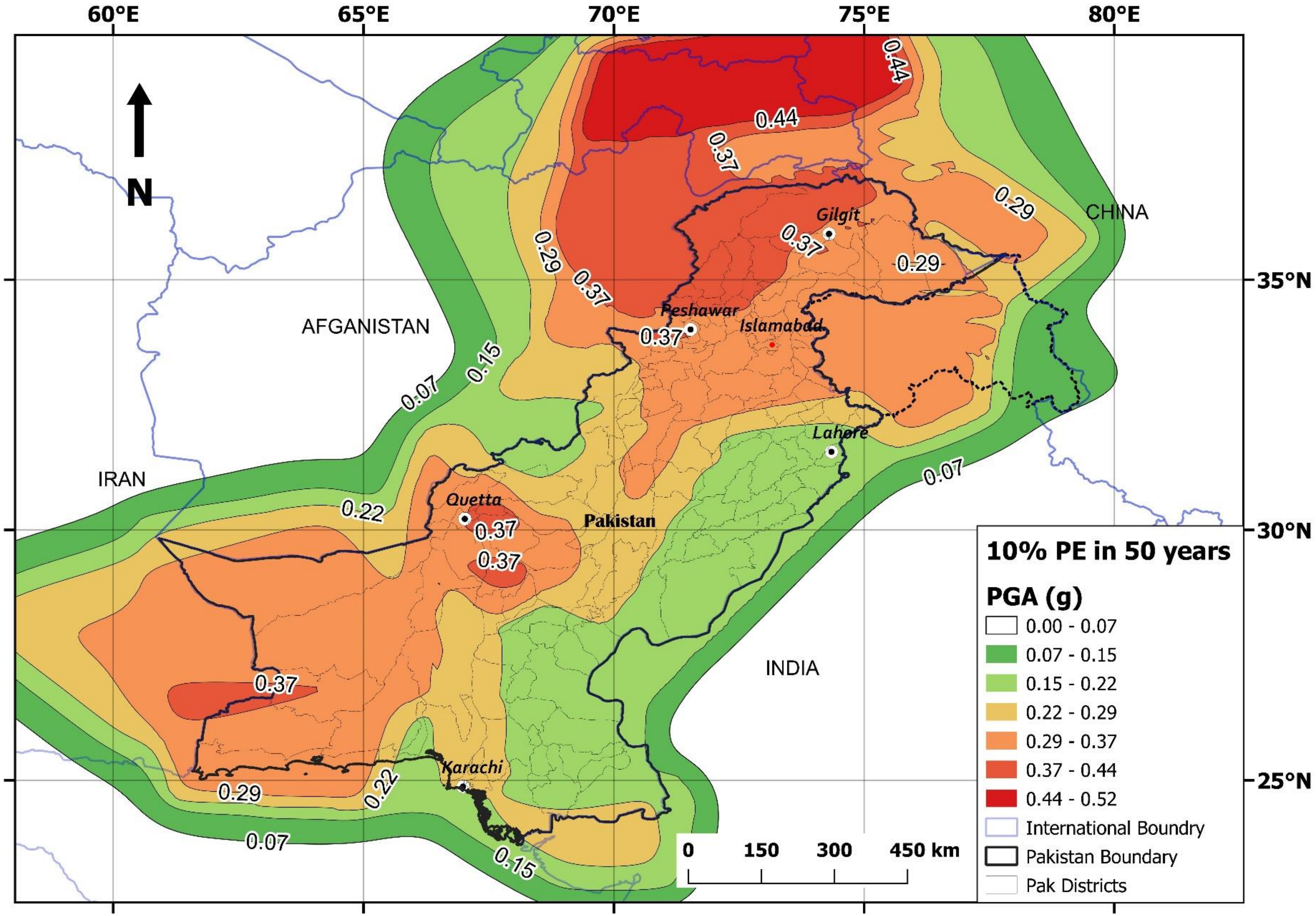
- The PSHA of Pakistan is carried out by using OpenQuake software (Pagani et al., 2014)



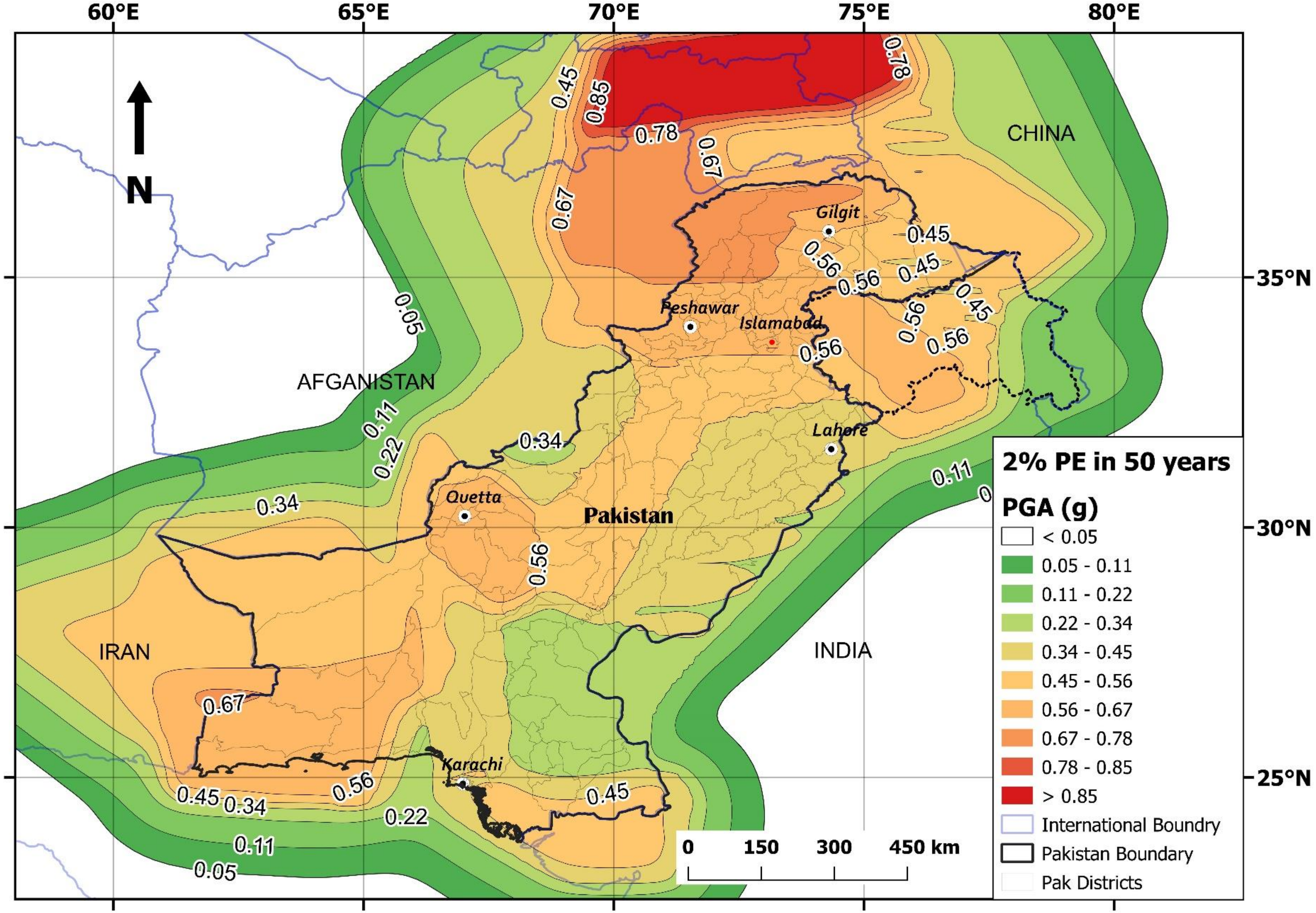
Peak Ground Acceleration (PGA) map for Service Level Earthquake (SLE)



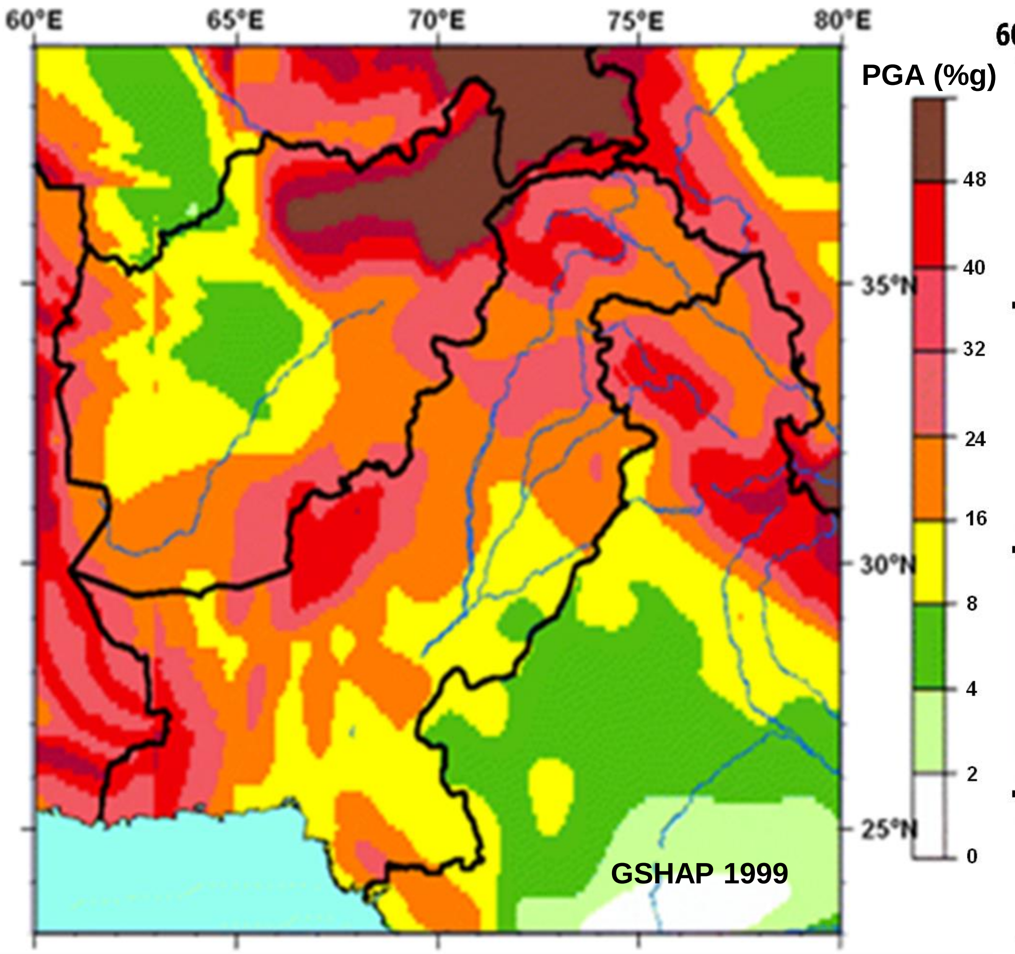
Peak Ground Acceleration (PGA) map for Design Basis Earthquake (DBE)

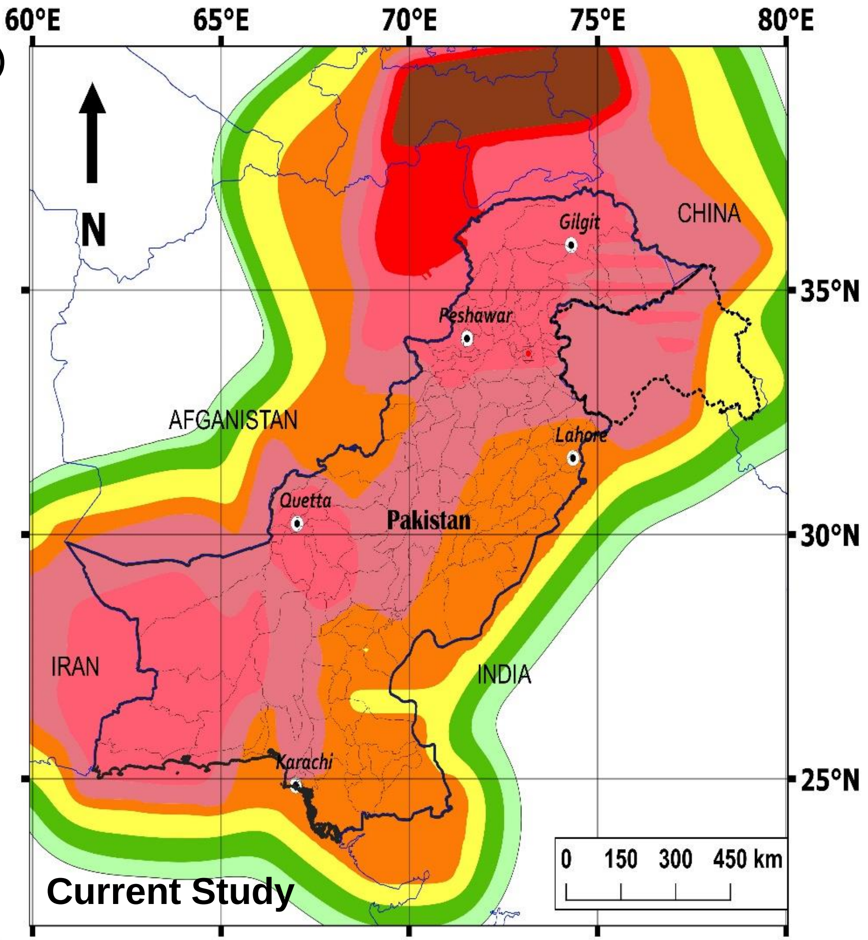


Peak Ground Acceleration (PGA) map for Maximum Credible Earthquake (MCE)



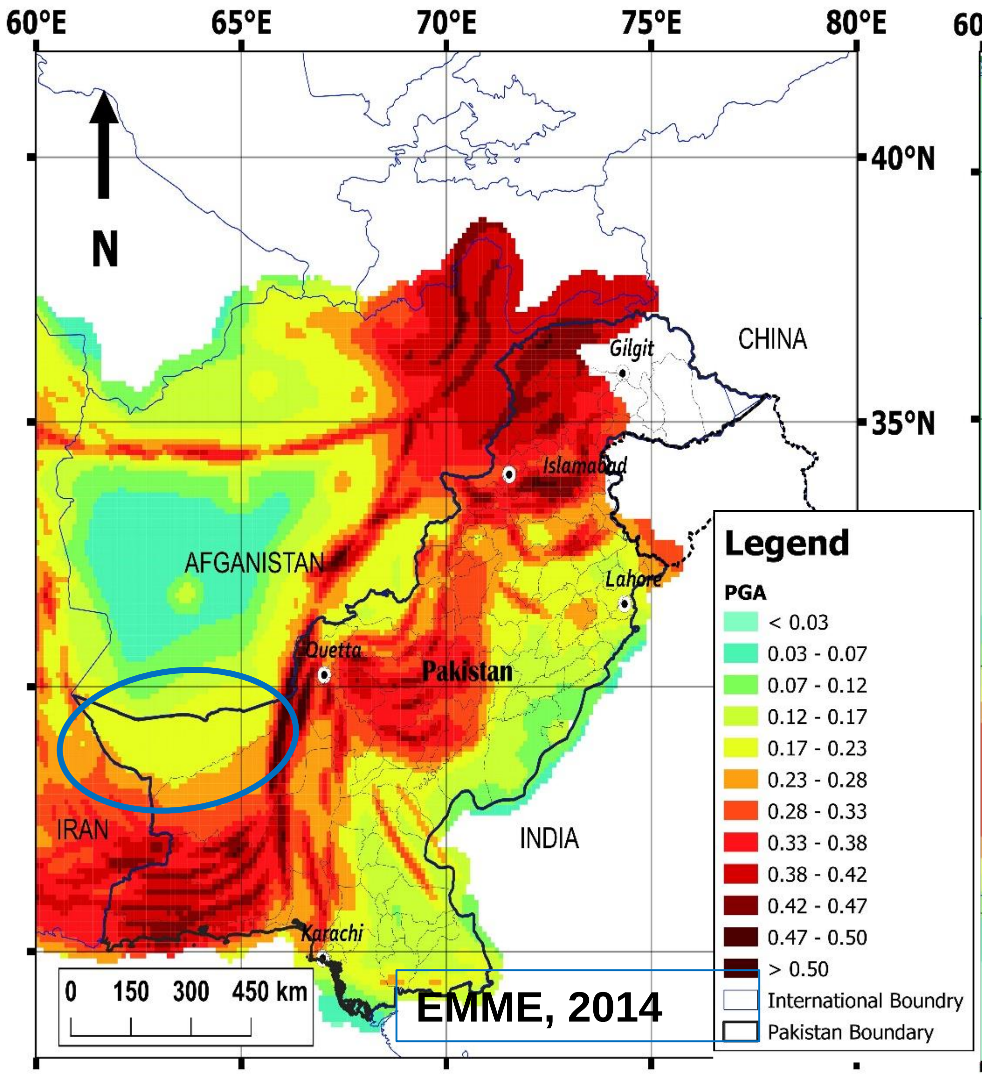
Comparison of GSHAP (1999) with current study (10% PE in 50 years)

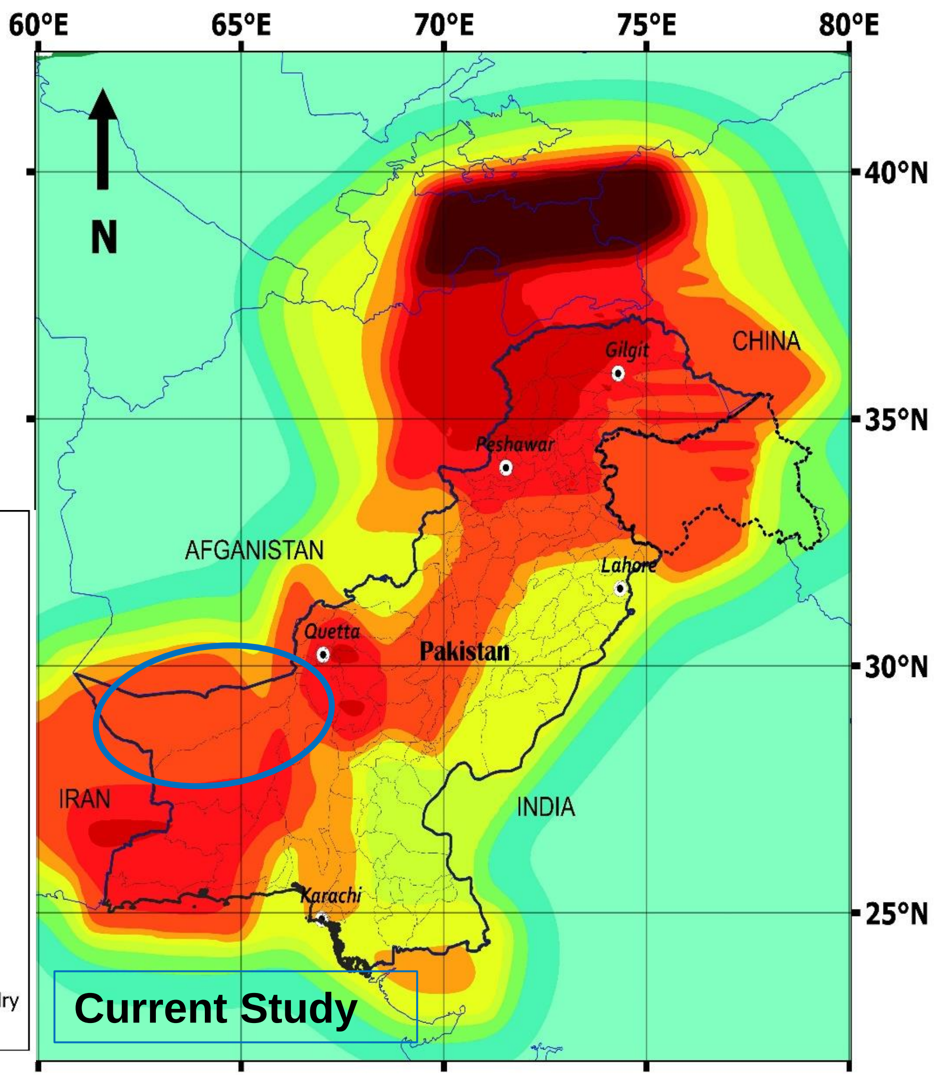




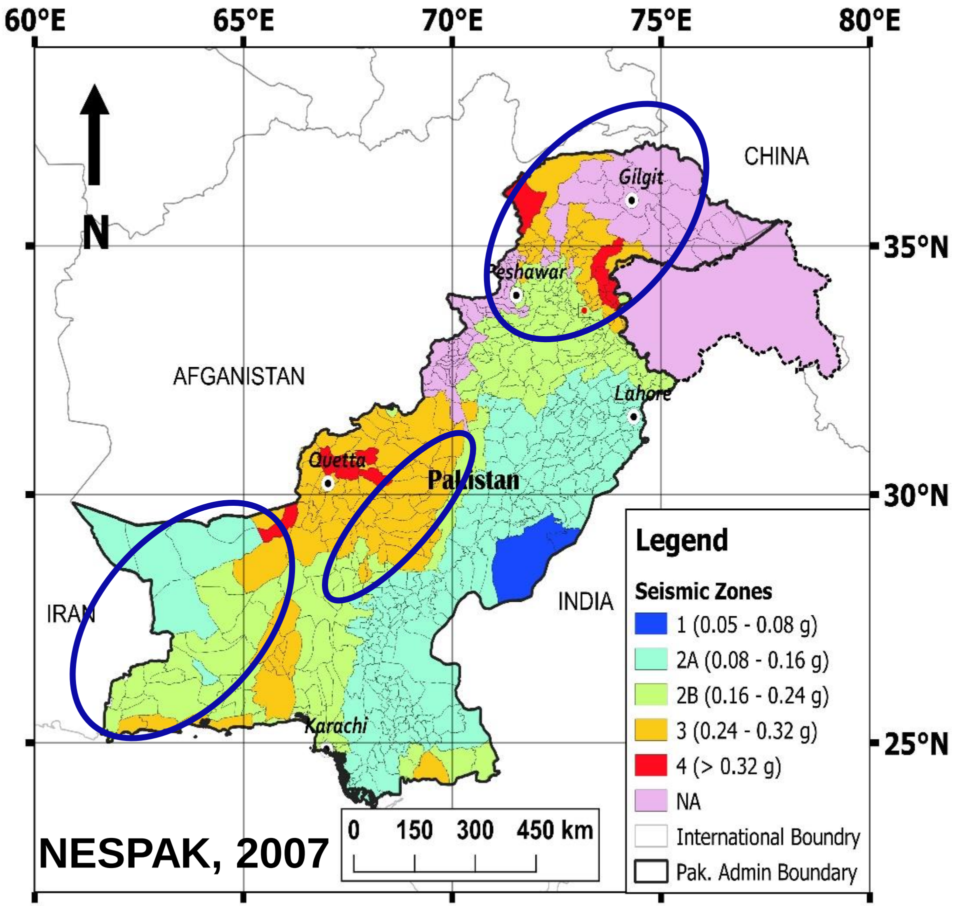
- Similar Hazard Pattern throughout Pakistan
- PGA larger than previous studies
- Number of earthquake events in the catalogue is the reason of larger values

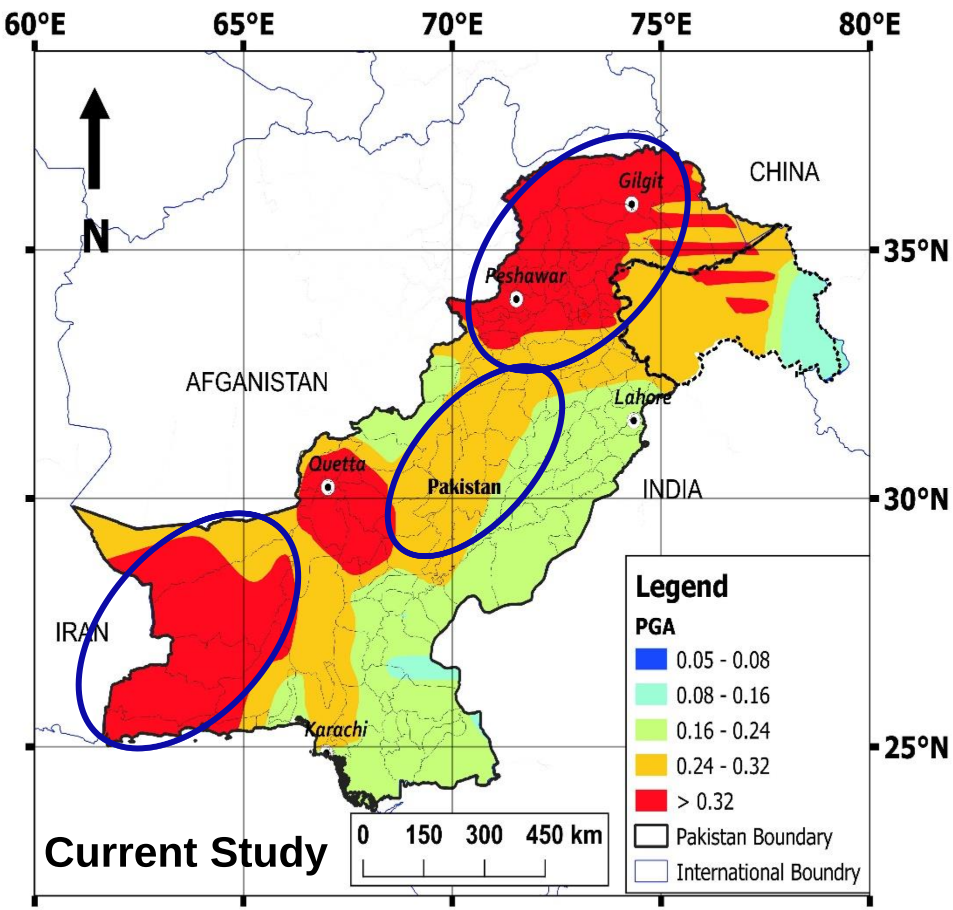
Comparison of EMME (2014) with current study (10% PE in 50 years)



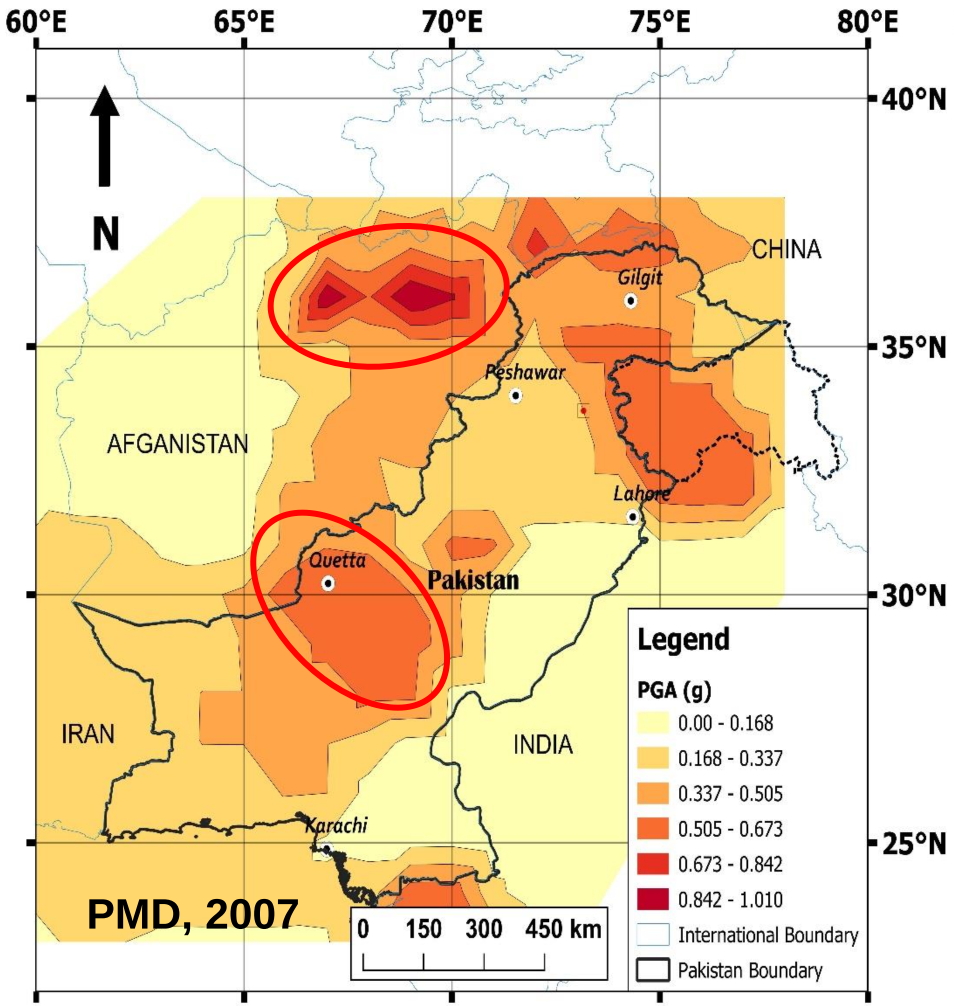


Comparison of NESPAK (2007) with current study (10% PE in 50 years)

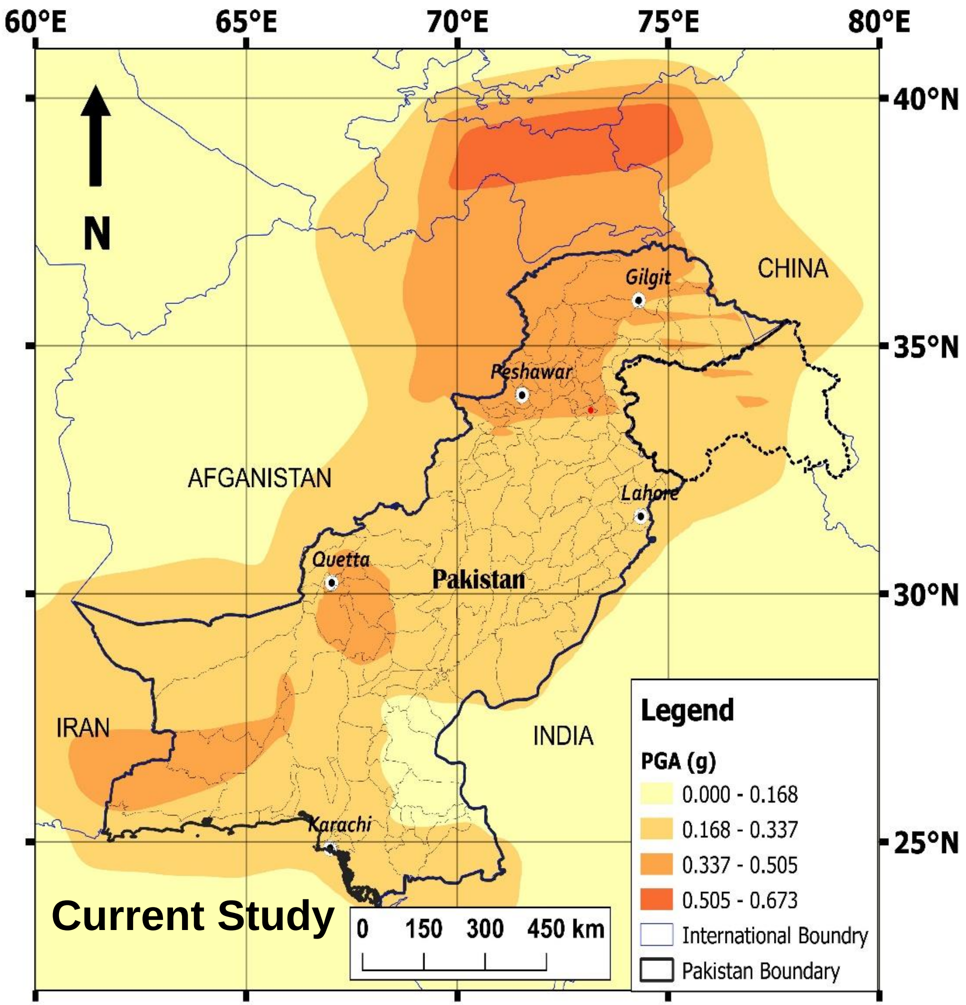




Comparison of PMD (2007) with current study (10% PE in 50 years)

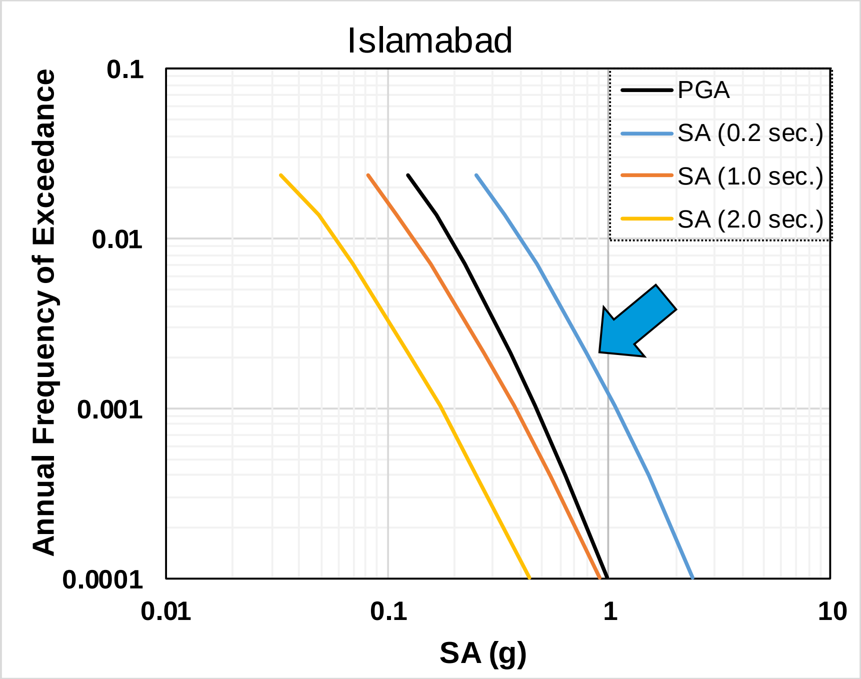


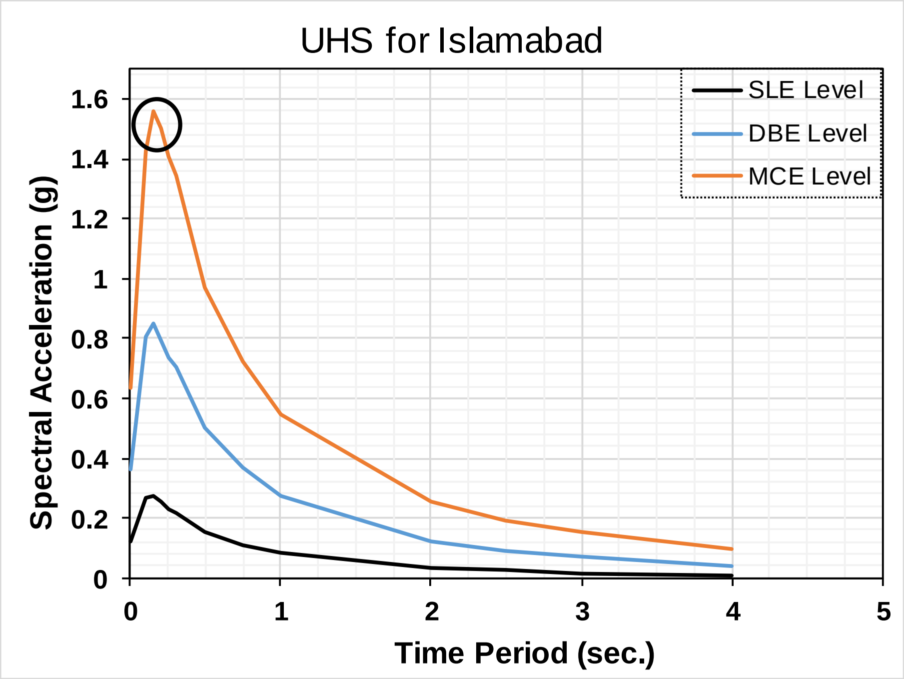
- Similar Hazard Pattern
- Very Coarse Grid ($1^o \times 1^o$)



- Similar Hazard Pattern
- Very Fine Grid ($0.1^o \times 0.1^o$)
- 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

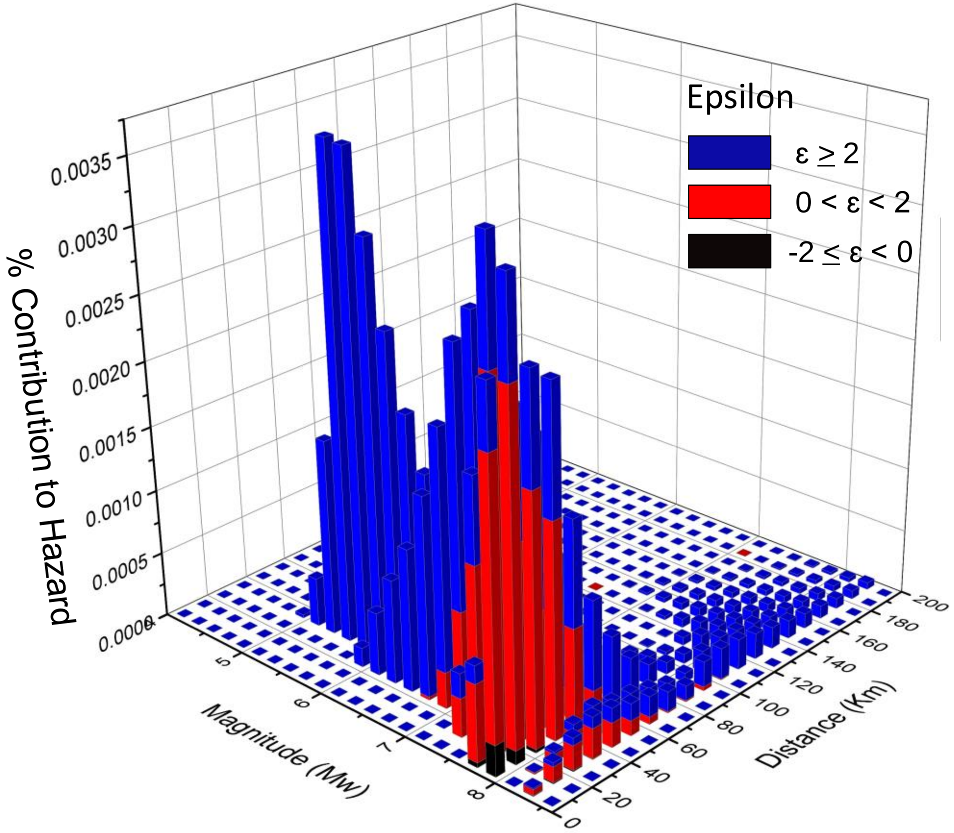
MCE Maximum Credible Earthquake
2% PE in 50 yrs, 2475 yrs Return Period

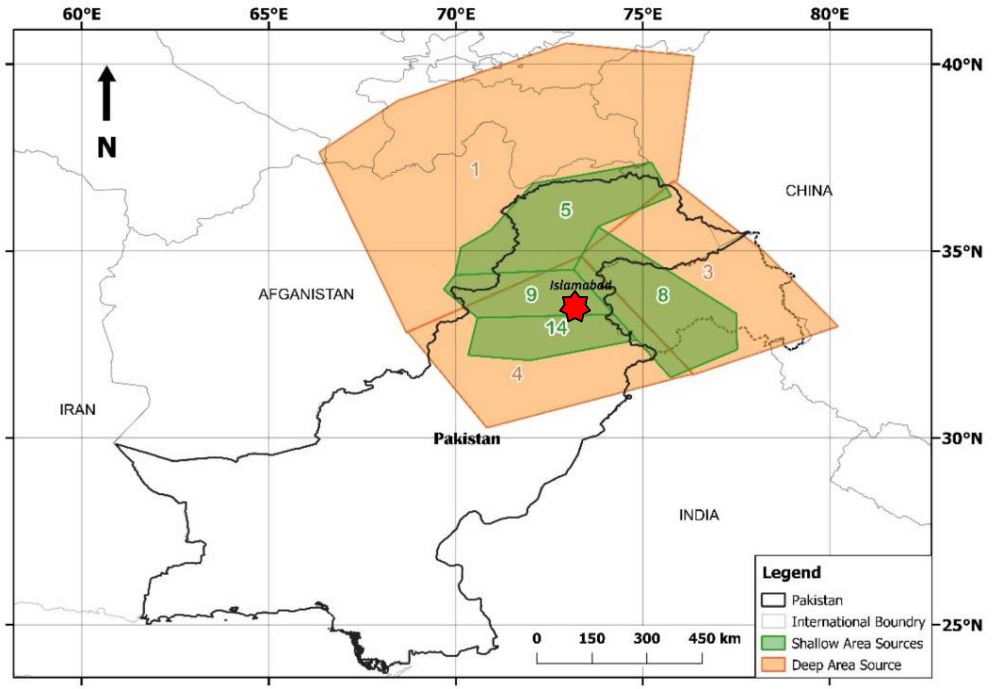
DBE Design Bases Earthquake
10% PE in 50 yrs, 475 yrs Return Period

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



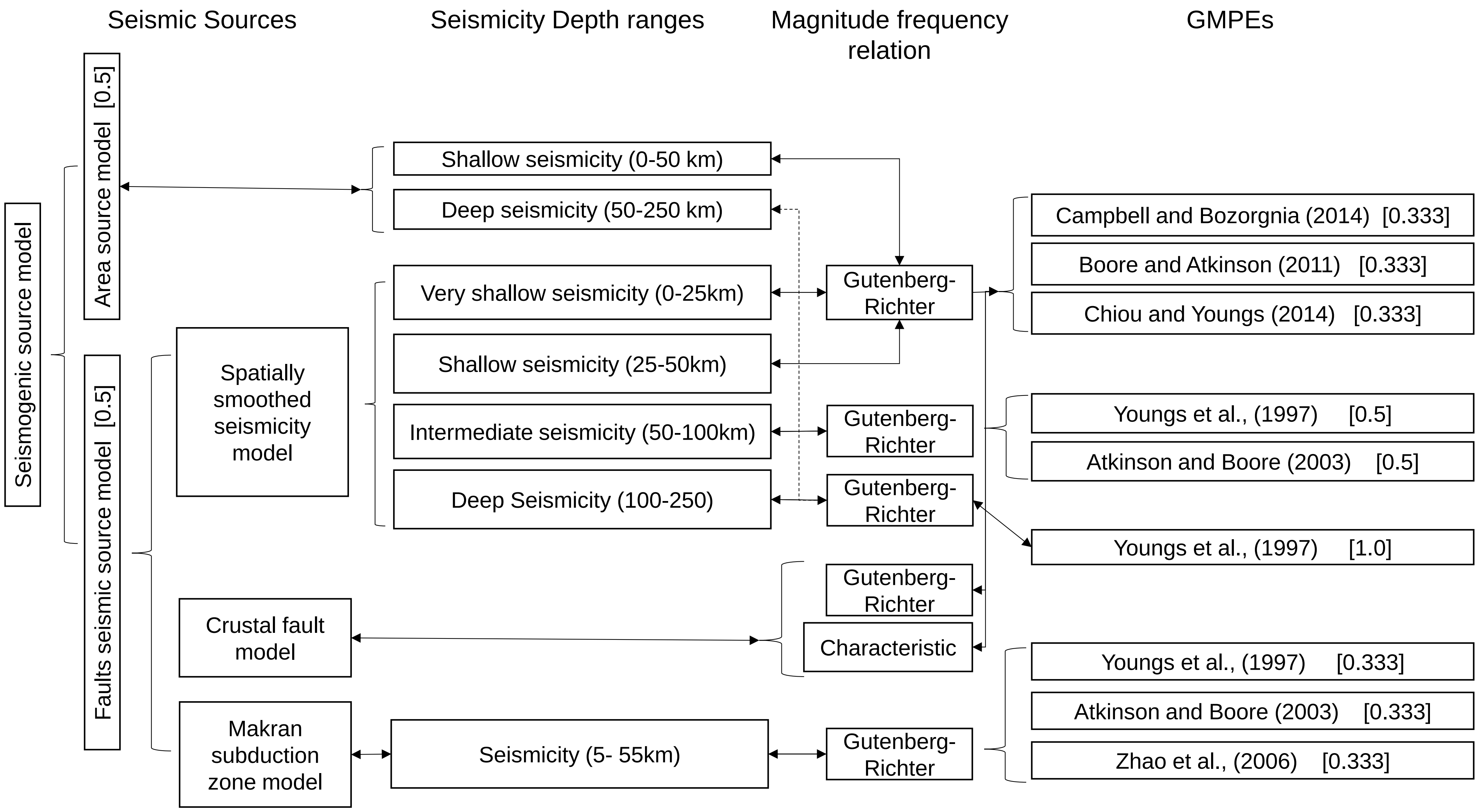


Updated PSHA of Pakistan using both the conventional and Spatially Smoothed Background Seismicity and Crustal Faults Model

Asad ur Rehman

MS Structural Engineering (2017)

Logic tree of the seismic source model and GMPEs



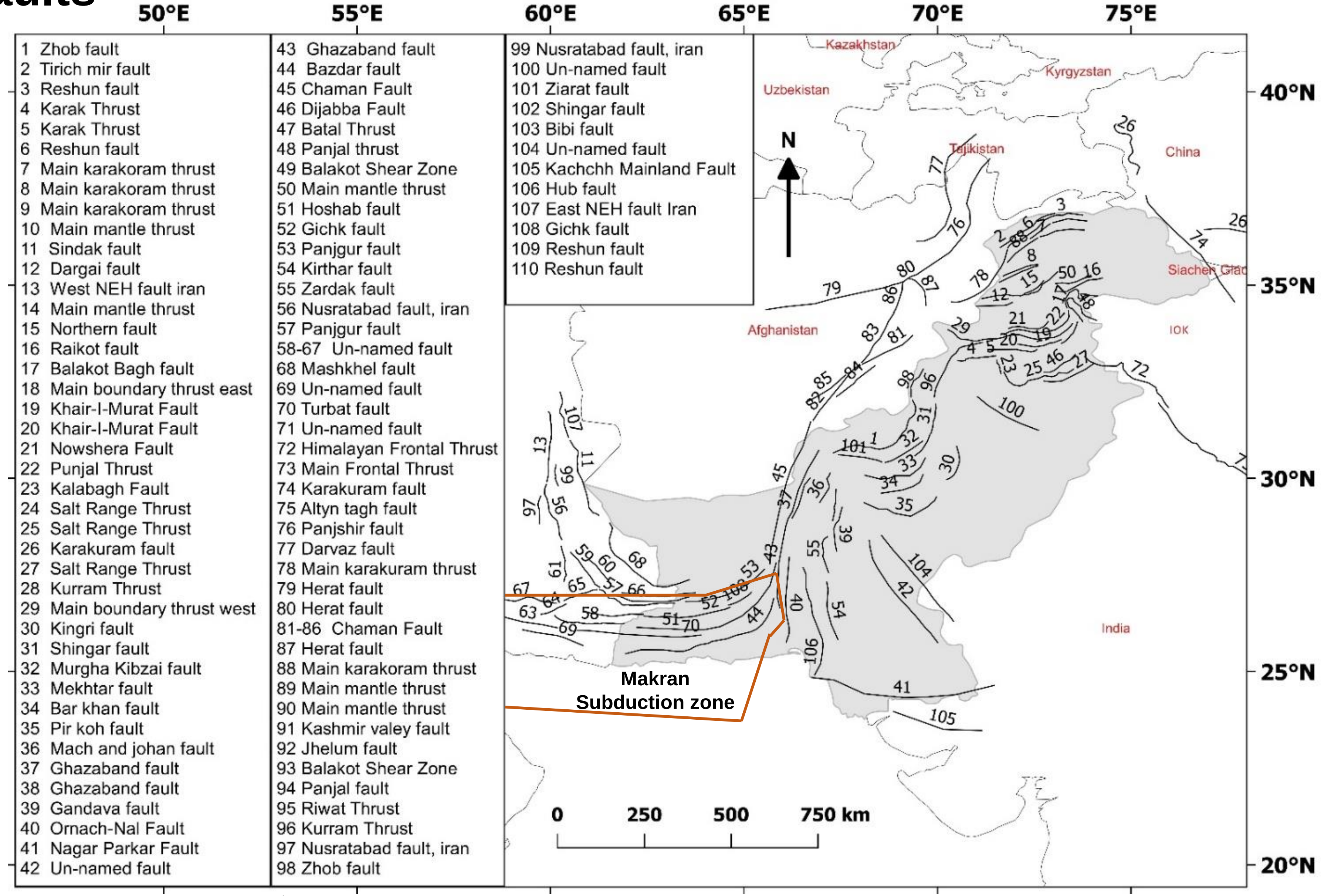
Comparison of the current study with the past PSHA studies

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.

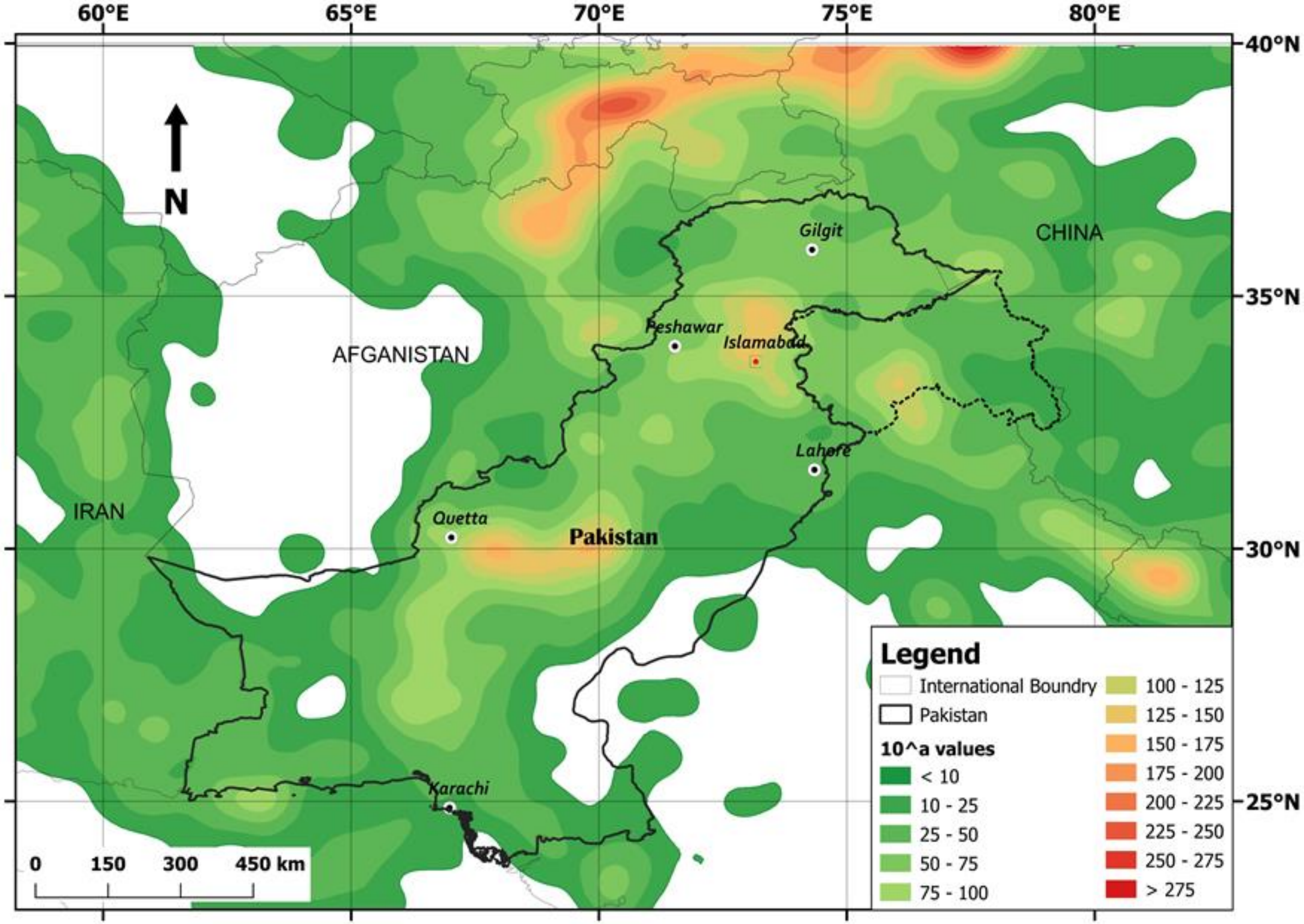
Study	GSHAP (Zhang et al. 1999)	PMD and NORSAR	NESPAK	Zaman et al. (2012)	EMME (2014)	Current study
Makran Subduction zone	Modeled as simple area source	Modeled as simple area source	Modeled as simple area source	The interface between two tectonic plates is modeled as sloping area source.	The inter slab 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.

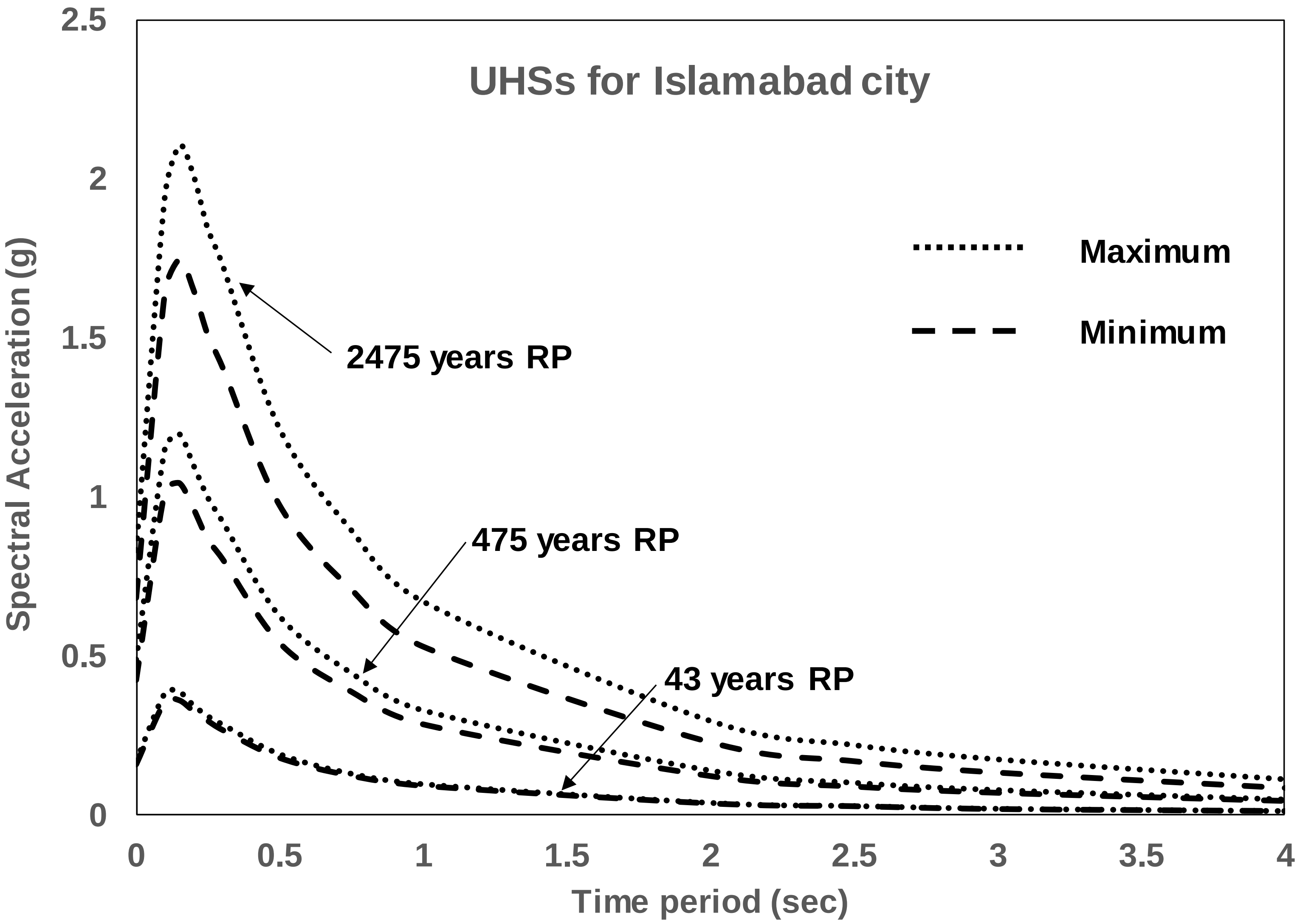
Crustal Faults



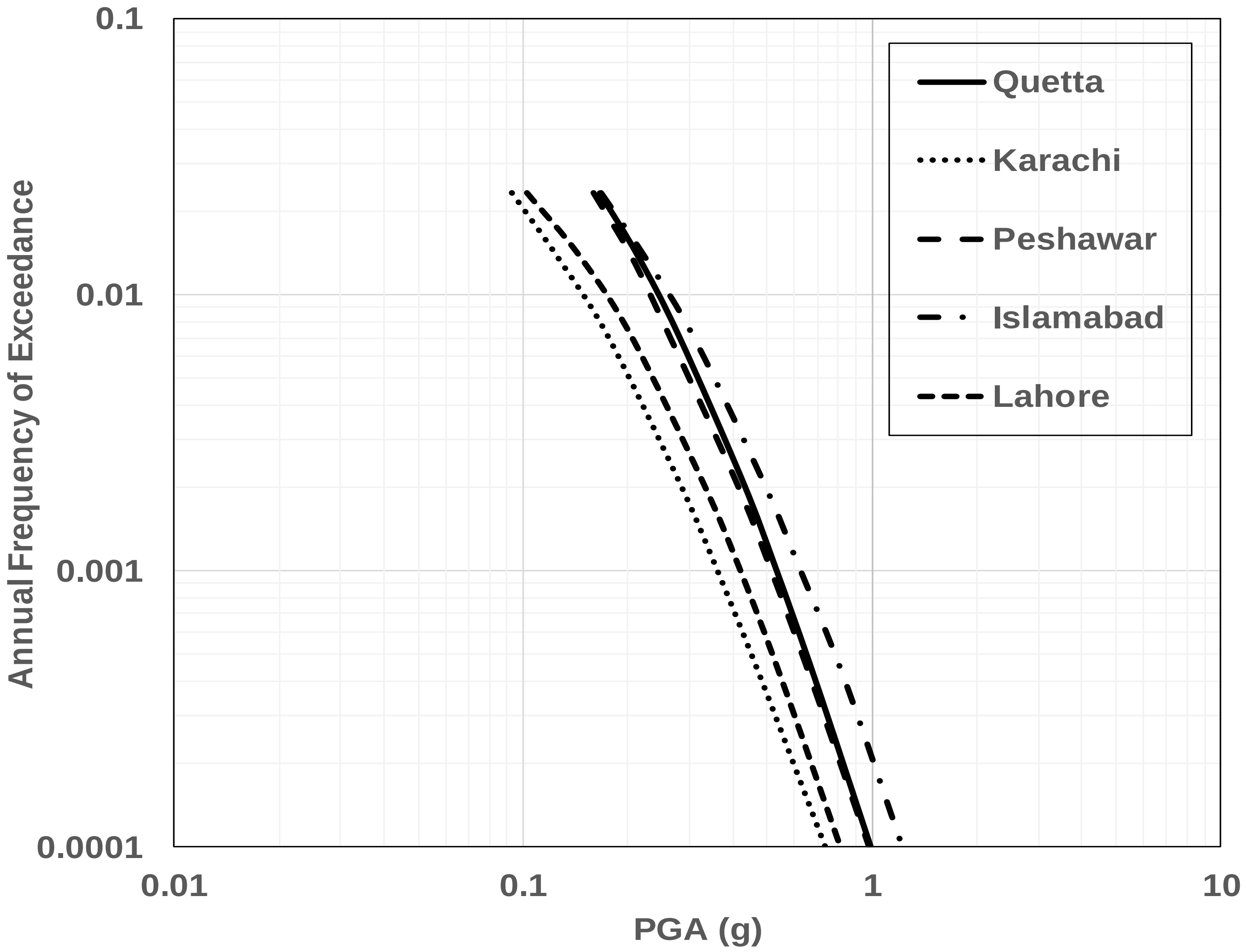
Spatially Smoothed Gridded Seismicity

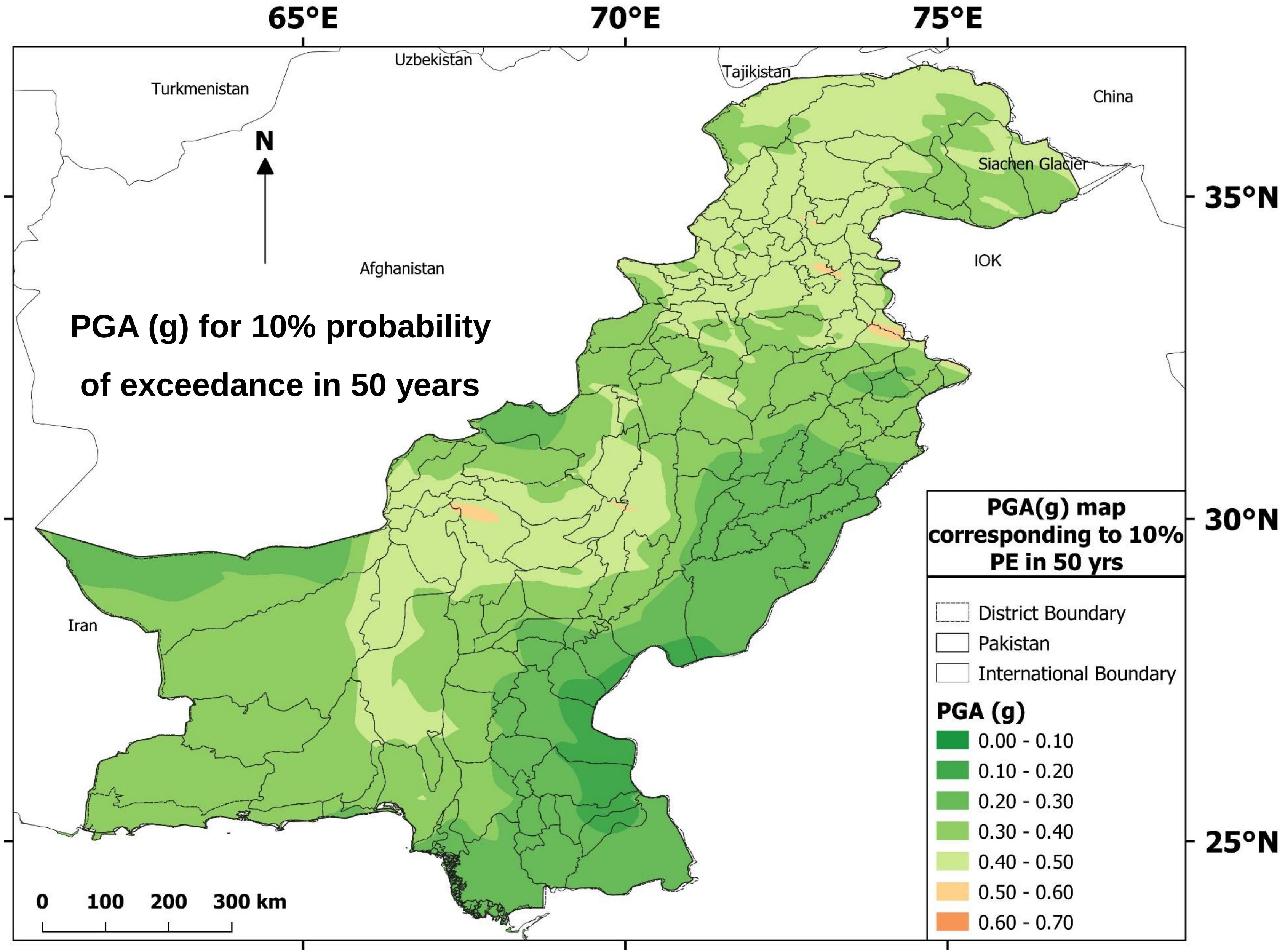


UHS for Islamabad

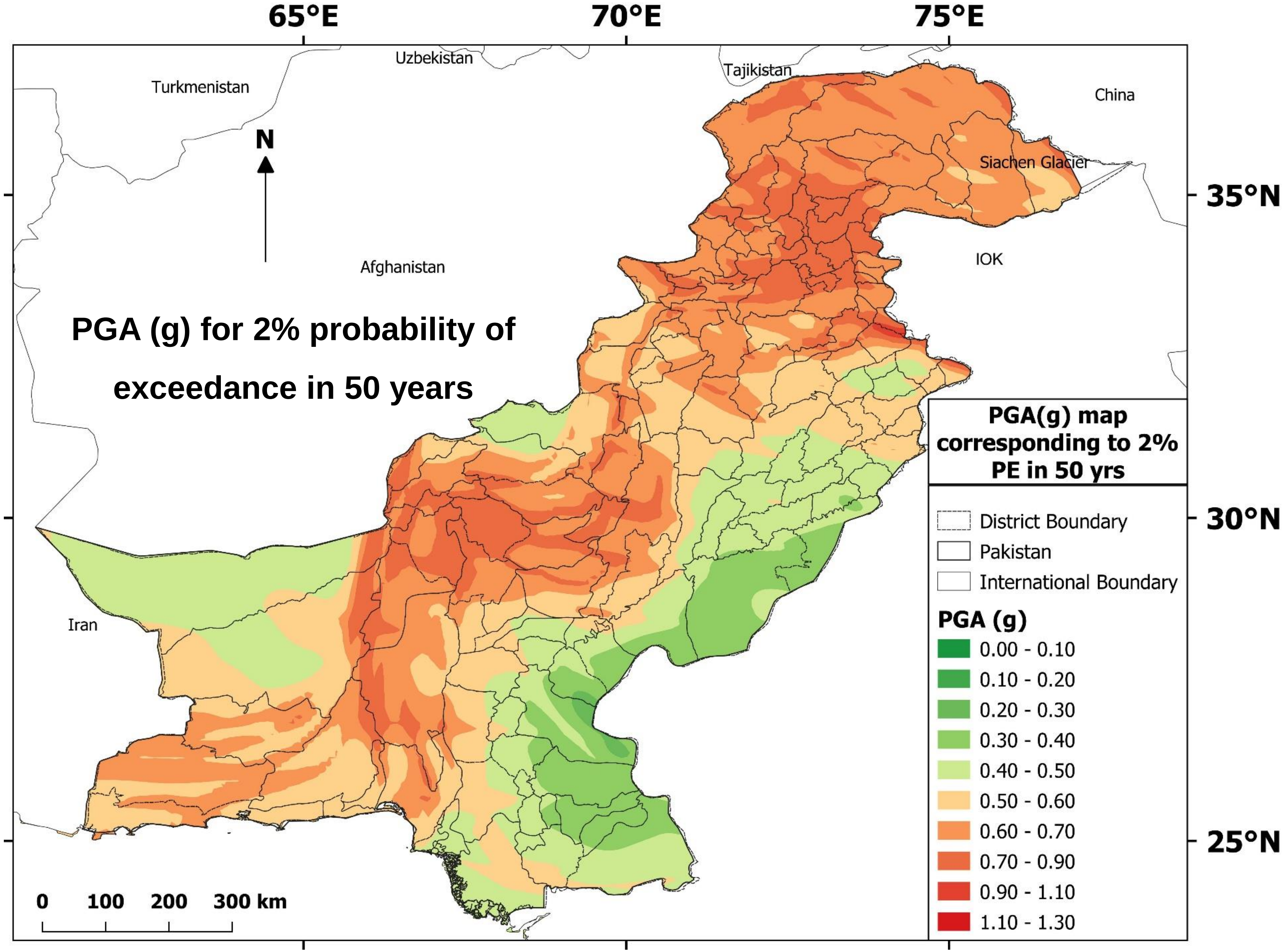


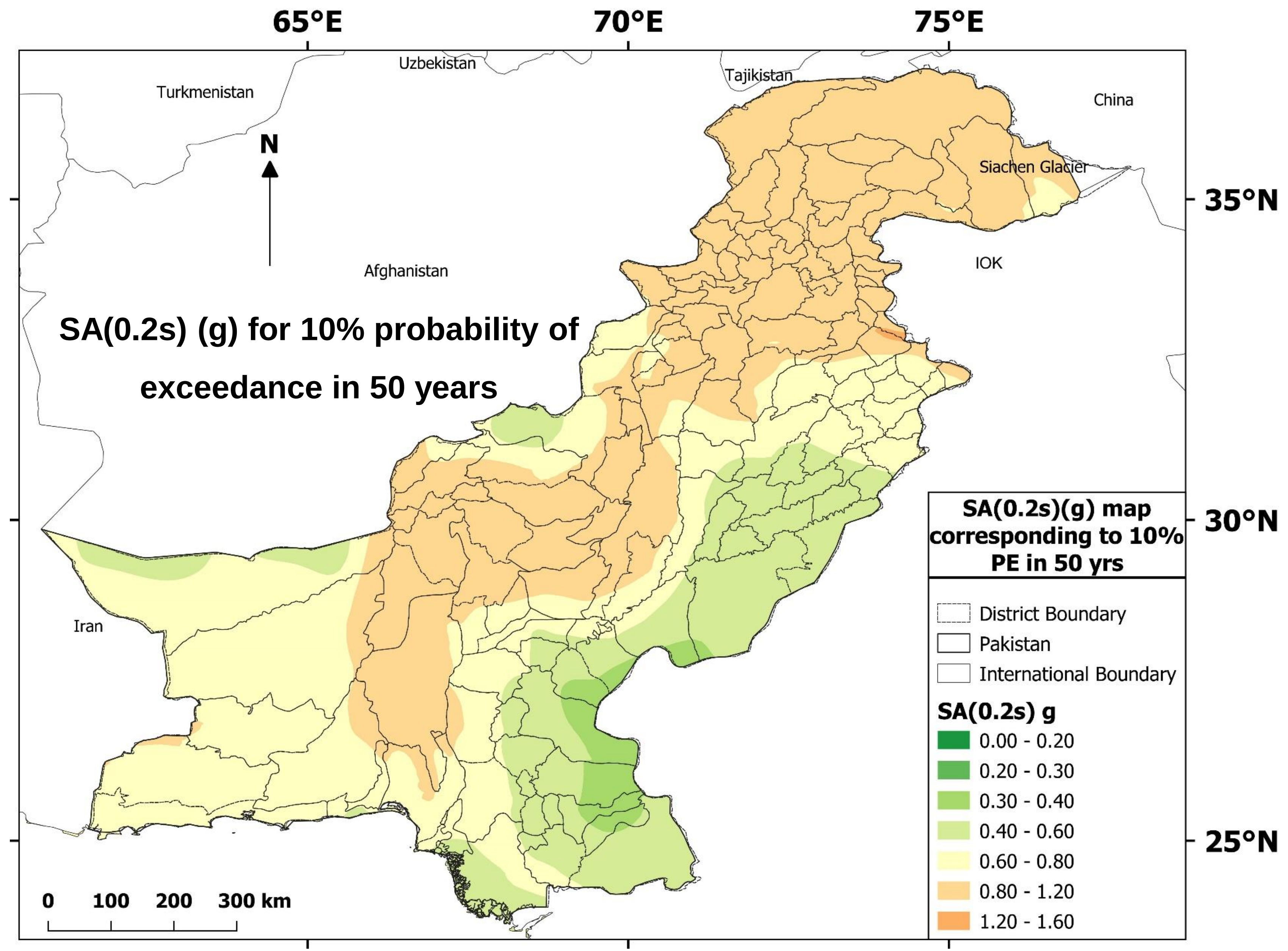
Hazard Curves for major cities of Pakistan

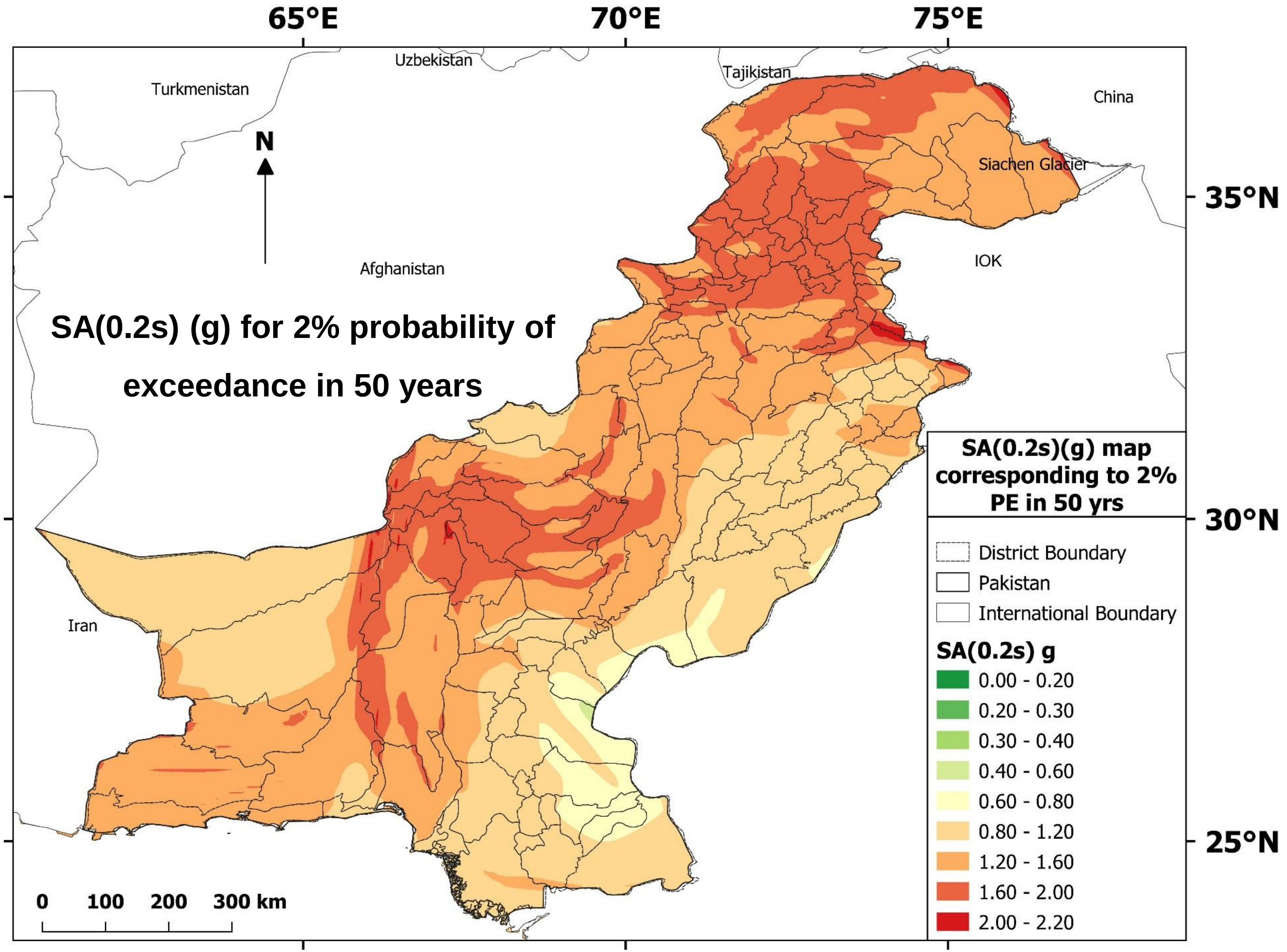


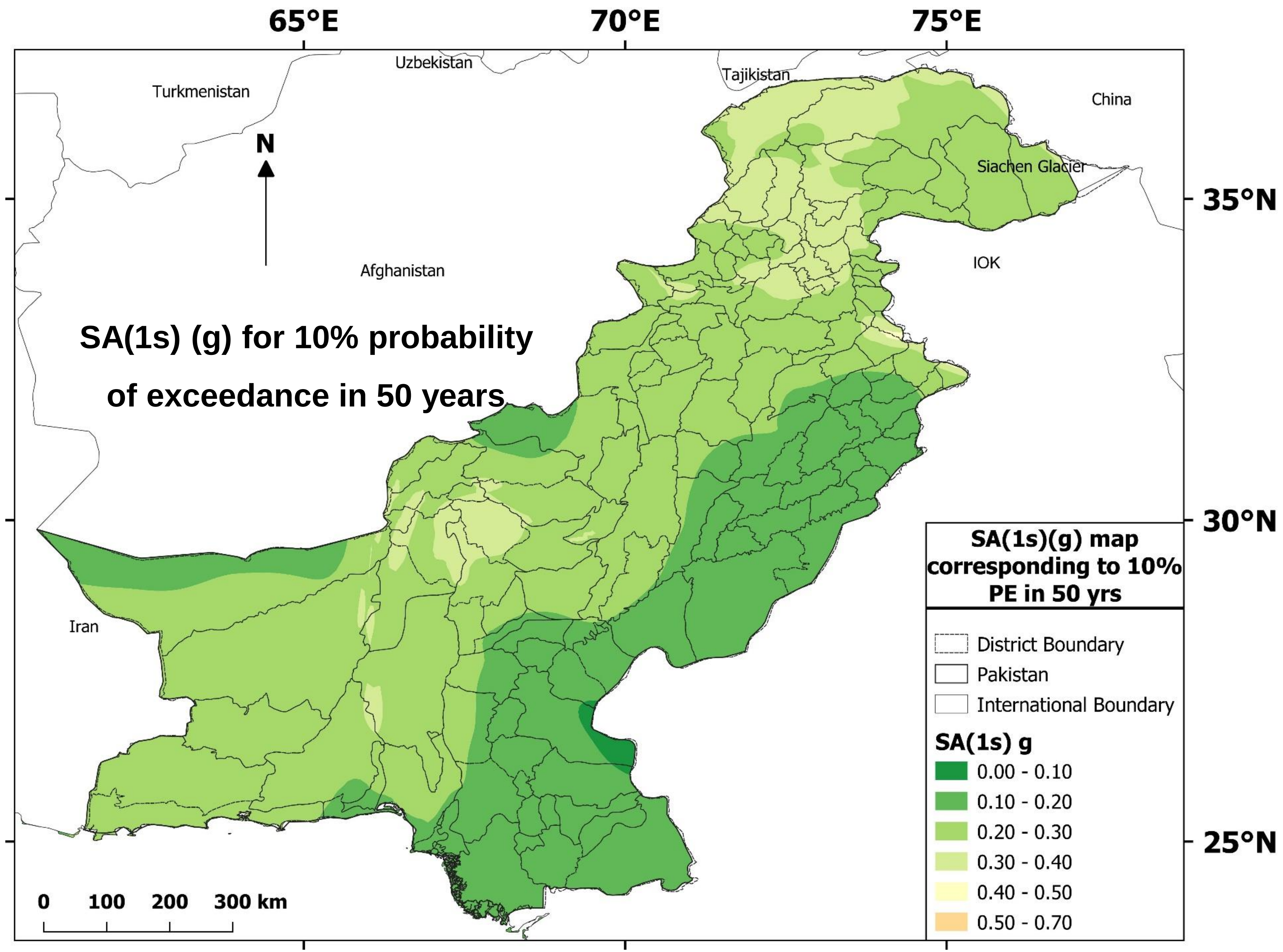

65°E
70°E
75°E
35°N
30°N
25°N
Uzbekistan
Tajikistan
Turkmenistan
China
N
Siachen Glacier
IOK
Afghanistan
PGA (g) for 10% probability
of exceedance in 50 years
Iran
0 100 200 300 km
PGA(g) map corresponding to 10% PE in 50 yrs
District Boundary
Pakistan
International Boundary
PGA (g)
0.00 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.60
0.60 - 0.70

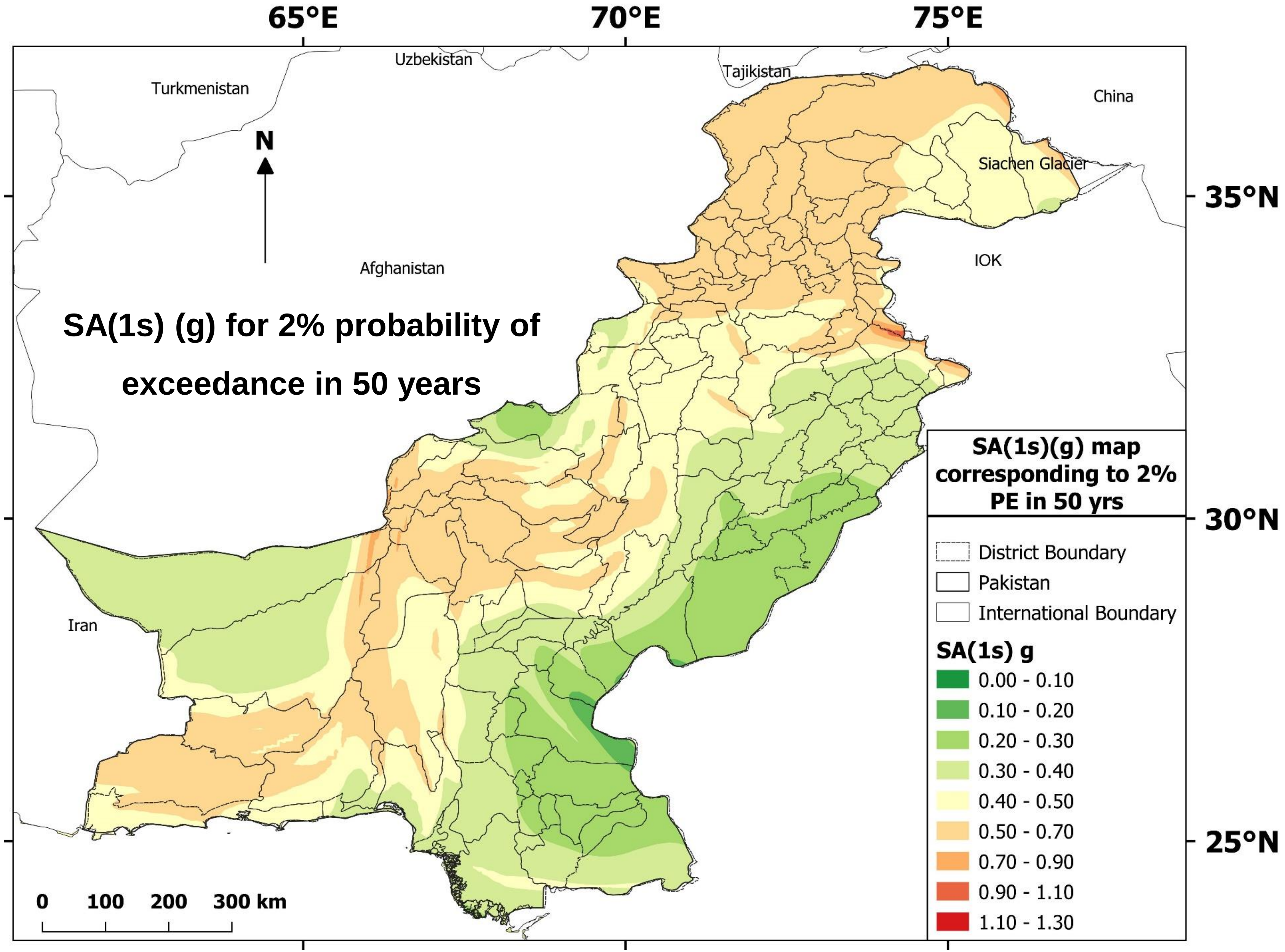
PGA (g) for 2% probability of exceedance in 50 years

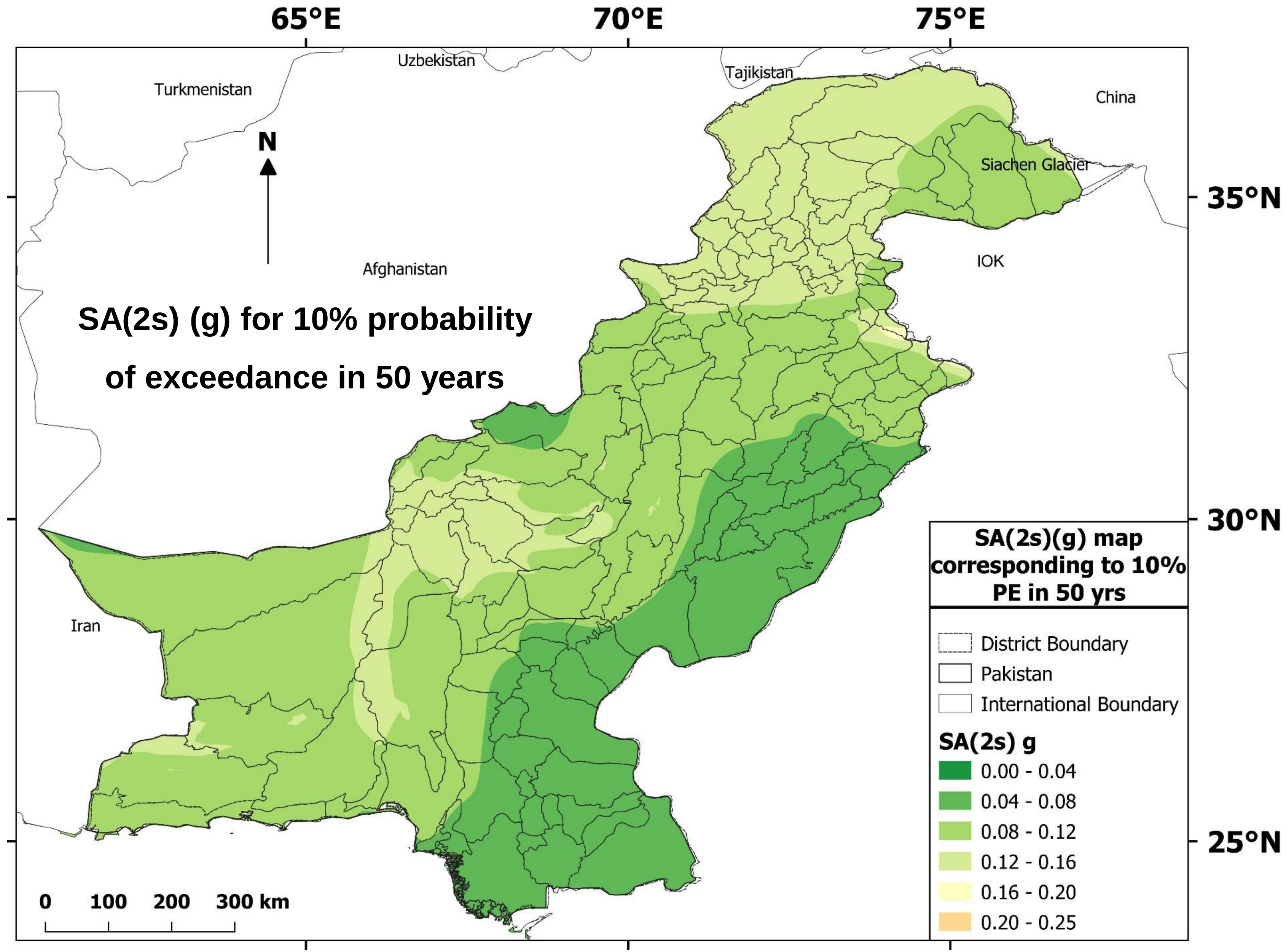


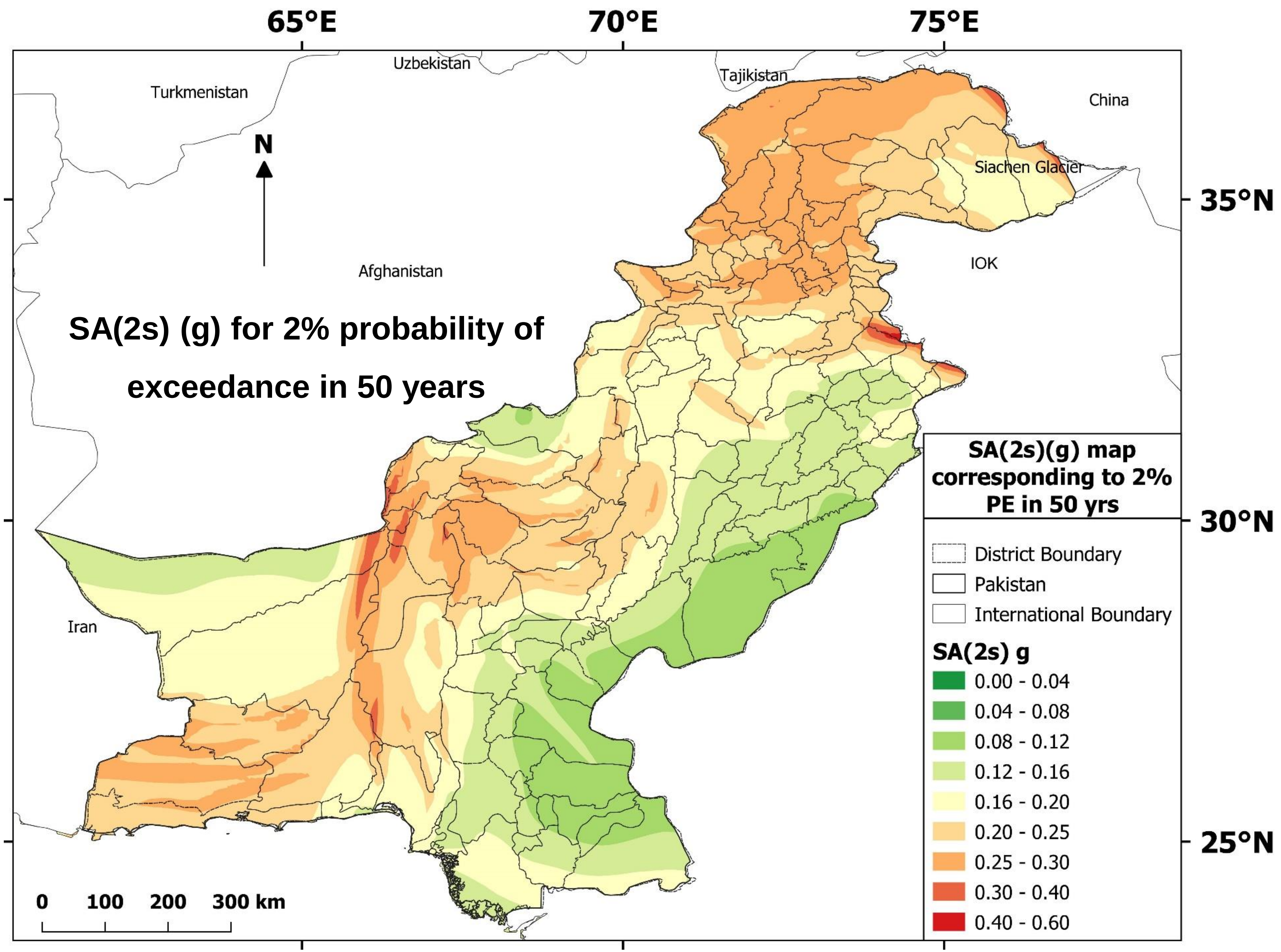

65°E
70°E
75°E
35°N
30°N
25°N
Uzbekistan
Tajikistan
Turkmenistan
China
Siachen Glacier
N
IOK
Afghanistan
Iran
SA(0.2s) (g) for 10% probability of exceedance in 50 years
SA(0.2s)(g) map corresponding to 10% PE in 50 yrs
District Boundary
Pakistan
International Boundary
SA(0.2s) g
0.00 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.60
0.60 - 0.80
0.80 - 1.20
1.20 - 1.60
0 100 200 300 km


65°E
70°E
75°E
35°N
30°N
25°N
Uzbekistan
Tajikistan
Turkmenistan
China
N
Siachen Glacier
IOK
Afghanistan
SA(0.2s) (g) for 2% probability of exceedance in 50 years
Iran
0 100 200 300 km
SA(0.2s)(g) map corresponding to 2% PE in 50 yrs
District Boundary
Pakistan
International Boundary
SA(0.2s) g
0.00 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.60
0.60 - 0.80
0.80 - 1.20
1.20 - 1.60
1.60 - 2.00
2.00 - 2.20


65°E
70°E
75°E
35°N
30°N
25°N
Uzbekistan
Turkmenistan
Tajikistan
China
N
Siachen Glacier
IOK
Afghanistan
SA(1s) (g) for 10% probability
of exceedance in 50 years
Iran
SA(1s)(g) map corresponding to 10% PE in 50 yrs
District Boundary
Pakistan
International Boundary
SA(1s) g
0.00 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.70
0 100 200 300 km


65°E
70°E
75°E
35°N
30°N
25°N
Uzbekistan
Tajikistan
Turkmenistan
China
N
Siachen Glacier
IOK
Afghanistan
SA(1s) (g) for 2% probability of exceedance in 50 years
Iran
0 100 200 300 km
SA(1s)(g) map corresponding to 2% PE in 50 yrs
District Boundary
Pakistan
International Boundary
SA(1s) g
0.00 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
0.40 - 0.50
0.50 - 0.70
0.70 - 0.90
0.90 - 1.10
1.10 - 1.30


65°E
70°E
75°E
35°N
30°N
25°N
Uzbekistan
Tajikistan
Turkmenistan
China
N
Siachen Glacier
IOK
Afghanistan
SA(2s) (g) for 10% probability
of exceedance in 50 years
Iran
SA(2s)(g) map corresponding to 10% PE in 50 yrs
District Boundary
Pakistan
International Boundary
SA(2s) g
0.00 - 0.04
0.04 - 0.08
0.08 - 0.12
0.12 - 0.16
0.16 - 0.20
0.20 - 0.25
0 100 200 300 km


65°E
70°E
75°E
35°N
30°N
25°N
Uzbekistan
Tajikistan
Turkmenistan
China
Siachen Glacier
N
IOK
Afghanistan
SA(2s) (g) for 2% probability of exceedance in 50 years
Iran
SA(2s)(g) map corresponding to 2% PE in 50 yrs
District Boundary
Pakistan
International Boundary
SA(2s) g
0.00 - 0.04
0.04 - 0.08
0.08 - 0.12
0.12 - 0.16
0.16 - 0.20
0.20 - 0.25
0.25 - 0.30
0.30 - 0.40
0.40 - 0.60
0 100 200 300 km

Thank you for your attention