RESPONSE TO THE EDITOR'S COMMENTS

The authors are very grateful to the Editors and Associate Editors for the kind consideration and possible publication of our article in the Natural Hazards and Earth System Sciences. The authors would like to thank all reviewers for suggesting improvements for the manuscript. Point-wise reply/answer to each comment is provided below (comments are shown in BOLD, answers are shown in REGULAR). All suggestions have been addressed, but still if reviewers have any other point/reservation, the authors are happy to incorporate. Furthermore, the authors appreciate the editors and reviewers for the timely handling of review process.

REVIEWER 1

<table>
<tr><th>Sr. No.</th><th>Questions with answers</th><th>Clarification made or Changes Incorporated</th></tr>
<tr><td>1</td><td>1. There is very little information is provided about the compilation of earthquake catalog, the historical era events may be discussed in the article and a small discussion on its compilation is required to be included.

The reviewer is thanked for this suggestion, the revised manuscript now incorporated the requested information. The catalogue was compiled till 2015 that also included historical earthquake data from Ambrasey (2000) and Ambrasey and Douglas (2004). Below is the priority list for the catalogue homogenization and correctness to remove the duplicate events:

<table>
<tr><th>Priority</th><th>Data Source</th></tr>
<tr><td>1</td><td>Ambrasey & Douglas (2004)</td></tr>
<tr><td>2</td><td>Ambrasey (2000)</td></tr>
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<tr><td>3</td><td>ISC</td></tr>
<tr><td>4</td><td>GCMT</td></tr>
<tr><td>5</td><td>NGDC</td></tr>
<tr><td>6</td><td>USGS</td></tr>
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</td><td></td></tr>
<tr><td>2</td><td>2. Completeness analysis and declustering of catalog is missing, both catalog completeness and declustering should be discussed, as these seriously effect the hazard values.

The authors fully agree with the reviewer. The requested information is provided in the revised manuscript.</td><td>YES</td></tr>
<tr><td>3</td><td>3. Several important studies concerning Peshawar, Khaliq et al. (2018); Waseem et al. (2018); Sesetayn et al. (2018) Ahmad et al. (2019) have been missed by the authors, they should be cited in the article, where required.

The authors thank the reviewer for this suggestion, the revised manuscript now incorporated the mentioned references.</td><td>YES</td></tr>
<tr><td>4</td><td>4. The results of this study should be discussed and compared with the similar studies.

The authors fully agree to the reviewer, the revised manuscript now compared the outcomes with relevant studies.</td><td>YES</td></tr>
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REVIEWER 2

Sr. No.	Questions with answers	Clarification made or Changes Incorporated
1	**1. Please justify why you opted for areal sources surpassing point and line sources. Or, why you did not opt for a combination of all?** The reviewer is thanked for pointing to this. The available catalogue and seismicity pattern is quite scattered and not very specific to suggest taking line/fault sources. There are not enough data (fault source information) to support line sources based hazard assessment. Moreover, due to the scattered seismicity pattern and large number of small fault-lines, the definition of fault line becomes challenging. Areal sources are reasonable approximation to idealize seismic sources and used in many similar studies. Few studies have used fault sources but that have resulted in very high seismic hazard, which is not justified by the history of earthquakes in Peshawar.	Comments are provided herein to clarify the author's intention.
2	**2. The attenuation relationship you are using is not from the Himalaya. Would it be possible to calibrate some subduction GMPE with the available records from Pakistan to obtain more realistic results?** The authors fully agree with the reviewer. Pakistan doesn't have specific GMPEs of its own, therefore, GMPEs from other similar region are adopted. The selected GMPEs were earlier tested in prediction of ground motion for selected earthquake events. The GMPEs, which have shown relatively better performance, were selected for hazard analysis. This is clarified in the revised manuscript.	YES
3	**3. As you contrasted yourself, the effects of deep earthquakes were pronounced recently in Pakistan yet you did not include the effect. Could you please reframe the logic tree in any way to incorporate this?** The authors fully agree with this. Deep sources were included in the hazard assessment, however, this had little influence on the final hazard maps. Possible reason seems to be the	Comments are provided herein to clarify the author's intention.

Sr. No.	Questions with answers	Clarification made or Changes Incorporated
	limited earthquake catalogue and the foreign GMPEs, which were not specific to the region. Also, the GMPEs lack to take into account the site effects common in Peshawar valley due to deep earthquakes. We didn't find any other alternative to manifest the deep sources effects accurately, however, we put this as a question for others to address.	
4	**4. The source zones are somehow interesting too. For instance, why zones 5, 6, and 7 have quite limited data? Could you please elucidate your zoning scheme?** The authors fully agree to the reviewer, however, the seismic sources used for shallow earthquakes were those obtained from the Building Code of Pakistan – Seismic Provisions. The deep sources were selected in consultation with the National Center of Excellence in Geology, Peshawar. Since, deep sources are not studied before for Peshawar. This is clarified in the revised manuscript.	Comments are provided herein to clarify the author's intention.
5	**5. As you have prepared the hazard maps for bedrock, I request you to consider hazard maps on the surface too [if possible]. If you have some site response/amplification studies, it would be interesting and also useful for the structural earthquake engineering communities. Please comment.** The authors fully agree to the reviewer, however, the focus of present study was to provide the base maps for hazard. Site-specific soil was not known so it was not addressed in the hazard assessment. Alternatively, the code suggests amplification factors for various soil from Type C to Type E as per NEHRP soil classification.	Comments are provided herein to clarify the author's intention.
6	**6. Please fix some grammatical bugs present in the manuscript.** The authors thank the reviewer for this suggestion, the revised manuscript is re-visited for English writing improvement.	YES

Seismic Hazard Maps of Peshawar District for Various Return Periods

Khalid Mahmood[1], Usman Khan[2], Qaiser Iqbal[3], Naveed Ahmad[4,*]

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[2]Department of Civil Engineering, UET Peshawar, KP Pakistan.
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Abstract:

The probabilistic seismic hazard analysis of Peshawar District has been conducted for a grid size of 0.01^{0}. The seismic sources for the target location are defined as the area polygon with uniform seismicity. The earthquake catalogue was based on the earthquake data obtained from different worldwide seismological networks. The earthquake events obtained in different magnitude scale were converted into moment magnitude using indigenous regression relationships. The homogenized catalogue was subdivided into shallow crustal and deep subduction zone earthquake events. The seismic source parameters were obtained using the bounded Gutenberg-Richter recurrence law. The seismic hazard maps were prepared in term of PGA at bedrock using different ground motion attenuation relationships. The study revealed; the selection of appropriate ground motion prediction equation is an important factor in defining the seismic hazard of Peshawar District. The inclusion of deep subduction earthquakes does not add significantly to the seismic hazard for design base ground motions. The calculated seismic hazard map for shallow crustal earthquake, including also the epistemic uncertainty, was in close agreement with the map given in the Building Code of Pakistan – Seismic Provision (2007) for a return period of 475 years on bedrock. The seismic hazard maps for other return periods; i.e., 50, 100, 250 475, and 2500 years were also presented.

Keywords: Seismic hazard map, probabilistic seismic hazard analysis, BCP-2007, Peshawar, CRISIS

1. Introduction:

Peshawar is the capital city of the Khyber Pakhtunkhwa province of Pakistan that has historical background in the history of indo-subcontinent. The city provides key access to the Central Asian States

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through Afghanistan along the Western borders of Pakistan. It is located at 710, 43.4' N latitude and 330, 93.7' E Longitude in the western Himalayan region.

Peshawar is characterized by high seismicity rates due to its vicinity to the active plate boundary between the Indian and Eurasian plates, which are converging at the rates of 37-42 mm/year (Chen et al., 2000). The Main Boundary Thrust (MBT) system along which the devastating Kashmir earthquake occurred in 2005 is located in the northern parts of the country together with some other active regional fault systems, which include Main Mantle Thrust (MMT) and Main Karakorum Thrust (MKT). These faults, if reactivated can act as a potential source of seismic hazard for the region including Peshawar (Waseem et al., 2013). This was confirmed also by the recent 2015 Afghanistan-Pakistan earthquake that caused widespread damages in the province of Khyber Pakhtunkhwa (Ahmad, 2015), including Peshawar, damaging a number of important structures in the historic city (**Fig. 1**).

The Building Code of Pakistan in 1986 has placed Peshawar in Zone 2 that corresponds to intensity V-VI on the Modified Mercalli Intensity scale. Mona Lisa et al. (2007), based on the probabilistic seismic hazard analysis for the NW Himalayan thrust, recommended a value of 0.15g for Peshawar. Hashash et al. (2012), using discrete faults model for Northern Pakistan, suggested PGA value in the range of 0.20-0.4g. Rafi et al. (2012), based on the probabilistic seismic hazard analysis and zonation for Pakistan and Azad Jammu and Kashmir, has evaluated a value of 0.175g for Peshawar. Several researchers either regionally or partially has studied the seismic hazard of Peshawar District (Table 1). The Geological Survey of Pakistan (2006) Seismic Zoning Map suggests a PGA value in the range of 0.03-0.1g, Zaman and Warnitchai (2010) suggests in the range of 0.33-0.4g while Zhang et al. (1999) suggested in the range of 0.166-0.244g. The Building Code of Pakistan – Seismic Provision (2007), which is a legal binding for the seismic design of structures in Pakistan, has placed Peshawar in Zone 2B. This zone has peak ground acceleration in the range of 0.16g to 0.24g for a return period of 475 years. This has revealed that previous seismic hazard studies of Peshawar and Northern Pakistan report widely conflicting results (Ahmad et al., 2019; Ambraseys et al., 2005; Khaliq et al., 2019; Sesetyan et al., 2018; Waseem et al., 2018).

The present study aims to re-calculate the seismic hazard of Peshawar, based on the up-to-date earthquake catalogue and ground motion prediction equations, and compare the same with that recommended by BCP-SP (2007). The PGA value at bedrock was calculated using the classical probabilistic seismic hazard analysis procedure. The area sources polygon as suggested by BCP-SP (2007) were used as seismic sources for which the earthquake catalogu was obtained from worldwide seismogram networks. The Modified Gutenberg-Richter empirical model was used to calculate the seismic zone parameters for both shallow crustal and deep subduction zone earthquakes. The seismic

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hazard in terms of PGA at bedrock was calculated and plotted in GIS environment. The different ground motion attenuation relationships compatible to the geology and seismicity of local environment were used to quantify the difference in seismic hazard results. Furthermore, the logic tree approach was used to take into consideration the epistemic uncertainty. The GIS based seismic hazard map developed for a return period of 475 years was compared with that given in the BCP-SP (2007). Seismic hazard maps were prepared for various other return periods; i.e. 50, 100, 250, 475 and 2500 years.

(a) Peshawar City, Qisa Khwani Bazar: Complete collapse of building roof.

(b) Peshawar City, Ganj: Sliding of overhead tank on the building roof.

(c) Peshawar City, Fort: Collapse of masonry retaining wall and backfill sliding of Fort "Qilla Bala Hisar".

Figure. 1 Damages observed in Peshawar during 2015 Afghanistan-Pakistan earthquake.

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Table 1. Seismic hazard of Peshawar reported by various researchers

S. No.	Authors	PGA (g)
1	Bhatia et al. (1999)	0.10 – 0.15
2	Mona Lisa et al. (2007)	0.15
3	Zhang et al. (1999)	0.16 – 0.24
4	Rafi et al. (2012)	0.17
5	Hashash et al. (2012)	0.20 – 0.40
6	Şeşetyan et al. (2018)	0.30 – 0.40
7	Khaliq et al. (2019)	0.32 – 0.34
8	Zaman and Warnitchai (2012)	0.33 – 0.40
9	Waseem et al. (2018)	0.38
10	Shah et al. (2019)	0.06
11	Ahmad et al. (2019)	0.16 to 0.24

2. Probabilistic Seismic Hazard Analysis

The uncertainties in the location, size and rate of recurrence of earthquake along with the variation in the ground motion intensity and spatial variability can be well considered in the probabilistic seismic hazard analysis procedures (Ornthammarath et al., 2011; Çağnan and Akkar, 2018; Rowshandel, 2018). The probabilistic seismic hazard analysis (PSHA) provides a framework in which these uncertainties can be identified, quantified, and combined in a rational manner to provide a more complete picture of the seismic hazard.

According to modified Gutenberg-Richter Law the earthquake exceedance rate $\lambda(M)$ for an earthquake magnitude $\boldsymbol{M}$ can be defined using Equation (1):

$$\boldsymbol{\lambda(M) = \lambda_o \frac{e^{-\beta M} - e^{-\beta M_u}}{e^{-\beta M_0} - e^{-\beta M_u}}\ , M_o \le M \le M_u} \qquad (\mathbf{1}),$$

λ_0 is the exceedance rate in the range of lower $\boldsymbol{M_o}$ and upper limit $\boldsymbol{M_u}$ of magnitude. β is the earthquake source parameter. For the Poisson process, the probability density of the earthquake magnitude is given by Equation (2):

$$P(M) = \lambda_o \beta \frac{e^{-\beta M}}{e^{-\beta M_o} - e^{-\beta M_u}} \qquad (2)$$

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The strong motion parameters; i.e. acceleration, velocity and displacement, are characterized using attenuation relationships that shows the variation in strong motion amplitude with source-to-site distance and depends on a number of source, path and site parameters (Douglas, 2019; Kramer, 1996; McGuire, 2004; Rupakhety and Sigbjörnsson, 2009). For example, the attenuation relationship for the peak horizontal acceleration has been developed by Campbell (1981) within 50 kM of fault rupture in magnitude 5.0 to 7.7 earthquake. Campbell and Bozorgnia (1994) developed attenuation relationships using worldwide moment magnitude in the range of 4.7 to 8.1. This relationship is more specific and provides additional terms for source characterization. Toro et al., (1994) has developed attenuation relation in term of peak horizontal acceleration on rock side for the continental portion of Northern America. Among others Boore and Atkinson (2008) and Akkar and Bommer (2010) have developed site specific attenuation relationship that can calculate peak acceleration in term of earthquake magnitude, source to site distance, fault mechanism and site condition. Boore and Atkinson (2008) model was developed based on the empirical regression of PEER NGA strong-motion database while that of Akkar and Bommer (2010) model was developed for Europe, Mediterranean and Middle east region.

The mentioned attenuation relationships can be used for ground motion prediction of shallow crustal earthquakes. However, several researchers including Crouse et al. (1988), Crouse (1991), Molas and Yamazaki (1993), Youngs et al. (1995) have pointed out different conditions of attenuation relationships for shallow and subduction zones. Lin and Lee (2008) and Kanno et al. (2006) have developed attenuation relationships for earthquake records of Taiwan and Japan respectively. The study of Lin and Lee (2008) showed lower attenuation for subduction zones than that for crustal shallow earthquakes. Therefore, the use of shallow crustal earthquake attenuation relationships may lead to underestimation of the seismic hazard for subduction earthquakes in probabilistic analysis.

In probabilistic seismic hazard analysis, the peak acceleration at a location is a function of magnitude and distance that is lognormally distributed with standard deviation. In the hazard analysis, the study area is first divided into seismic sources based on tectonics and geotechnical characteristics. The different seismic sources are assumed to occur independently, and the occurrence of seismic events is considered to be uniformly distributed over the source. The acceleration exceedance rates $v_i(a)$ for the single seismic source i[th] is calculated using Equation (3):

$$v_i(a) = \sum_i w_{ij} \int_{M_o}^{M_u} \left(-\frac{d\lambda_i\,(M)}{dM}\right) Pr\big(A > a|M, R_{ij}\big)dM \qquad (3)$$

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where M_0 is the smallest and M_u is the largest magnitude of seismic source, $Pr(A>a|M,R_{ij}))$ is the probability that acceleration A exceeds the value a at distance R_{ij} for an earthquake of magnitude M. The acceleration exceedance $v(a)$ due to all sources-N is calculated through combining all sources, as given in Equation (4):

$$v(a) = \sum_{i=1}^{N} v_i(a) \qquad (4)$$

3. Seismicity of Peshawar

The collision of Eurasian and Indian plate has resulted in the formation of active Himalayan orogenic system that is further classified into Tethyan, Higher, Sub and Lesser Himalayas (Gansser, 1964). The divisions are based on the tectonic blocks formed and separated by major faults boundary.

The Microsoft Encarta Reference Library (2003) shows that the valley of Peshawar, consists of southern part of Eurasian plate and northern part of Indo-Australian plate. This part of the Himalayas is variably interpreted to be Lesser Himalayas (Tahirkheli et al., 1982) and Tethyan Himalayas (DiPietro and Pogue 2004). The seismic hazard study of Waseem et al. (2006) has identified about twenty-one seismogenic faults around Peshawar. Most of these faults have reverse fault mechanism and have a Joyner and Boore distance R_{JB} in the range of 19-100 km. According to Ali and Khan (2004), most of the significant earthquakes felt at Peshawar have their origin in the Hindu Kush region of Afghanistan and few in northern areas of Pakistan.

4. Case Study PSHA of Peshawar

The seismic hazard software CRISIS-2007 was used to calculate the peak acceleration at bedrock for Peshawar District. **Fig. 2** shows the geographical location of Peshawar District within the geo-political boundaries of KP Province of Pakistan. The hazard analysis requires seismic source geometry, earthquake reoccurrence relationship and the selected ground motion attenuation relationship. In the present study the ground motion attenuation relationships of Boore and Atkinson (2008) and Akkar and Boomer (2010) were used for shallow crustal seismic earthquakes and that of Lin and Lee (2008) and Kanno et al. (2006) for deep subduction zone earthquakes. Earthquake events within 50 km depth were considered as shallow while earthquake events occurring at depth larger than 50 km were considered as deep earthquakes. The

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seismic hazard maps were prepared in GIS environment based on a grid size of 0.01^0 for various return periods; i.e. 50, 100, 250, 475 and 2500 years.

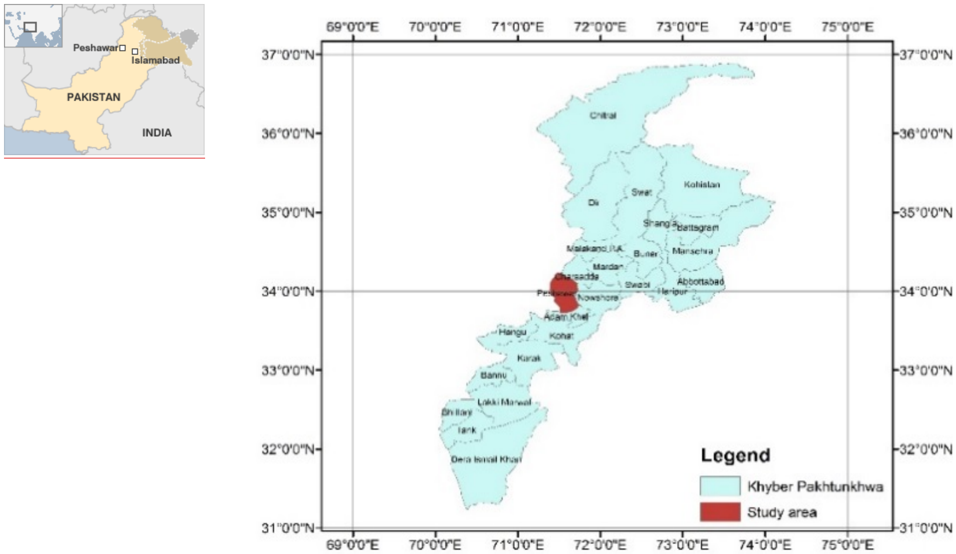

Figure. 2 Location of study area

4.1 Seismic Sources Identification and Characterization

The Building Code of Pakistan (BCP-SP, 2007) has defined the potential shallow seismic sources for Pakistan including northern areas. Those within 200 km of Peshawar were considered potential sources for earthquake activity impacting Peshawar (**Fig. 3**). The potential seismic sources (seven seismic sources in present study) for Peshawar region in a rectangular shape with latitude (31.888~ 36.006) and longitude (69.562~73.620), as shown in **Fig. 4**, were considered for the compilation of earthquake catalogue data collection. The earthquake catalogues were obtained using worldwide seismogram network sources i.e., United States of Geological Survey, (USGS), National Geophysical Data Center (NGDC), Global Centroid Moment Tensor (GCMT) and International Seismological Center (ISC) using the time span of 1500 AD till 2015 with focal depth up to 1000 m. The catalogue also included historical data from Ambrasey (2000) and Ambrasey and Douglas (2004). These different network already discussed gives earthquake magnitude in different scales e.g. moment magnitude, surface magnitude and low magnitude, etc. According to Kanamori (1977) and Hanks and Kanamori (1979) the moment magnitude is the most accurate scale that does not saturate in higher magnitude events. Therefore, all the magnitudes were converted into moment magnitude (Mw) using regression analysis. **Fig. 5** shows the empirical

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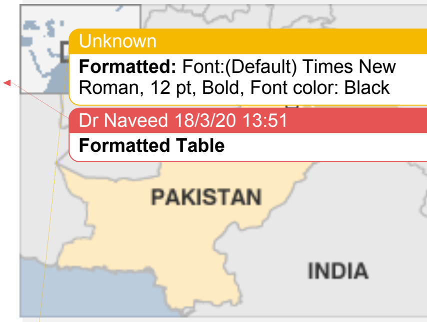

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relationships established in present study for earthquake magnitude conversion, which were employed for the catalogue homogenization.

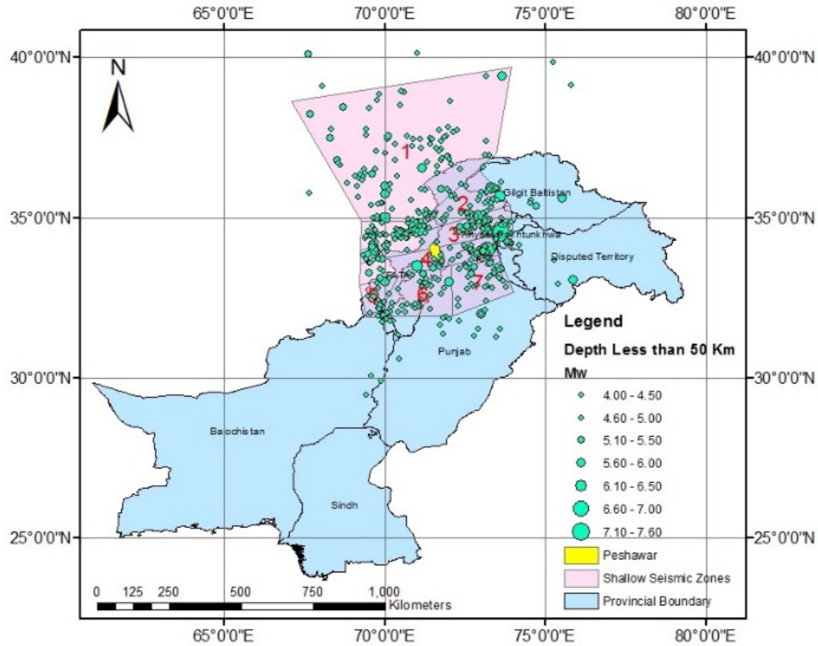

Figure. 3 Shallow seismic sources for Peshawar (BCP-2007)

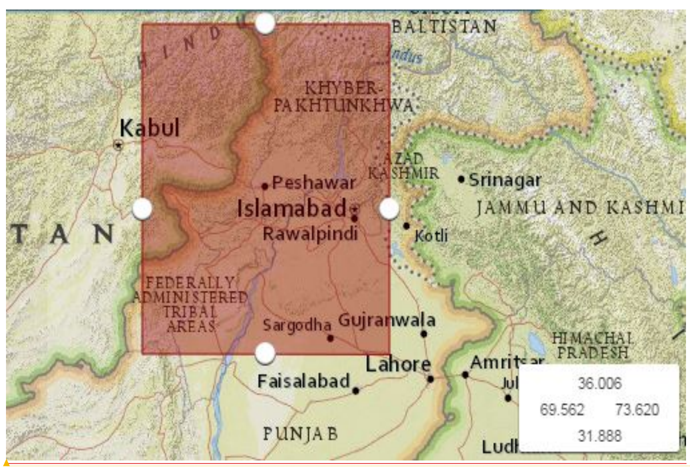

Figure. 4 Seismic source identification with defined latitude and longitude. © Google Map.

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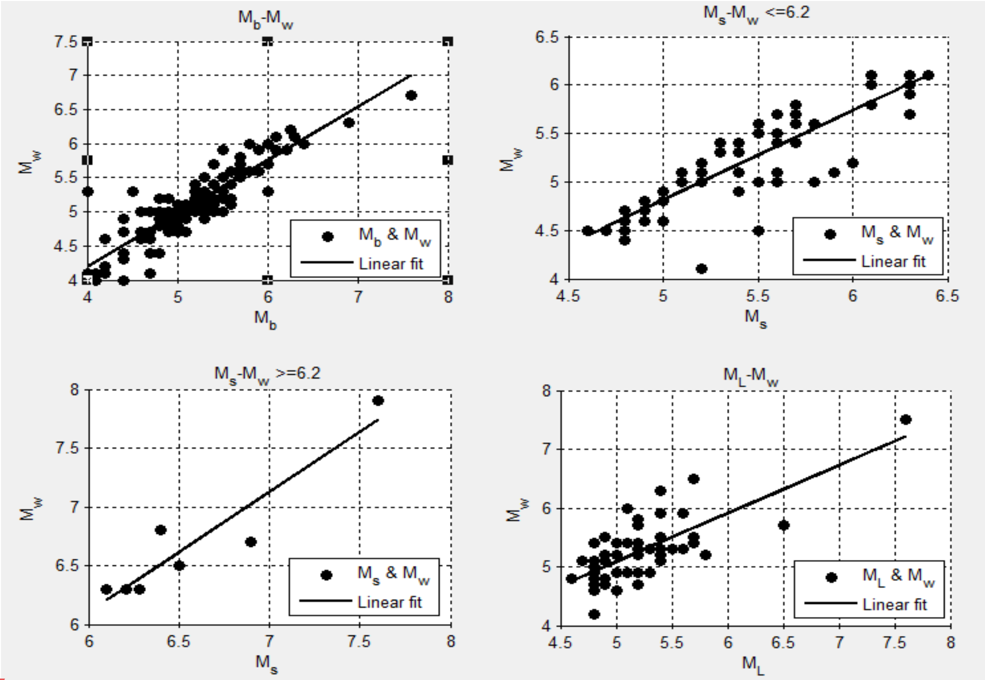

Figure. 5 Empirical relationships for moment magnitude

The moment magnitude catalogue was further subdivided into shallow (depth less than 50 km) and deep (depth more than 50 km) earthquake events. **Fig. 6** shows the shallow and deep earthquake records along with seismic zones as defined in BCP-SP (2007). Furthermore, **Table 2** reports the number of earthquakes in each seismic source along with maximum and minimum magnitude of each source. Deep earthquakes were found primarily in seismic source 1 and seismic source 2 that included the Hindu Kush seismic region. The deep sources were selected in consultation with the National Center of Excellence in Geology, Peshawar. Since, deep sources were not studied before for Peshawar.

Table. 2: No. of earthquakes, minimum and maximum magnitude in shallow and deep seismic source

Zones	**1**		**2**		**3**	**4**	**5**	**6**	**7**
Depth, (kM)	<50	>50	<50	>50	<50	<50	<50	<50	<50
No. of Earthquakes	99	454	79	23	76	43	17	35	32
Minimum (Mw)	4.0	4.0	4.1	4.2	7.6	4.0	4.1	4.1	4.1
Maximum (Mw)	6.2	7.7	4.0	5.1	7.5	6.8	6.0	6.0	5.5

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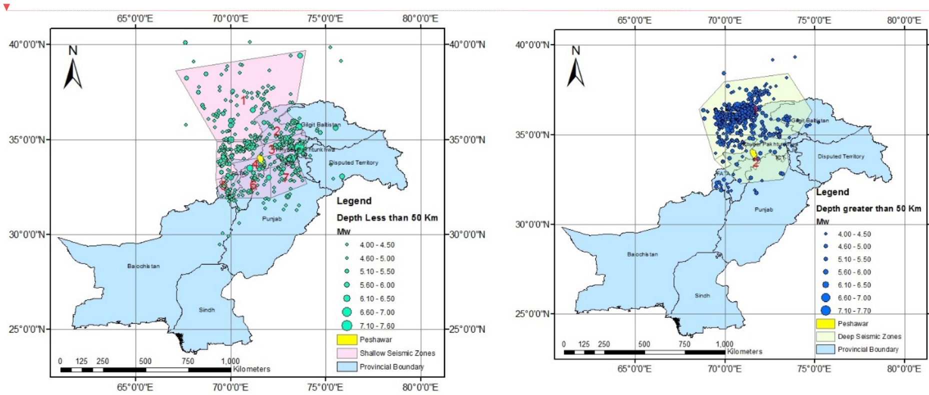

(a) Shallow crustal earthquake (b) Deep subduction zone earthquake

Figure. 6 Earthquake records from homogenized catalogue and with defined seismic sources

4.2 Processing of Earthquake Catalogue

De-clustering

In seismic hazard analysis the probability of earthquake occurrence follows poison's distribution which considers the independent events only (main shocks). This is to avoid over estimation of the seismic hazard. The dependent events (foreshocks and aftershocks) are temporally and spatially dependent on the main shocks. For this purpose Declustering was performed to remove the dependent events for the catalogue. The Gardner & Kenopoff (1974) Declustering algorithm method was used for removing foreshocks and aftershocks (Gardner and Knopoff, 1974). This performs windowing procedure in time and space on the event magnitude to identify the dependent events. To perform theses analysis Z-Map coding developed by ETHZ (freely available) was used. The homogenized catalogue was converted into Z-map specified format to perform the routine analysis. A total of 926 independent events were remained after Declustering.

Completeness Analysis:

This catalogue reports events from very past, which cannot be considered complete for all the magnitudes and time. The time window starts from the year 1500 and that time no serious efforts were made in obtaining the earthquake data. The instrumental observation of seismic data was started after 1960 which observes complete details of the earthquake events. Due to these reasons the specified time window (1500-2015) cannot be considered in obtaining the activity rate which is no. of events per time window,

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as this will result in underestimation of the activity rate. For this purpose completeness analysis were performed using visual cumulative method (CUVI) formulated by Mulargia and Tinti (1985). It is a simple procedure based on the observation that earthquakes follow a stationery occurrence process. It is used to find the completion point (CP) after which the catalogue is considered to be complete (Tinti and Mulargia, 1985). The procedure is to divide the magnitudes form 4 to 8 into various bands having 0.5 range. The selected bands are: 4.00 to 4.50. 4.51 to 5.00, 5.01 to 5.50, 5.51 to 6.00, 6.01 to 6.50, 6.51 to 7.00, 7.01 to 7.7. In each band cumulative number of earthquakes is plotted against the year of earthquakes, the period of completeness (Tc) is considered to begin at the earliest time when the slope of the fitting curve can be well approximated by a straight line (**Fig. 7**). **Table 3** reports the completeness points and time periods for each magnitude band.

Table 3:Completeness intervals and completion period of each magnitude band

Magnitude Range	**Average Magnitude**	**Completion Interval**	**Completion Period (Tc)**
4.00 – 4.50	4.25	1995 – 2015	20
4.51 – 5.00	4.75	1985 – 2015	30
5.01 – 5.50	5.25	1972 – 2015	43
5.51 – 6.00	5.75	1954 – 2015	61
6.01 – 6.50	6.25	1928 – 2015	87
6.51 – 7.00	6.75	1878 – 2015	137
7.01 – 7.77	7.35	1842 – 2015	173

4.3 Seismic Source Parameters

The modified Gutenberg-Richter reoccurrence law, as discussed earlier, was used in the present seismic hazard analysis to characterize the G-R parameters. The seismic source parameters (i.e., η_o, β) were calculated from setting linear trend line to the graph between $log_{\lambda_m} \sim M_w$ as shown in **Fig. 8** for both shallow and deep earthquakes for all seismic zones. Table 4 reports the seismic source G-R parameters for all seismic sources and both shallow and deep earthquakes.

Table. 4 Seismic source parameters for shallow and deep sources

Seismic Source	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1***	**2***
$\boldsymbol{\lambda_o}$	10.055	3.625	4.075	2.876	1.059	2.143	2.731	24.143	5.652
$\boldsymbol{\beta = 2.303b}$	2.832	2.03	2.10	2.24	2.03	2.10	2.5	2.17	2.97
$\boldsymbol{M_u}$	6.2	7.6	7.5	6.8	6.0	6.0	5.5	7.7	6.0

1,2,3,4,5,6 and 7 are shallow seismic sources and 1*, 2* are deep seismic sources

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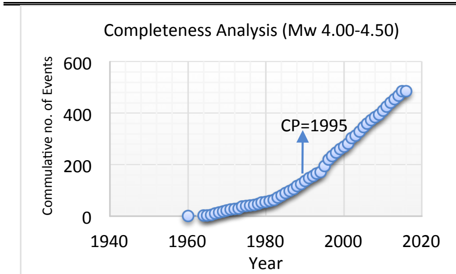
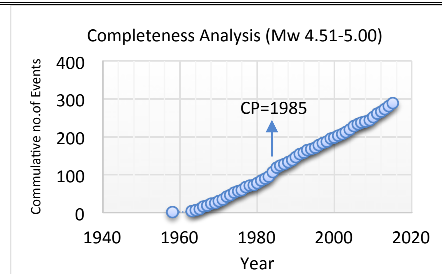
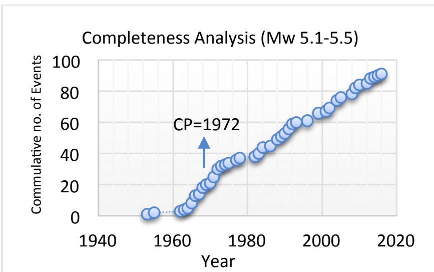


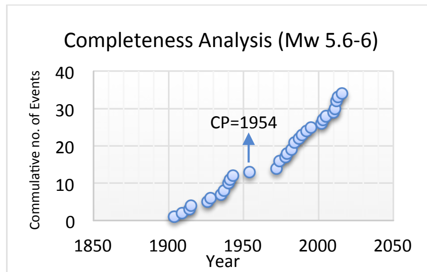
(Completeness period 20years:1995-2015)



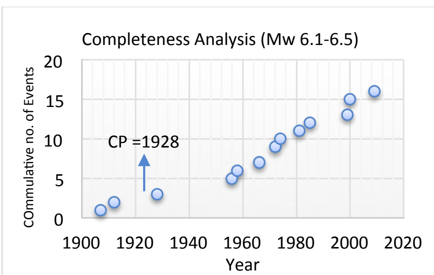
(Completeness period 30years:1985-2015)



(Completeness period 43 years: 1972-2015)



(Completeness period 61 years: 1954-2015)



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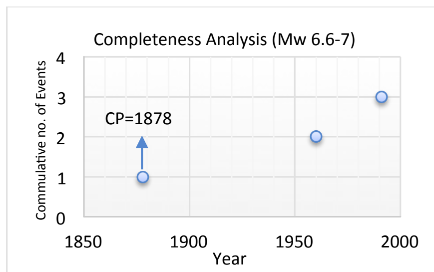
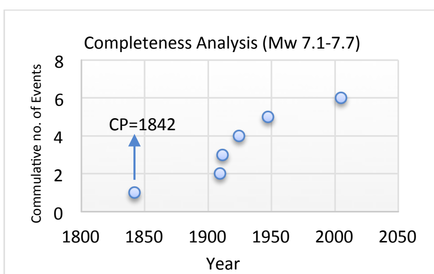


(Completeness period 137 years: 1878-2015)



(Completeness period 173 years: 1842-2015)

Figure 7. Completeness Period for earthquake catalogue for specified band

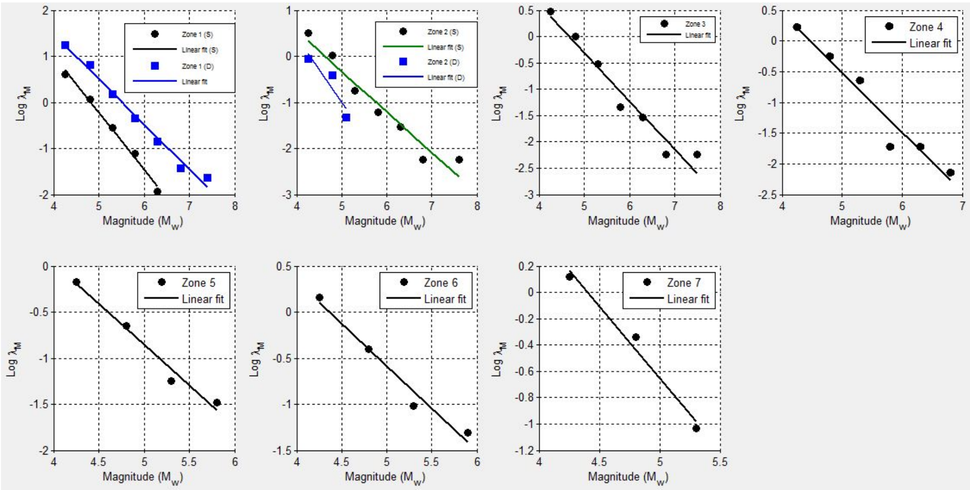


Figure. 8 The graph $log_{\lambda_m} \sim M_w$ for seismic source parameters of seven zones

4.4 Attenuation Relationships and Peak Ground Acceleration

The attenuation relationships for a site are developed using substantial dataset information (Cotton et al. 2006), however, these are not available for Pakistan because of the scarcity of available strong motion data. The alternative to this is to use the already available attenuation relationships of other regions having similar tectonic and geological conditions to Pakistan. In case of shallow earthquake, the candidate attenuation relationships for north Pakistan should be the one developed for the active tectonic crustal earthquake region. Thus, the ground motion attenuation relationship of Akkar and Boomer (2010) and Bore and Atkinson (2008) were used to calculate the Peak Ground Acceleration for shallow seismic sources. However, the ground motion attenuation relationships of Lin and Lee (2008) and Kanno et al. (2006) developed for subduction zones were used for deep seismic sources. The seismic hazard in term of PGA was then calculated at bedrock site for different return periods, such as 50, 100, 250, 475 and 2500 years, as the cumulative seismic hazard due to both shallow and deep seismic sources. The various GMPEs were combined through logic tree approach and assigning equal weightages to each GMPE. The ground motions calculated were plotted in Geographical Information System (GIS) environment to obtain the seismic hazard maps for these different ground motion attenuation relationships.

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4.5 Seismic Hazard Maps

The seismic hazard levels (**Table 5**), based on peak acceleration, defined in the BCP-SP (2007) were considered as basis for zoning of the seismic hazard at bedrock:

Table. 5 Seismic hazard levels used for seismic zoning, obtained from BCP-SP (2007)

Seismic Hazard Level	Peak acceleration, (g)
Very low	< 0.08 g
Low	0.08 - 0.16 g
Medium	0.16 - 0.24
High	0.24 - 0.32
Very high	> 0.32 g

The seismic hazard maps for a return period of 475 years in case of shallow crustal earthquakes and deep earthquakes for Peshawar District are reported in **Fig. 9** and **10** respectively. **Figure. 9** shows that for a return period of 475 years, the predictive relationship of Akkar and Boomer, (2010) overestimate the PGA value in comparison to that of Boore and Atkinson (2008), especially in the Northern parts of the District. According to Arango et al. (2012), the distance scaling factor of the later appears to be more adequate then the previous. Furthermore, **Table. 6** shows a slight comparison of both ground motion prediction equations that suggests that in terms of N_R=Number of records, T_{max}= longest response period, M_w = moment magnitude and [R] = distance range, the prediction equation of Boore and Atkinson (2008) is more appropriate and reliable than that of Akkar and Boomer (2010) for hazard assessment.

Table. 4 Comparison of predictive equations used for shallow crustal earthquake (after, Arango, et al., 2012)

Predictive equation	Tectonic Regime	Region	N_R	T_{max}	M_w	[R]
Boore and Atkinson (2008)	Shallow crustal	Worldwide	1574	10	5-8	0-200
Akkar and Boomer (2010)	Shallow crustal	Europe/Middle east	532	3	5-7.6	0-100

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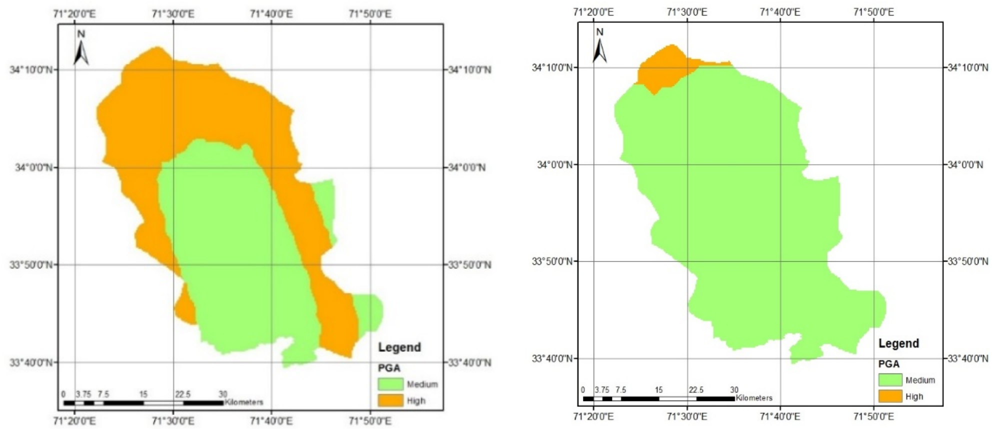
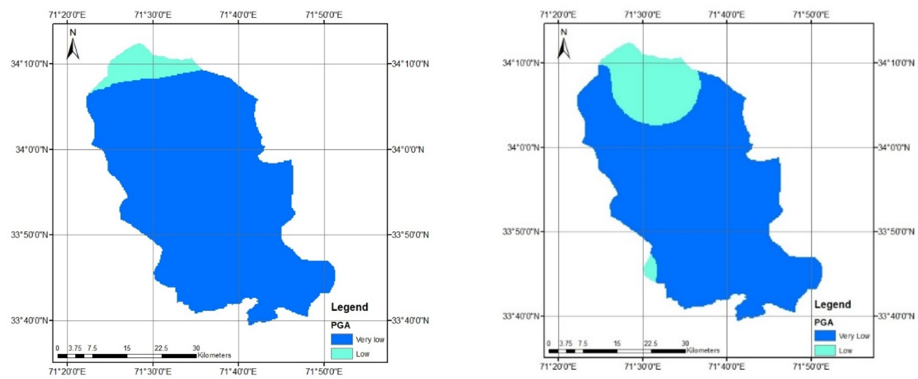


(a) Akkar and Boomer (2010) (b) Boore and Atkinson, NGA (2008)

Figure. 9 Seismic hazard maps for shallow crustal earthquake using different attenuation equations



(a) Lin and Lee (2008) (b) Kanno et al. (2006)

Figure. 10 Seismic hazard maps for deep subduction earthquake using different attenuation equations and for a return period of 475 years

Figure. 10 shows, the seismic hazard maps for deep subduction earthquakes using the Lin and Lee (2008) and Kanno et al. (2006) for a return period of 475 years. According to this **Fig. 10** both the attenuation equations resulted in roughly similar seismic hazard for Peshawar District. Furthermore, it is also evidenced from **Fig. 10** that, the inclusion of deep subduction zones in the seismic hazard does not contribute significantly i.e., it remains low (0.08-0.16g) to very low (<0.08g). The cumulative seismic hazard may slightly increase ground motion level, especially in the southern parts.

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In probabilistic seismic hazard analysis (PSHA), one of the major sources of uncertainty is the epistemic uncertainty arising from the selection of predictive relationship. Thus, the different ground motion attenuation relationships already discussed were further used to find out the epistemic uncertainty in the seismic hazard analysis. This was accomplished through the logic tree approach, assigning equal weigthing factor to each GMPE (Fig. 11), the seismic hazard was combined from all GMPEs.

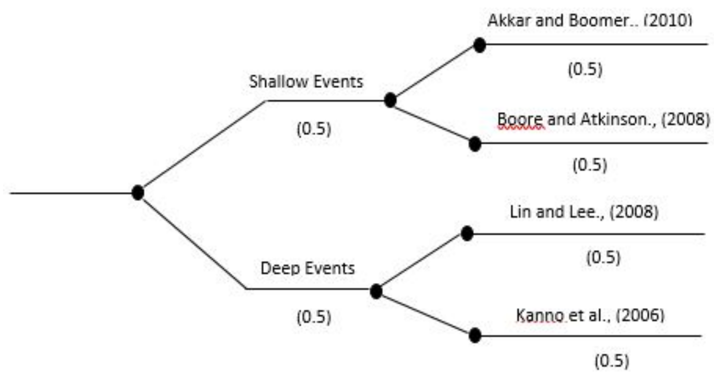

Figure. 11 Logic Tree for incorporating epistemic uncertainty

Figure. 12 shows the seismic hazard maps for shallow and deep events after incorporating the epistemic uncertainty. As can be seen in **Fig. 12a**, the seismic hazard of Peshawar District becomes balanced when taken average of the seismic hazard calculated using the Akkar and Boomer (2010) and Boore and Atkinson (2008) models. The reason is that of providing equal weightage to both the predictive relationship in hazard analysis. The seismic hazard in case of deep subduction zone earthquake remains roughly the same after incorporating epistemic uncertainty (**Fig. 12b**). It can also be further concluded that the earthquake produced by deep subduction zone are not significant in term of seismic hazard and may be reasonably ignored. Thus, the shallow seismic sources are sufficient for seismic hazard assessment of Peshawar. The calculated seismic hazard map after incorporating epistemic uncertainty is compared with the hazard map from the BCP-2007. For the return period of 475 years, a close agreement between the two seismic hazard maps can be noticed (**Fig. 13**). After this check the seismic hazard maps for other return periods i.e. 50, 100, 250, 475 and 2500 years were prepared (**Fig. 14**), which may be used for seismic risk assessment. Hazard maps for various cases are reported in Appendix Fig. A1 through Fig. A8.

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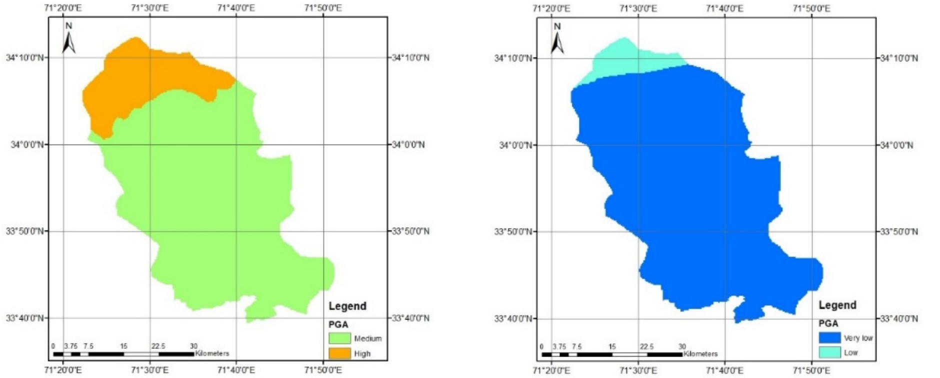
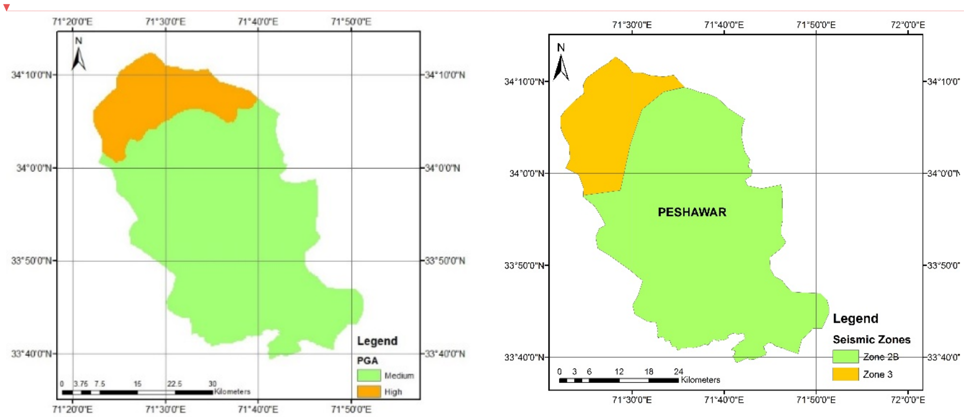


(a) Shallow crustal earthquake (b) Deep subduction zone earthquake

Figure. 12 Seismic hazard maps after incorporating epistemic uncertainty for 475 years return period



(a) Calculated with epistemic uncertainty (b) BCP (2007)

Figure. 13 Comparison of seismic hazard maps for a return period of 475 years

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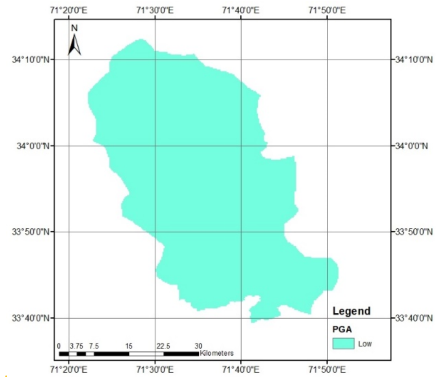

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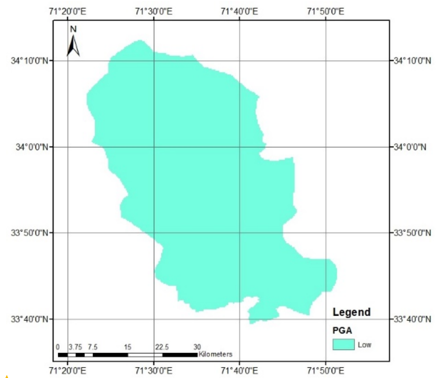

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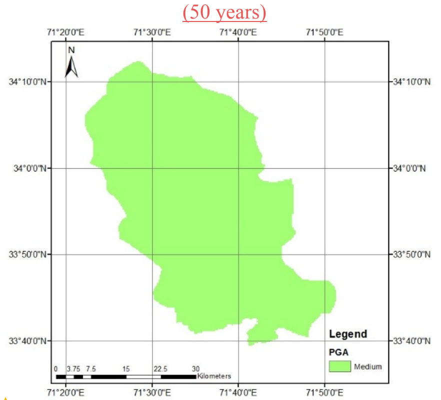

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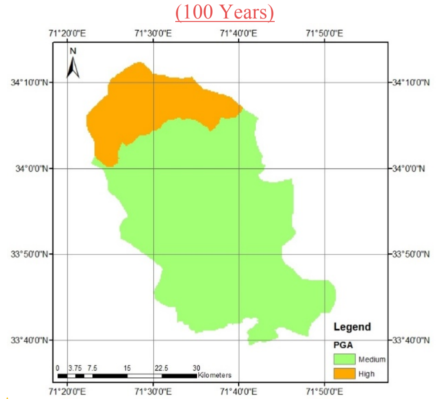
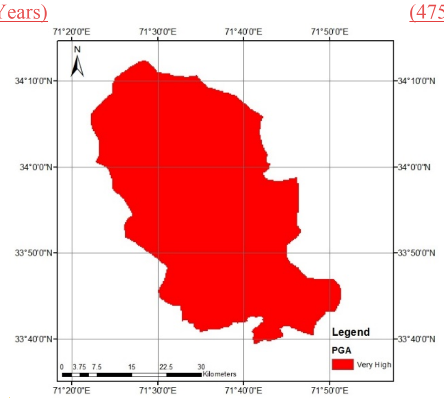


(475 Years)



(2500 Years)

Figure. 14 Mean seismic hazard maps for various return periods i.e. 50, 250, 475, 2500 years, considering all GMPEs and both shallow and deep earthquake sources.

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5. Conclusions and Recommendations

The following were concluded on the basis of literature reiew of past seismic hazard studies of Peshawar and classical PSHA conducted for Peshawar in the present study:

- The selection of appropriate ground motion prediction equation is an important factor in defining the seismic hazard of Peshawar District. In case of shallow crustal earthquake, the predictive relationship of Akkar and Boomer (2010) provide higher estimate of the PGA value in comparison to that of Boore and Atkinson (2008). The distance-scaling factor of the later appears to be the reason for this disparity among the two models.
- The inclusion of deep subduction earthquakes does not add significantly to hazard and may be neglected in term of seismic hazard. Therefore, these are only the shallow crustal earthquakes that contributes to the seismic hazard of Peshawar District. However, recent earthquakes in Peshawar from deep sources earthquakes has caused widespread destruction in various parts of the district. This raises concern for the existing GMPEs and the classical PSHA procedure to simulate such effects.
- The epistemic uncertainty was used by providing equal weightage to the attenuation equation of Akkar and Boomer (2010) and Boore and Atkinson (2008). The mean seismic hazard maps thus produced was balanced and was found in a close agreement with the design base seismic hazard given in the BCP-SP (2007) for bedrock hazard. However, the BCP places Peshawar in Zone 2B, which is reasonable for most of the locations but it underestimates ground motions especially in northern parts of the District.
- The mean seismic hazard calculated for Peshawar was also compared with the previous studies (Table 6). It can be observed that the seismic hazard performed by independent researchers suggests an average PGA equal to about 0.24g, which is in agreement with the PGA = 0.24g given in the BCP-SP (2007) for seismic Zone 2b (0.16g to 0.24g) for bedrock. The present PSHA study performed using the most up-to-date earthquake catalogue, recent GMPEs and considering both the shallow and deep seismic sources confirmed the validity of seismic hazard given in the BCP-SP (2007). It is worth mentioning that the calculated mean hazard may be approximated as the 50^{th} percentile seismic hazard. **Table 6** reports that recent hazard studies considering the fault sources have resulted in larger estimate of seismic hazard that places Peshawar in seismic Zone 3 and Zone 4, however, the idealization of seismic sources as discrete faults for Peshawar are not reliable due to the scarcity of detailed information regarding the fault sources in Northern Pakistan. This higher seismic hazard is not justified by the earthquake history of Peshawar.

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Table 6. Placement of Peshawar based on the present study: classical PSHA with areal sources, considering both shallow and deep earthquakes. Listed in ascending order.

S. No.	Authors	PGA (g)
1	Shah et al. (2019)	0.06
2	Bhatia et al. (1999)	0.10 – 0.15
3	Mona Lisa et al. (2007)	0.15
4	Zhang et al. (1999)	0.16 – 0.24
5	Rafi et al. (2012)	0.17
6	Ahmad et al. (2019)	0.16 to 0.24
7	**Present Study**	**0.16 – 0.32**
8	Hashash et al. (2012)	0.20 – 0.40
9	Şeşetyan et al. (2018)	0.30 – 0.40
10	Khaliq et al. (2019)	0.32 – 0.34
11	Zaman and Warnitchai (2012)	0.33 – 0.40
12	Waseem et al. (2018)	0.38

It is worth mentioning that the focus of the present study was to provide the base maps for seismic hazard in Peshawar. Site-specific soil properties were not known, therefore, it was not addressed in the present study. Alternatively, the code suggests amplification factors for various soils from Type C to Type E as per NEHRP soil classification. This may be considered to amplify/deamplify the seismic hazard provided in the present study.

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Acknowledgement

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Data Availability Statement

All data, models, or code generated or used during the study are available from the corresponding author by request (Naveed Ahmad, naveed.ahmad@uetpeshawar.edu.pk). Items, which may be requested: earthquake catalogue (raw and processed data), excel sheets used for G-R parameters derivation, CRISIS input files, etc.

Author Contribution

Naveed Ahmad has contributed as the advisor/supervisor of the research, in the analysis of earthquake catalogue for derivation of seismic parameters, selection of GMPEs, preparation of input files for CRISIS program and paper drafting. Usman Khan has contributed in the compilation of earthquake catalogue and processing of data, analysis of hazard through CRISIS program and developing hazard maps. Khalid Mahmood has contributed in the data organization, literature review and integration of work tasks and preparation of initial paper draft. Qaiser Iqbal has contributed in selecting/designing seismic sources for both shallow and deep earthquakes, assignment of source parameters in CRISIS program, output data compilation and result plotting.

Competing Interest

The authors do not report any potential conflict of interest.

References

Ahmad, N. (2015) "A note on the strong ground motions and behavior of buildings during 26th Oct. 2015 Afghanistan- Pakistan earthquake", Earthquake Engineering Research Institute (EERI), Oakland, CA, USA.

Ahmad, N., Ullah, S. and Waseem, M. (2019) "Discussion of "Assessment of the seismicity of Peshawar region in line with the historical data and modern building codes (ASCE-07 & IBC3-2006)" by Shah et al", Journal of Earthquake Engineering. https://doi.org/10.1080/13632469.2019.1692743.

Ali, Q., Khan, A.N.: A critical review of the seismic hazard zoning of Peshawar and Adjoining areas. Journal of Earthquake Engineering, 9, 587-607.

Akkar, S., Bommer, J.J.: Empirical Equations for the Prediction of PGA, PGV, and Spectral Accelerations in Europe, the Mediterranean Region, and the Middle East. Seismological Research Letters, 81, 2010.

Ambraseys, N.N., Douglas, J., Sarma, S. K. and Smit, P. M.: Equations for the estimation of strong ground motions from shallow crustal earthquakes using data from Europe and the Middle East: horizontal peak ground acceleration and spectral acceleration. Bulletin of Earthquake Engineering, Vol. 3, pp. 1-53, 2005.

Arango, M.C., Free, M.W., Lubkowski, Z.A., Pappin, J.W., Musson, R.M.W., Jones, G., Hodge, E.: Comparing predicted and observed ground motions from UK earthquakes. Proceeding of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal, 2012.

Bhatia, S. C., Kumar, M. R. and Gupta, H. K.: A probabilistic seismic hazard map of India and adjoining regions", *Annali di Geofisica*, Vol. 42, pp. 1153-1164, 1999.

BCP: BCP-SP - Building Code of Pakistan Seismic Provision. Ministry of Housing and Works, Islamabad, 2007.

Boore, D.M., Atkinson, G.M.: Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s. Earthquake Spectra, 24, 99-138, 2008.

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Çağnan, Z. and Akkar, S.: Assessment of Aleatory and Epistemic Uncertainty for Ground-Motion Intensity Measure Prediction in Turkey. Bulletin of the Seismological Society of America, 109(1), pp. 263-283.

Campbell, K.W., Bozorgnia., Y.: Empirical analysis of strong ground motion from the 1992 Landers, California, earthquake. Bulletin of the Seismological Society of America, 84, 573-588, 1994.

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Chen, Z., Burchfiel, B.C., Liu, Y., King, R.W., Royden, L.H., Tang, W., Wang, E., Zhao, J., Zhang, W.: GPS measurement from eastern Tibet and their implications for India/Eurasia intercontinental deformation. Journal of Geophysical Research, 105, 16-215, 2000.

Cotton, F., Scherbaum, F., Bommer, J.J., Bungum, H.: Criteria for selecting and adjusting ground-motion models for specific target regions: application to central Europe and rock sites. Journal of Seismology, 10, 137-156, 2006.

CRISIS: User Manual Crisis 2007 Version 7.2. In: Ordaz, M., Aguilar, A., Arbulida, J. (Eds.). A computer program for seismic hazard assessment. Institute of Ingeneria, UNAM, 2007.

Campbell, K.W.: Near source attenuation of peak horizontal acceleration. Bulletin of the Seismological Society of America, 71, 2039-2070, 1981.

Crouse, C.B.: Ground-motion attenuation equations for earthquakes on the Cascadia subduction zone. Earthquake Spectra, 7, 210-236, 1991.

Crouse, C.B., Vyas, Y.K., Schell, B.A.: Ground motions from subduction-zone earthquakes. Bulletin of the Seismological Society of America, 78, 1- 25, 1988.

DiPietro, J.A., Pogue, K.R.: Tectonostratigraphic subdivisions of the Himalaya: A view from the west. Tectonics, 23, 1-20, 2004.

Douglas, J.: Ground motion prediction equations 1964-2019. Technical Report, Department of Civil and Environmental Engineering, University of Strathclyde, Glasgow, UK.

Gansser, A.: Geology of the Himalayas. Inter-Science Publication. Jon Wiley and Sons, London, 1964.

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Hanks, T. C., Kanamori, H.: A moment magnitude scale. Journal of Geophysical Research, 84, 2348 - 2350, 9B0059, doi:10.1029/JB084iB05p02348, 1979.

Hashash, Y.M, Kim, B., Olson, S.M., and Ahmad, I.: Seismic hazard analysis using discrete faults in Northwestern Pakistan: Part I-methodology and evaluation. Journal of Earthquake Engineering, 16, 963-964, 2012.

Kanamori, H.: The energy release in great earthquakes. Journal of Geophysical Research, 82, 298 I-2987, 1977.

Kanno, T., Narita, A., Morikawa, N., Fujiwara, H., Fukushima, Y.: A new attenuation relation for strong ground motion in Japan based on recorded data. Bulletin of the Seismological Society of America, 96, 879-897, 2006.

Khaliq, A.H., Waseem, M., Khan, S., Ahmed, W. and Khan, M.A.: Probabilistic seismic hazard assessment of Peshawar District, Pakistan. Journal of Earth System Sciences, Vol. 128(6), 2019.

Lin, P-S., Lee, C.T.: Ground-Motion Attenuation Relationships for Subduction Zone Earthquakes in Northeastern Taiwan. Bulleting of the Seismological Society, 98, 220-240, 2008.

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McGuire, R.K.: Seismic hazard and risk analysis. Earthquake Engineering Research Institute (EERI), CA, USA, 2004.

Molas, G.L., Yamazaki, E.: Attenuation of earthquake ground motions in Japan including deep focus events. Bulletin of the Seismological Society of America, 85, 1343-1358, 1995.

MonaLisa, Khawaja, A.A., Jan, M. Q.: Seismic hazard assessment of NW Himalayan thrust belt using probabilistic approach. Journal of Earthquake Engineering, 11, 257-301, 2007.

Ornthammarath, T., Douglas, J., Sigbjörnsson, R. and Lai, C.: Assessment of ground motion variability and its effects on seismic hazard analysis: A case study for Iceland. Bulletin of Earthquake Engineering, Springer Verlag, 2011, 9 (4), pp.931-953.

Rafi, Z., Lindholm, C., Bungum, H., and Ahmed, N.: Probabilistic seismic hazard analysis and zonation of Pakistan, Azad Jammu and Kashmir. Natural Hazards, 61, 1317-1354, 2012.

Rowshandel, B.: Capturing and PSHA implementation of spatial variability of Near-source ground motion hazard, Proceedings of the Geotechnical Earthquak Engineering and Soil Dynamics V, June 10-13, Austin, Texas, 2018.

Rupakhety, R. and Sigbjörnsson, R.: Ground-motion prediction equations (GMPEs) for inelastic displacement and ductility demands of constant-strength SDOF systems. Bulletin of Earthquake Engineering, 7(3), pp. 661-679.

Şeşetyan, K. et al.: The 2014 seismic hazard model of the Middle East: overview and results. Bulletin of Earthquake Engineering, Vol. 16(8), pp. 3535-3566, 2018.

Zaman, S., and Warnitchai, P.: Probabilistic seismic hazard maps for Pakistan. In Proceedings of the 15th World Conference on Earthquake Engineering, Bangkok, Thailand, 2010.

Tahirkheli, R.A.: Geology of the Himalayas, Karakorum, and Hindu Kush in Pakistan. University of Peshawar Geological Bulletin, 15, 1-49, 1982.

Toro, G.R., Abrahamson, N.A. and Schneider, J.F.: Model of strong ground motions from earthquakes in Central and Eastern North America: best estimates and uncertainties. Seismological Research Letters, 68, 41-57, 1997.

Toro, G.R., Abrahamson, N.A., and Schneider, J.F., 1995. Engineering model of strong ground motions from earthquake in the central and eastern United States, Earthquake Spectra, in press.

Waseem, M., Khan., M.A., Javed., M. W., Ali., S.M.: Deterministic seismic hazard analysis for Peshawar, Pakistan. Journal of Himalayan Earth Sciences, 46, 67-72, 2013.

Waseem, M., Spacone, E. and Lai, C. G.: Seismic hazard assessment of northern Pakistan. Natural Hazards, Vol. 90(2), pp. 563-590. 2018.

Youngs, R.R., Abrahamson, N.A., Makdisi, E., Sadlgh, K.: Magnitude dependent dispersion in peak ground acceleration. Bulletin of the Seismological Society of America, 85, 1161-1176, 1995.

Youngs, T.LR., Chiou, S.J., Silva, W.L., Humphrey, J.R.: Strong ground motion attenuation relationships for subduction zone earthquakes based on empirical data and numerical modeling (abs.), Seismological Research Letters, 64, 58-73, 1993.

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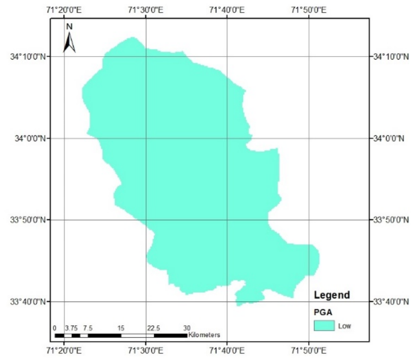
Zhang, P. Z., Yang, Z-X, Gupta, H.K., Bhatia, S.C., Shedlock, K.M.: Global seismic hazard assessment program (GSHAP) in continent Asia; Annali di geofisica, 42, 1167-1190, 1999.

APPENDIX:



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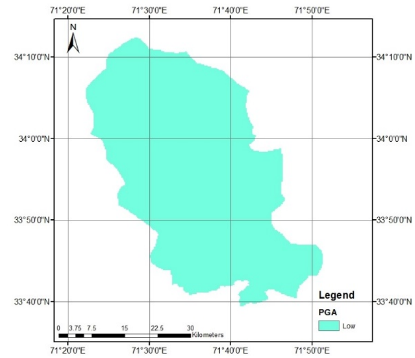

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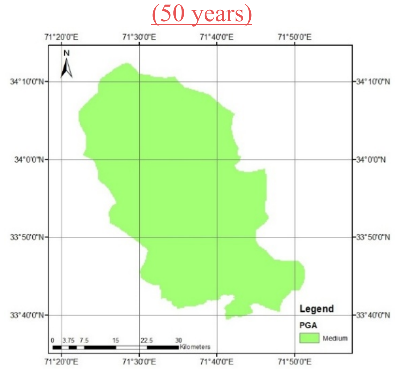

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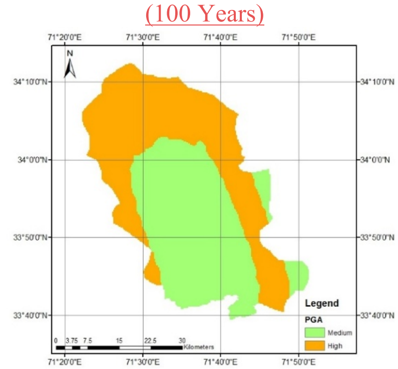

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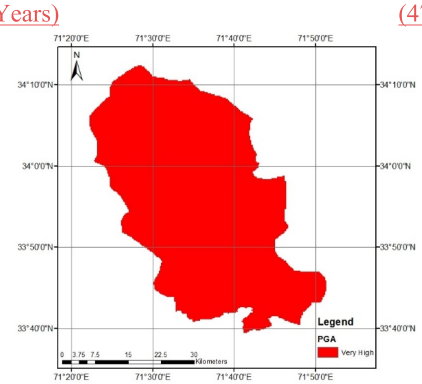

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Fig A1. Calculated seismic hazard maps using Akkar and Boomer, 2010 GMPE for shallow earthquakes

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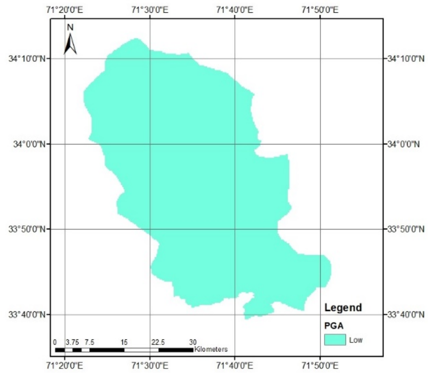

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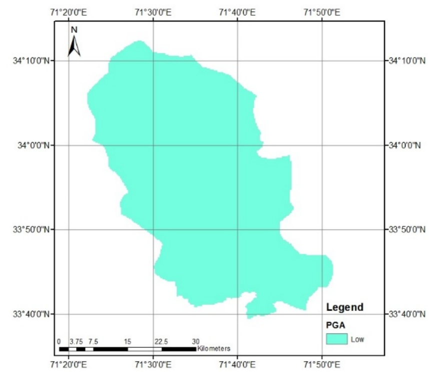

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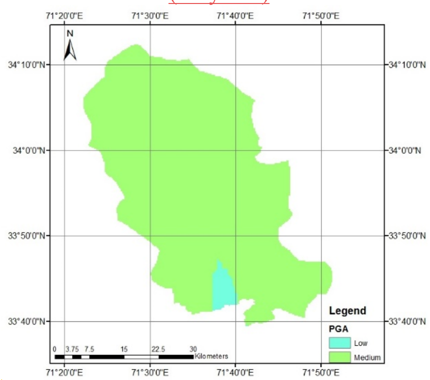

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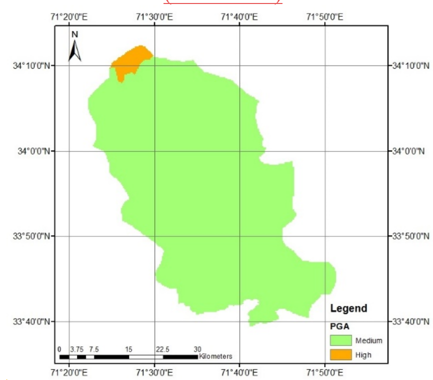

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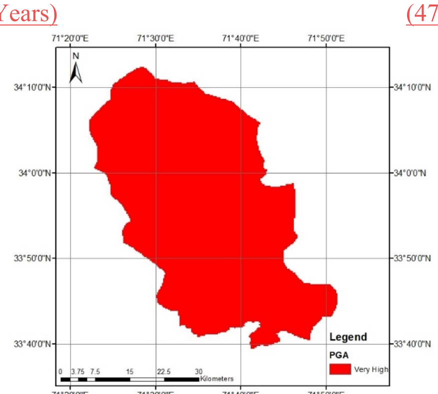

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Fig A2. Calculated seismic hazard map using Bore and Atkinson, NGA 2008 GMPE for shallow earthquakes

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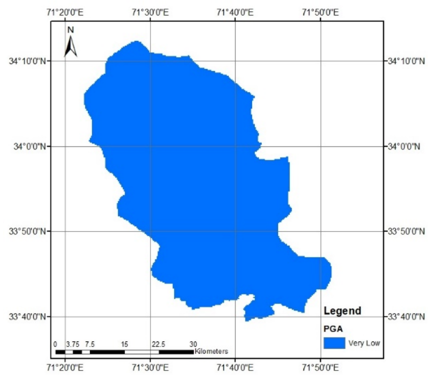

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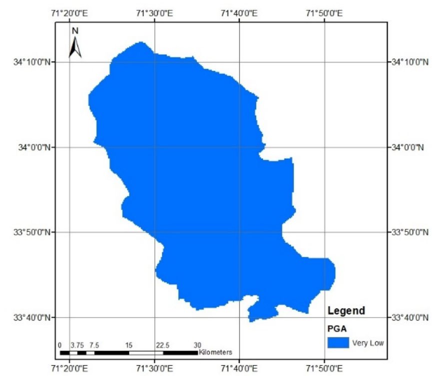

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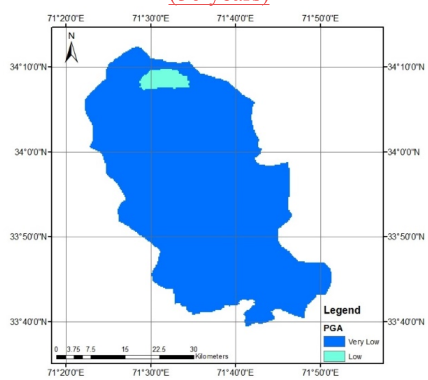

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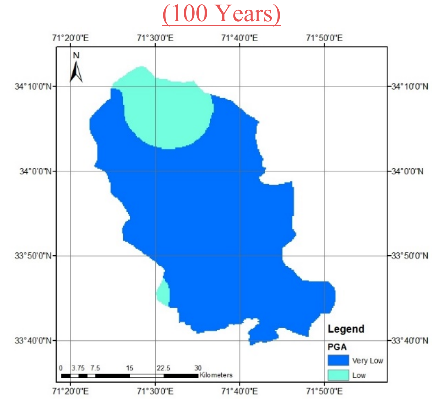

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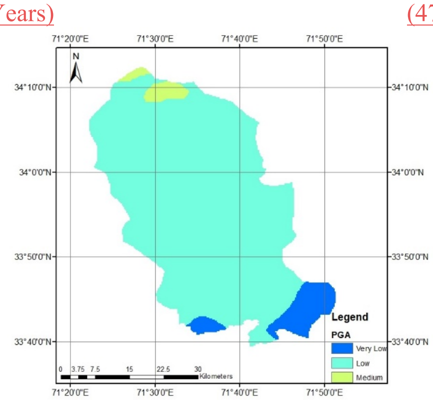

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Fig A3. Calculated seismic hazard map using Kanno et al, 2006 GMPE for Deep earthquakes

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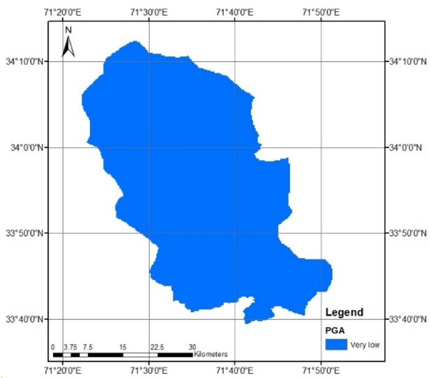

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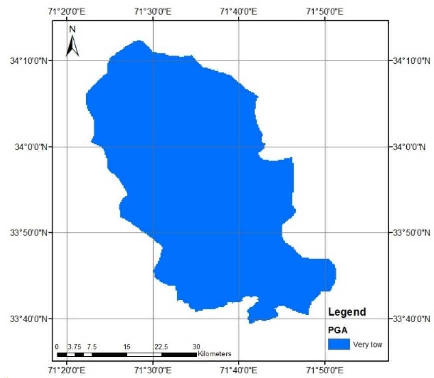

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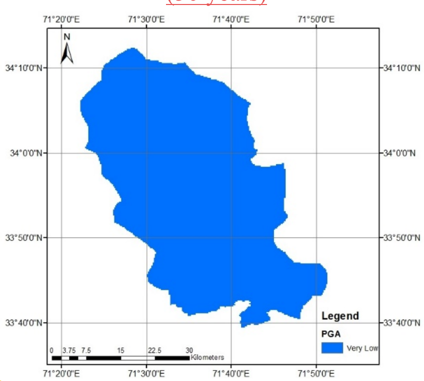

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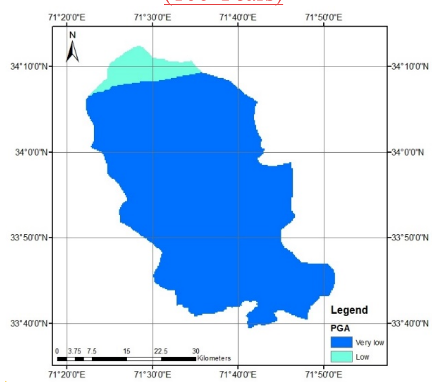

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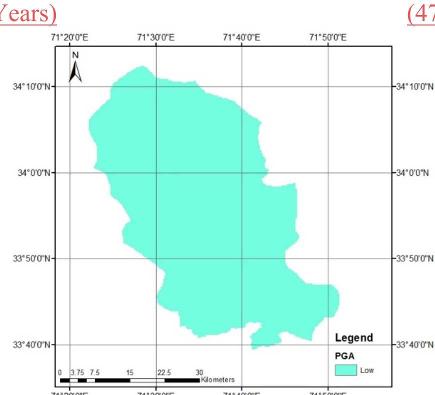

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Fig A4 Calculated seismic hazard map Lin and Lee, 2008 GMPE for Deep earthquakes

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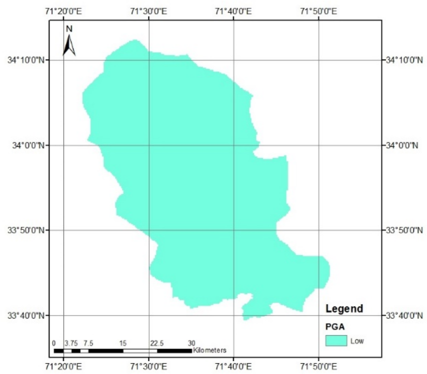

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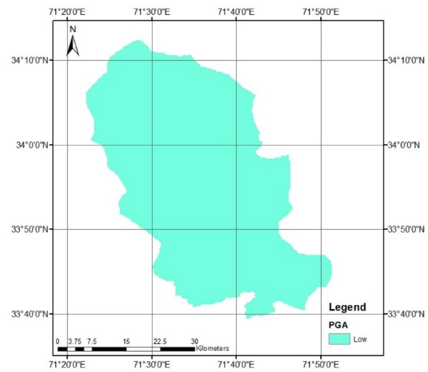

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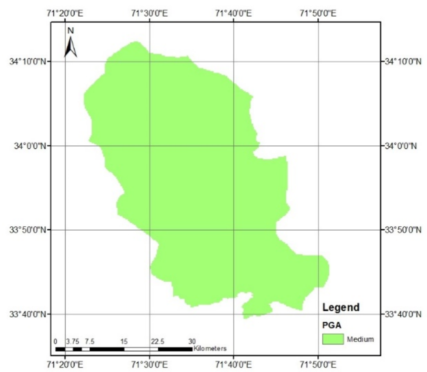

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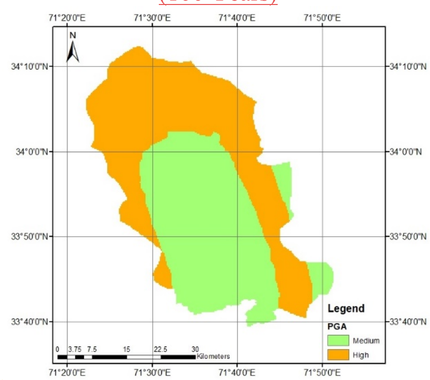

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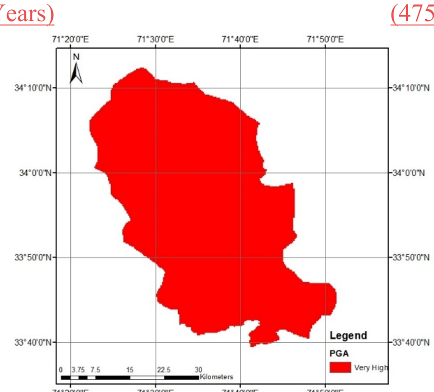

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Fig A5. Calculated seismic hazard map considering Akkar and Boomer, 2010 for shallow earthquakes and Kanno et al, 2006 for Deep earthquakes

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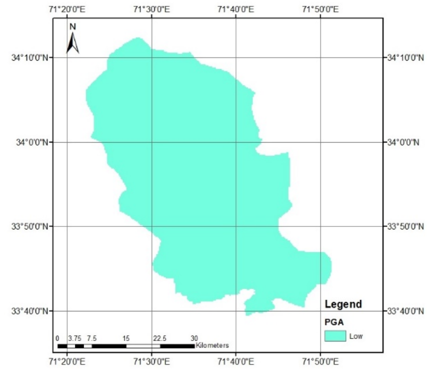

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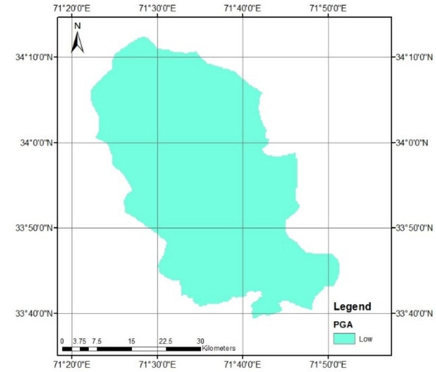

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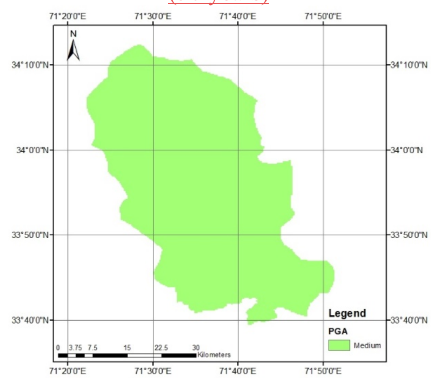

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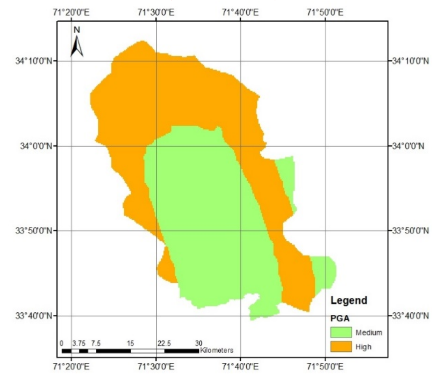

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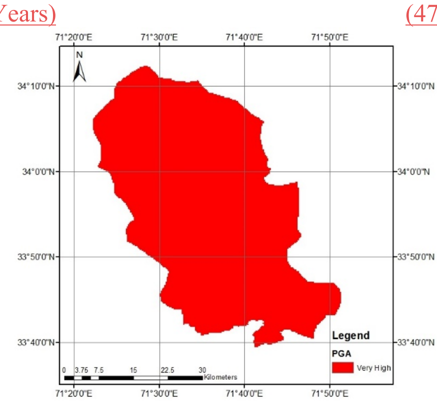

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Fig A6. Calculated seismic hazard map considering Akkar and Boomer, 2010 for shallow earthquakes and Lin and Lee, 2008 for Deep earthquakes

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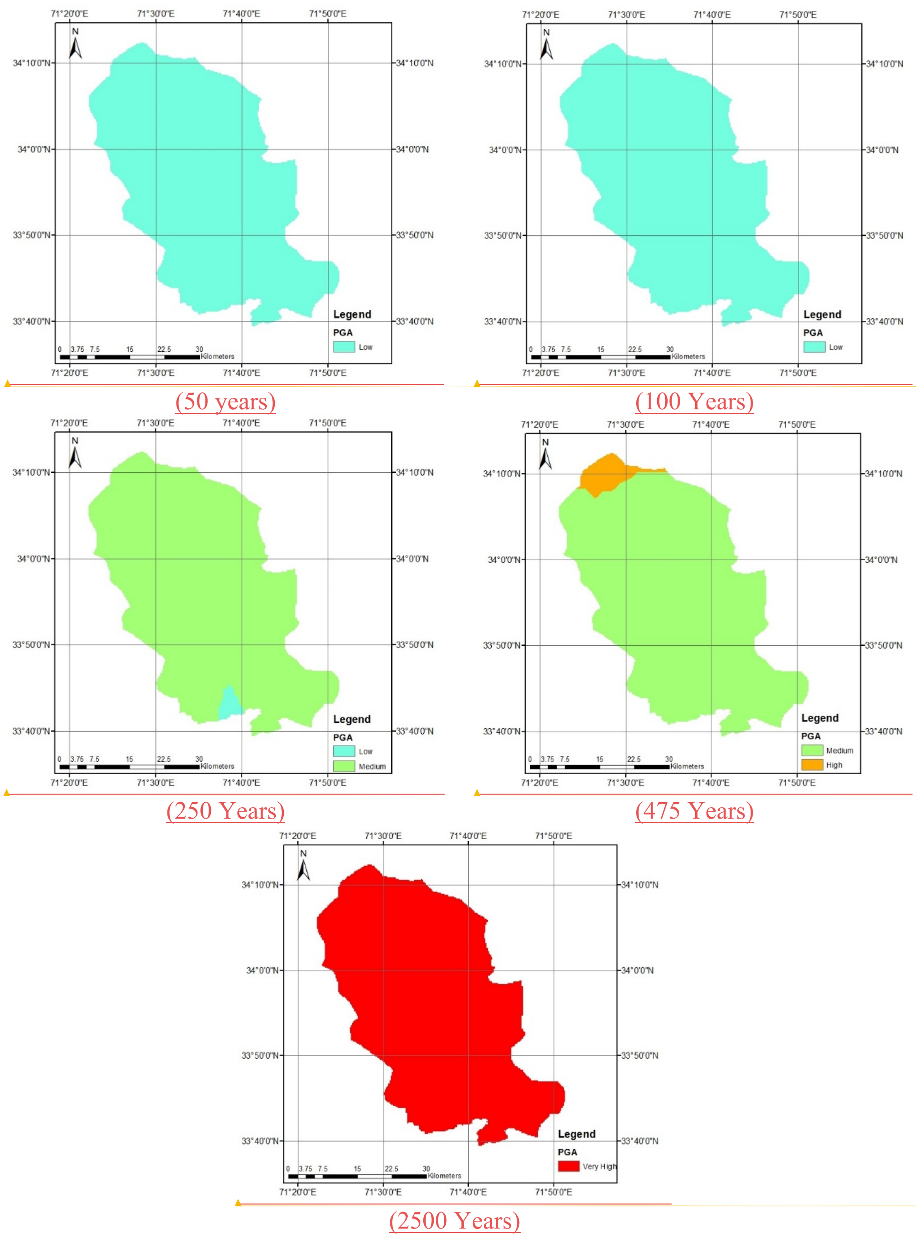

Fig A7. Calculated seismic hazard map considering Bore and Atkinson, NGA 2008 for shallow earthquakes and Kanno et al, 2006 for Deep earthquakes

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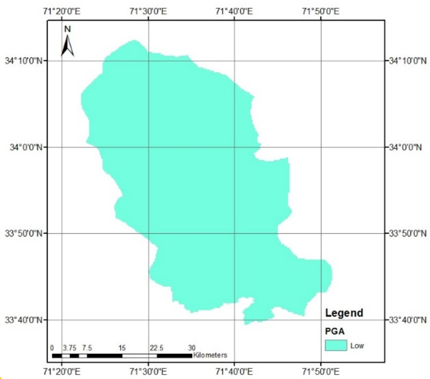

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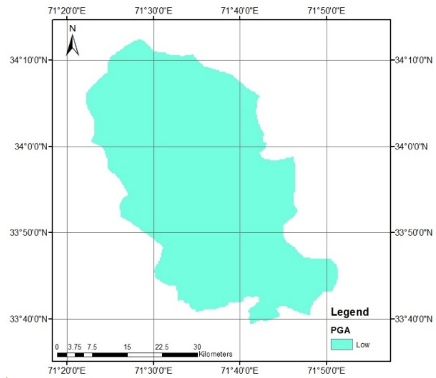

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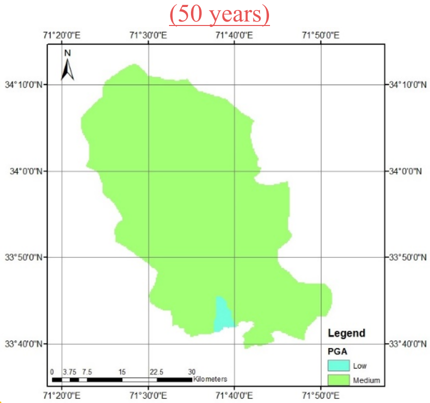

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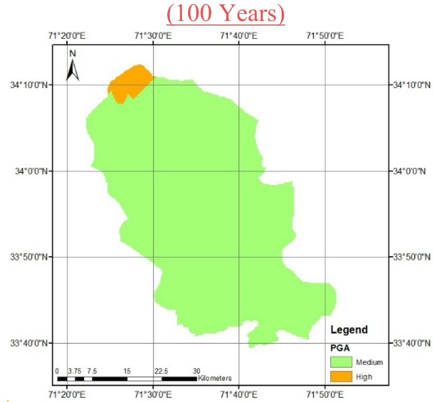

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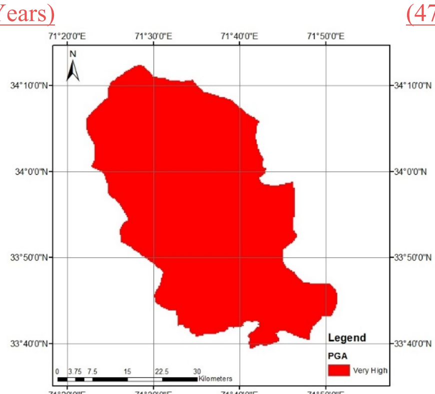

(2500 Years)

Fig A8. Calculated seismic hazard map considering Bore and Atkinson, NGA 2008 for shallow earthquakes and Lin and Lee, 2008 for Deep earthquakes

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Table. 1: No. of earthquakes, minimum and maximum magnitude in shallow and deep seismic source

Zones	**1**	**2**	**3**	**4**	**5**	**6**	**7**

Depth, (kM)	<50	>50	<50	>50	<50	<50	<50	<50	<50
No. of Earthquakes	99	454	79	23	76	43	17	35	32
Minimum (Mw)	4.0	4.0	4.1	4.2	7.6	4.0	4.1	4.1	4.1
Maximum (Mw)	6.2	7.7	4.0	5.1	7.5	6.8	6.0	6.0	5.5

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Table. 2 Seismic source parameters for shallow and deep sources

Seismic Source	1	2	3	4	5	6	7	1*	2*
$\boldsymbol{\lambda_o}$	10.055	3.625	4.075	2.876	1.059	2.143	2.731	24.143	5.652
$\boldsymbol{\beta = 2.303b}$	2.832	2.03	2.10	2.24	2.03	2.10	2.5	2.17	2.97
$\boldsymbol{M_u}$	6.2	7.6	7.5	6.8	6.0	6.0	5.5	7.7	6.0

1,2,3,4,5,6 and 7 are shallow seismic sources and 1*, 2* are deep seismic sources

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. The attenuation relationships are not available for Pakistan because of the very scarcity of available strong motion data

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The seismic hazard level based on peak acceleration, (g) at bedrock are given in **Table. 3**.

Table. 3 Seismic hazard level used in GIS

Seismic Hazard Level	Peak acceleration, (g)
Very low	< 0.08 g
Low	0.08 - 0.16 g
Medium	0.16 - 0.24
High	0.24 - 0.32
Very high	> 0.32 g

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The seismic hazard maps for a return period of 475 years in case of shallow crustal earthquake and deep earthquake for Peshawar District are shown in **Fig. 7** and **8** respectively.

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Figure. 7 shows that for a return period of 475 years, the predictive relationship of Akkar and Boomer, (2010) overestimates the PGA value in comparison to that of Boore and Atkinson (2008). According to Arango et al. (2012), the distance scaling factor of the later appears to be more adequate then the previous. Furthermore, **Table. 5** shows a slight comparison of both ground motion prediction equations that suggests that in term N_R=Number of records, T_{max}= longest response period, M_w = moment magnitude and [R] = distance range, the prediction equation of Boore and Atkinson (2008) is more appropriate and reliable than
that of Akkar and Boomer (2010).

Table. 4 Comparison of predictive equations used for shallow crustal earthquake (after, Arango, et al., 2012)

Predictive equation	**Tectonic Regime**	**Region**	N_R	T_{max}	M_w	**[R]**
Boore and Atkinson (2008)	Shallow crustal	Worldwide	1574	10	5-8	0-200
Akkar and Boomer (2010)	Shallow crustal	Europe/Middle east	532	3	5-7.6	0-100

Figure. 8 shows, the seismic hazard maps for deep subduction earthquake using Lin and Lee (2008) and Kanno et al. (2006) for a return period of 475 years. According to this **Fig. 8** both the attenuation equations resulted somewhat same seismic hazard for Peshawar District. Furthermore, it is also clear from the **Fig. 8** that, the inclusion of deep subduction zones in the seismic hazard does not contribute significantly i.e., it remains low (0.08-0.16g) to very low (<0.08g).

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The calculated seismic hazard map after incorporating epistemic uncertainty is compared with the hazard map from the BCP-2007. For the return period of 475 years, a close agreement between the two seismic hazard maps can be noticed (**Fig. 11**). After this check the seismic hazard maps for other return periods i.e., 25, 50, 100, 250 and 2500 years were prepared.

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Discussion and Conclusions

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by that developed using these attenuation relationships. Furthermore, there was also a close agreement between the calculated seismic hazard and that developed by BCP-2007 for a return period of 475 years on bedrock

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Kramer, L.K.: Geotechnical Earthquake Engineering. Prentice-Hall, New Jersy, USA, 1996.