International Journal of Earth Sciences Knowledge and Applications (2021) 3 (3) 217-225

International Journal of Earth Sciences Knowledge and Applications
www.ijeska.com

Research Article

e-ISSN: 2687-5993

Source Characteristics of Earthquake 24 Sep 2019 and Their Consequences

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INFORMATION

Article history
Received 02 February 2021
Revised 15 March 2021
Accepted 16 March 2021
Available 15 July 2021

Keywords
Syntaxial bend
Focal mechanism
Seismicity distribution
Annual rate of exceedance
Peak ground acceleration

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ABSTRACT

Seismogenic forces have very intense behavior in and around Pakistan. Northwest Himalayan Fold and Thrust Belt Pakistan produced due to these forces. A sequence of these stresses accumulates due to the collision of two continental plates in and around the Pakistan since 35 Ma. To explore this region and their seismotectonic activity, I have studied recently happened an unexpectedly seismic event near Jhelum Fault with epicenter 73.76^{0}E 33.10^{0}N of M_w 5.6 at focal depth 10 km. Seismotectonic map, seismicity map and focal mechanism of the study area (32^0–35^0), (72^0–75^0) was drawn. Remaining source parameters such as radiated seismic energy (E), seismic moment, P and S wave arrival time, velocity of seismic wave and surface wave magnitude were also evaluated. Intensity scale of the area was also drawn. Jhelum Fault is a strike slip fault which is almost 80 km away from epicentral location but according to source geometry of focal planes, there is no evidence for this event about strike slip fault. It seems this may be happened due to plane of weakness or stresses accumulated inside the plate due to overburden pressures, compacted and cemented rock or any due to ancient fault. So, research proclaimed that it was an intra plate earthquake with normal faulting. Additionally, peak ground acceleration of this event was also determined for further enhancement in this area i-e at 10% probability for exceedance is 2.53 m/s^2 for 50 years for return period is 475 years.

1. Introduction

Human can never be prepared himself for some kind of natural catastrophes in which earthquake is one of them. This natural disaster has no sign of initial warning in all over the world inside the earth crust. All hazard like flood, storm and heavy rain as well as snow falling all have some or little bit warning system. Ground shaking due to some sort of energy released inside the earth generate rupture on surface which tells about the shearing strength. Pakistan tectonically situated in active zone particular the Northern side although Western and South Western side are not much safer but comparatively North region is most vulnerable in seismic sense. Due to seismically active environment of Pakistan, many faults and fold system have been generated since collision started about 35 Ma (Dejong and Subhani, 1979; Kazmi, 1979). The relative movement along these faults and folds changed the geological setting and topography of surface. These faults spread hundreds to thousands of kilometers (Khalid et al. 2016). Earthquake comes in the region of Pakistan is in dangerous situation. Every year one of big or moderate earthquake must be strike in any region of Pakistan. The reason is that plate movement in the subsurface.

The epicenter location of earthquake 24 Sep 2019 timed 11.01 was 73.76^{0}E, 33.10^{0}N with focal depth of 10 km having

M_w 5.6. Almost more than 30 people were killed, 700 people were wounded and more than 141 building has been damaged severely. Most damages were found in New Mirpur where 4 persons were killed and more than 12 injured. Severe cracks were found on roads and some highways were completely destroyed. Their cracks pattern was longitudinal covered widened area. Apparently, it is located nearby Jhelum Fault which is strike slip. The geographic location of the epicenter is shown (Fig.1). No foreshock was recorded but two aftershocks were also observed. The focus point of this article to explore the source characteristics of this event their relation with local tectonics. Before the study of this event firstly we explore the Jhelum Fault. How much Jhelum Fault is near to this event? What is seismicity around location of this event including Jhelum Fault? What is description of focal mechanism around the epicenter and Jhelum Fault? All these questions will be able to clear the source geometry of this event. The active Jhelum Fault is strike slip fault (Kazmi and Jan, 1997) was just 70km approx. away from the epicentral location. In Oct 2005 Kashmir earthquake M_w 7.6 at shallow depth has been occurred along the MBT just 165 km towards North from this Mirpur event.

This research article is focus on the seismicity and seismotectonic scenario around the Jhelum Fault and above-mentioned seismic event is a supportive feature used some sort of evidence to elaborate the inter and intra plate earthquake in this regime. Further some source parameters are associated with this event were also determined

Earthquake after impact is so dangerous especially higher magnitude. These earthquakes deformed the structures, damages roads and buildings. Many earthquakes are shallow which causes more harmful than deeper. In this case many long highways and building damages can be seen in Fig.2, massive mud flow and land sliding is also showing. The lateral and vertical longitudinal and transverse cracking can be seen in this figure.

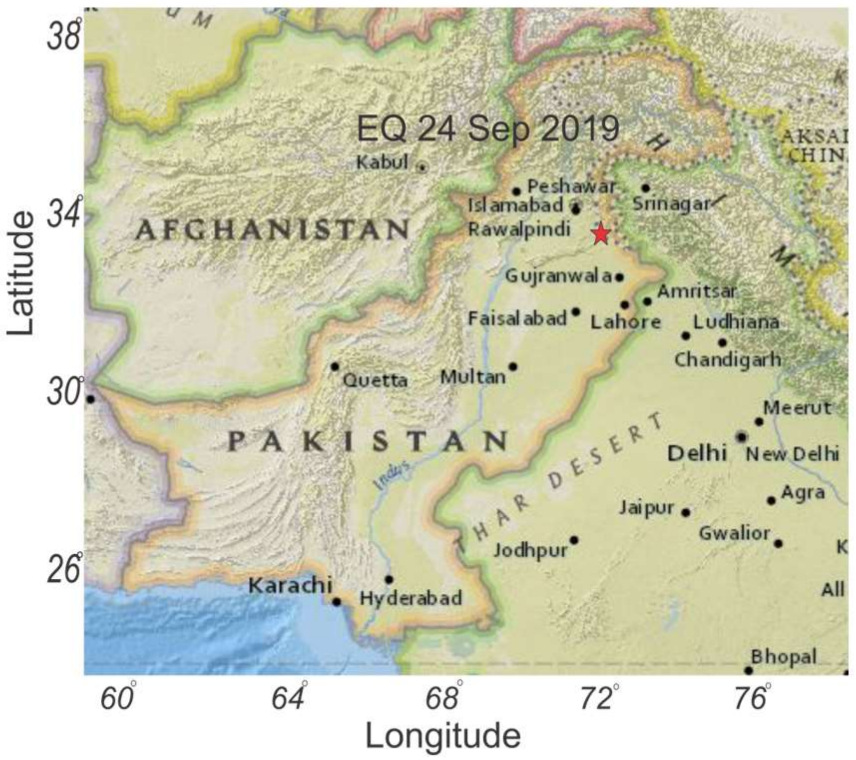

Fig. 1. Epicentral location of the earthquake 24 Sep 2019 on geographic map of Pakistan

2. Tectonic Activity and Plate Motion in Study Area

Indo-Pak plate was sited between Australian, Antartic and African plates in Southern Hemisphere from Permian through Middle Jurassic period and covered some part of Gondwana (Wandrey, 2004). According to the D.N. (1931) these two faults known by Punjal Thrust and Murree Thrust. Therefore, Murree Thrust after given the name by (Treloar et al., 1989; Grecco, 1991) announced by mega boundary thrust (MBT). The direction of this fault continually moving towards north-west then westward and finally tilted headed for Southward at Balakot. The dip angle of this fault line is 50^0 to 70^0 north west of the Muzaffarabad. Marghala hills situated on Murree Fault in the east west direction towards south. In (Fig. 3), the tectonic setting and plate movement around the Jhelum Fault and its surrounding areas also showing the tectonic features of northern Pakistan. Many active faults in Northern Pakistan, India and Afghanistan are governed by the dynamic collision of the convergent plate boundary. Due to this collision highest mountain ranges have been generating like Hindu Kush, Pamir, Himalaya and Karakorum. Indian plate is being subduction under Eurasian plate in northward direction (Kazmi and Rana, 1982). In Northern Pakistan active fault system having strong earthquake history due to this collision. Mega boundary thrust (MBT) made by the Hazara Kashmir Syntax and Kashmir earthquake 2005 M_w is 7.6 and its severe aftershocks with M_w 6.9 are related with this. Main Mantel thrust (MMT), main Karakorum Thrust (MKT) and Kohistan Fault which is extension of the MMT, Raikot Fault (RF), Himalayan Frontal Thrust (HFT) sequence (Kazmi and Jan, 1997) are the main active faults in this region. In these faults system, Jhelum Fault (JF) is one of the most active faults like Mianwali Fault (MF), Kalabagh Fault (KBF) and Salt Range Thrust (SRT). These are belonging to Sub Himalaya and Central Himalayan Mountain ranges. East west direction as (Kazmi, 1979) western part of Syntaxis bend was the left lateral strike slip fault known as Jhelum Fault where Abbottabad and Hazara Formation deformed at Muzaffarabad, Kohala and Balakot (Lawrence and Shroder, 1987). Jhelum Fault terminates eastward direction of NW Himalaya Fold and Thrust Belt whereas in western side this fault dislocates the MBT. This is the youngest tectonic feature in this syntaxial zone.

Immense geological structures, Himalayan make a bend like hair pin in northeast and northern corner of the Pakistan (Desio, 1976) who stated as west Himalaya Syntaxis. Different authors give the different nomenclature for this structure for example (Carey, 1958) give the name Punjab Orocline, (Gansser, 1964; Gansser, 1981) called Western Himalayan Syntaxis and finally Hazara Kashmir Syntaxis by (Calkins et al., 1975; Desio, 1976). Murree formation truncates from the east, north and west by system of faults like hair pin shaped.

Fig. 2. Earthquake damages in around the epicenter in Jattalan Mir Pur City

3. Methodology

The coordinates of area including this event, covered the Jhelum Fault is latitude (32^0–35^0), longitude (72^0–75^0). A selected earthquake catalogue was prepared including foreshocks and aftershocks for $M_w \geq 3.0$ contained more than 1500 events. The main sources for catalogue are International Seismological Centre (ISC), United State of Geological Survey (USGS), Pakistan Meteorology Department (PMD) Centroid Moment Tensor (CMT) European Mediterranean Seismological Centre (EMSC) and IRIS earthquake repository. Focal mechanism was also drawn with respect to their source parameters of nodal planes. The moment magnitude M_w was used to arrange the catalogue which is calculated from (Hanks and Kanamori, 1979) as give in *Eq. 1*.

$$M_w = \frac{2}{3}\log M_0 - 10.7 \quad (1)$$

where; M_0 is seismic moment ($M_0 = \mu DA$) defined by (Aki, 1966; Aki, 1972) where A is rupture area, D is displacement shows the radiated seismic energy due to elastic strain and μ is modulus of rigidity taken as ($3\text{x}10^{11}$ dyne/cm) for crust. Surface wave magnitude M_s can be obtained from relations given by Gutenberg and Richter (1956) in *Eq. 2*.

$$LogE = 1.5M_s + 11.8 \quad (2)$$

A proposed model by (Orowan, 1960) has been utilized for determine the radiated seismic energy (E) from any shallow event. The relation is given in *Eq. 3*.

$$E = \left(\frac{\Delta\sigma}{2\mu}\right)M_0 \quad (3)$$

where; μ is modulus of rigidity taken $3x10^{11}\ dyn/cm^2$, $\Delta\sigma$ is stress drop measured in MPa near the fault. As we now the stress drop has not much dependent on magnitude of an earthquake (Aki, 1972) but it depends on the earthquake inside crust scenario either it is interplate or intra plate earthquake. So, according to the (Kanamori and Anderson, 1975) 3.0 MPa stress drop can used for intraplate and 10 MPa for interplate earthquake Now utilize the $\Delta 6/\mu$ as 10^{-4} so taking above relation E can be obtained dividing by $2x10^4$. Similarly, M_o was also measured using above relation. Therefore, simplification above equation will be in *Eq. 4*.

$$E = \frac{1}{2 \times 10^4} M_0 \tag{4}$$

The IRIS data management center (DMC) was used to extract the waveform of the selected event recorded at Nilore (Nil) Seismic Station in Pakistan with epicentral distance 0.72^0 (81 km approx.) and 629-meter elevation. The latest seismograph Nanumetric Trilluim 240 seismometer was installed at this station for recording waves along three directional components (E-W, N-S and Z). Before the analysis of the above-mentioned event, we should explore the seismicity around the Jhelum Fault and its pattern as well as their focal mechanism solution (FMS). Find the length of the Jhelum Fault measured by the distance formula in *Eq. 5*.

$$\overline{AB} = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \tag{5}$$

The assessment of Peak ground acceleration (PGA) of any area is best tool to explore the site condition and future construction of large infra structure. Seismic probabilistic hazard assessment allocates the level of earth shaking at specified site (Ahmed et al., 2016). This is initial stage to determine the risk of the seismic zone utilizing their site condition, subsurface material and local geology and tectonic setting. Giardini et al. (1999) and Giardini et al. (2003) designed Global Seismic Hazard Map Assessment Program (GSHAP) in which the seismic hazard map can be drawn for any requisite area. This map provides the useful information about the values of peak ground acceleration at particular site with colorful effect in different projection. The mathematical probability-based *Eq. 6* used in GSHAP is given below which is refined solution of probability theorem in statistical manners.

$$P[G] = \iint P[G|mandr] f_M(m) f_R(r) dmdr \tag{6}$$

where G is event of interest for specific site during seismic waves, P is conditional probability, m and r are the random variables. Strong ground motion depends on the magnitude and travel time for all possible earthquake in the adjacent region. The main purpose of this GSHAP program to map the global level ground motion severity which also represents the PGA, PGV, PHA and spectral acceleration SA as well as intensity. The global seismic hazard map represents PGA with 10% probability of exceedance in 50 years, corresponding to a return period of 475 years.

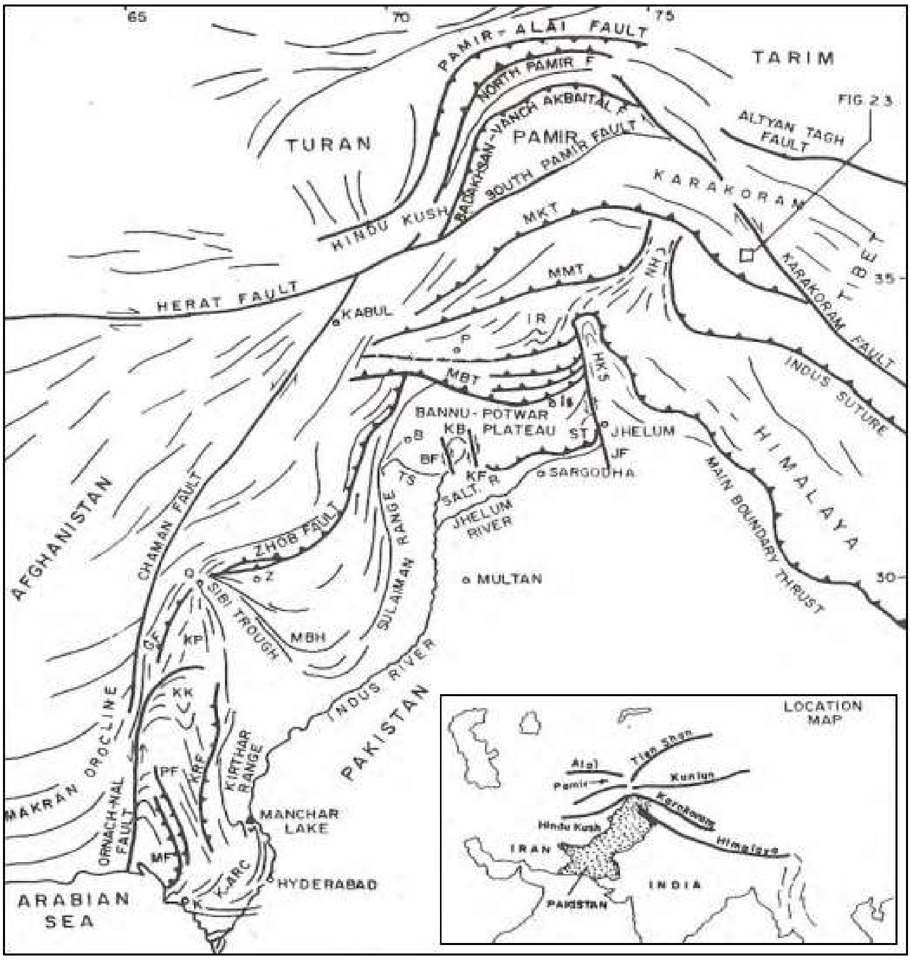

Fig. 3. Tectonic map of Pakistan (Kazmi and Jan, 1997)

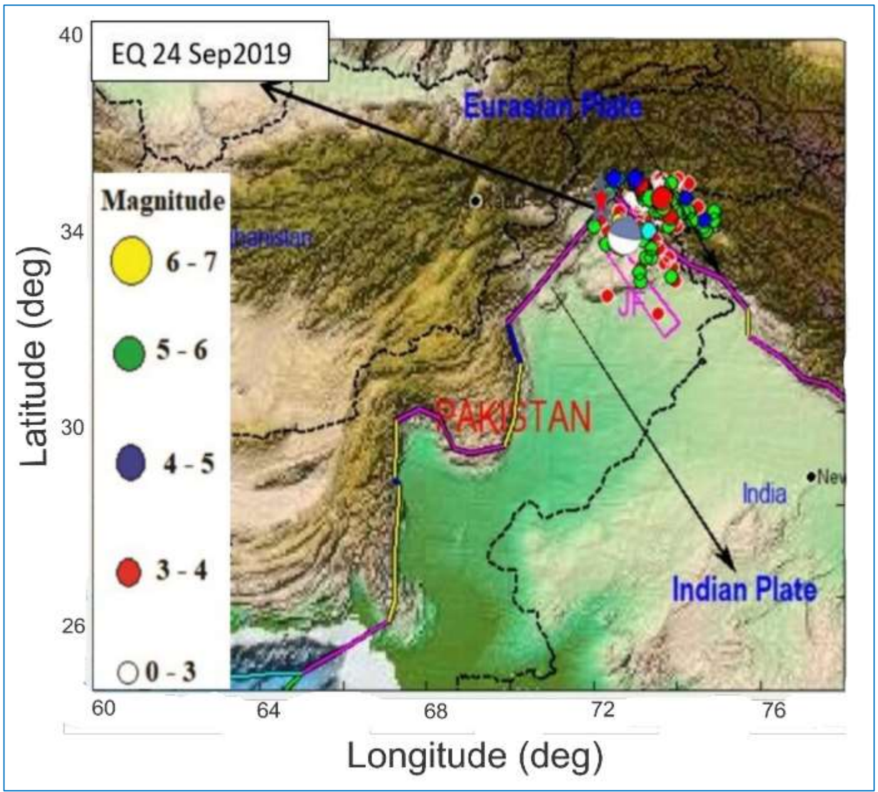

Fig. 4. Seismicity map around the event including Jhelum Fault magnitude distribution

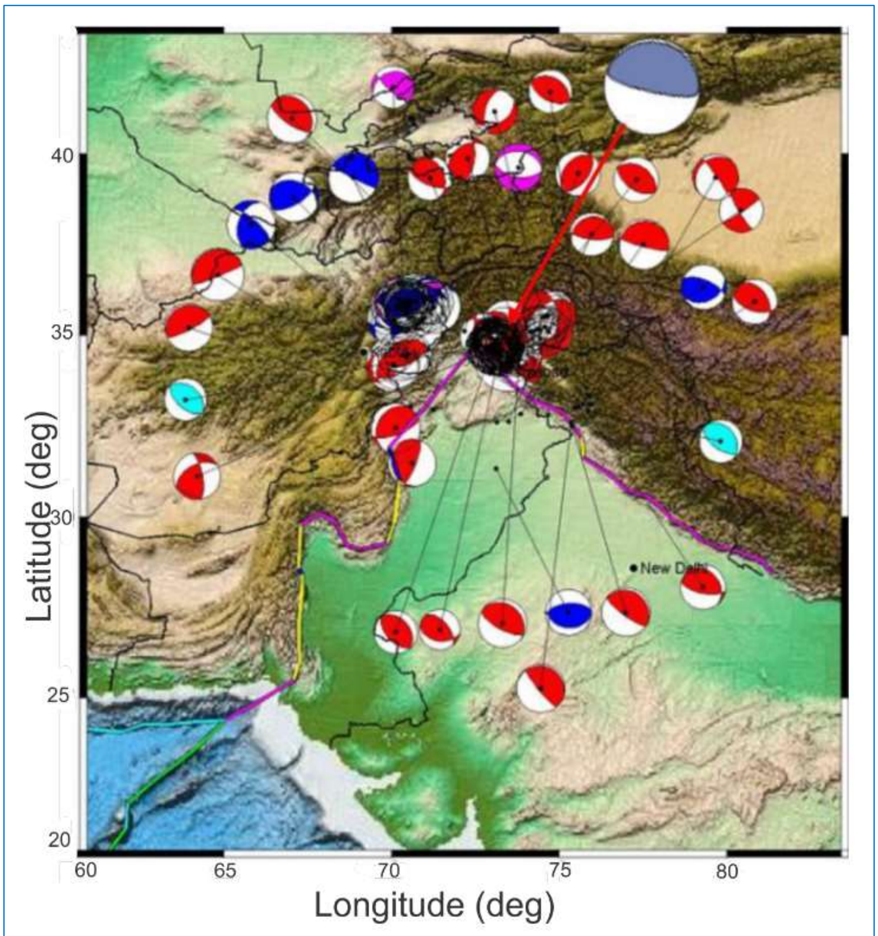

Fig. 5. Focal plane solution around the event including Jhelum Fault. Normal fault (sky blue) reverse fault (red) and strike slip (dark blue)

4. Results and Discussion

The earthquake happened on 24 Sep 2019 at 11.01 (UTM) in area of New Mirpur City about 70 km away from the Jhelum Fault according to the epicentral location (33.10^0N, 73.76^0E. The direction of the Jhelum Fault toward East West where its western part is left lateral strike slip where Abbottabad and Hazara Formation deformed at Muzaffarabad. In the Kohala and Balakot, Jhelum Fault terminates eastward direction of NW Himalaya fold and thrust belt whereas in western side this fault dislocates the MBT. This is the youngest tectonic feature in this syntaxial zone. The length of the Jhelum Fault is about 182 km East to West. The event exists nearby the Jhelum Fault, so the seismicity map (Fig. 4) latitude (32^0–35^0), longitude (72^0–75^0) was prepared including this event in which more than 1500 events covered the area. The seismicity of the area shows that shallow earthquakes have been occurring nearby the Jhelum Fault but not a significant seismic event exactly cover the Jhelum Fault. On the other hand, if we examine the focal plane solution (FMS) generated by Global CMT of same study area. According to the fault mechanism the parameters of the fault planes are given (Table 1).

All types of faulting reverse, normal and strike slip can be seen in beach ball orientation on map. This mean this earthquake does not depend upon the large existing fault line, it may be intraplate fault. Because during plate motion the released accumulated seismic energy deformed the internal crust into different broken parts and these broken parts move and hit the other one to generate another fault. It can be inferring that this event may be an intra plate earthquake.

Table 1. Focal mechanism parameters of fault planes

FPs	Strike^0	Dip^0	Rake^0
NP1	197	16	1
NP2	106	90	106
Axis	**Plunge**	**Azimuth**	
T	43	32	
P	42	181	

Table 2. Radiated seismic energy and seismic moment along with surface wave magnitude

Source parameters	Seismic moment (Dyne/cm)	Surface wave magnitude (*Ms*)	Radiated energy (ergs)
	2.570×10^{24}	5.5	1.283×10^{20}

The above mechanism and their related earthquakes showing beach ball solution of the fault plane. This seismicity rate indicates that around the Jhelum Fault there are many fault systems (Fig. 5) with different fault regime. According to the fault mechanism the parameters of the fault planes are given (Table 1).

The seismic source parameters utilized for determine the earthquake energy, seismic moment and surface wave magnitude (Table 2). After studied the waveform given (Fig. 6) P wave polarity is upward direction indicates the compressional zone producing reverse fault. P wave arrival time is 11:02:58 and S wave arrival time is 11:3:48 and S-P describes the difference between P and S wave i-e 70 seconds.

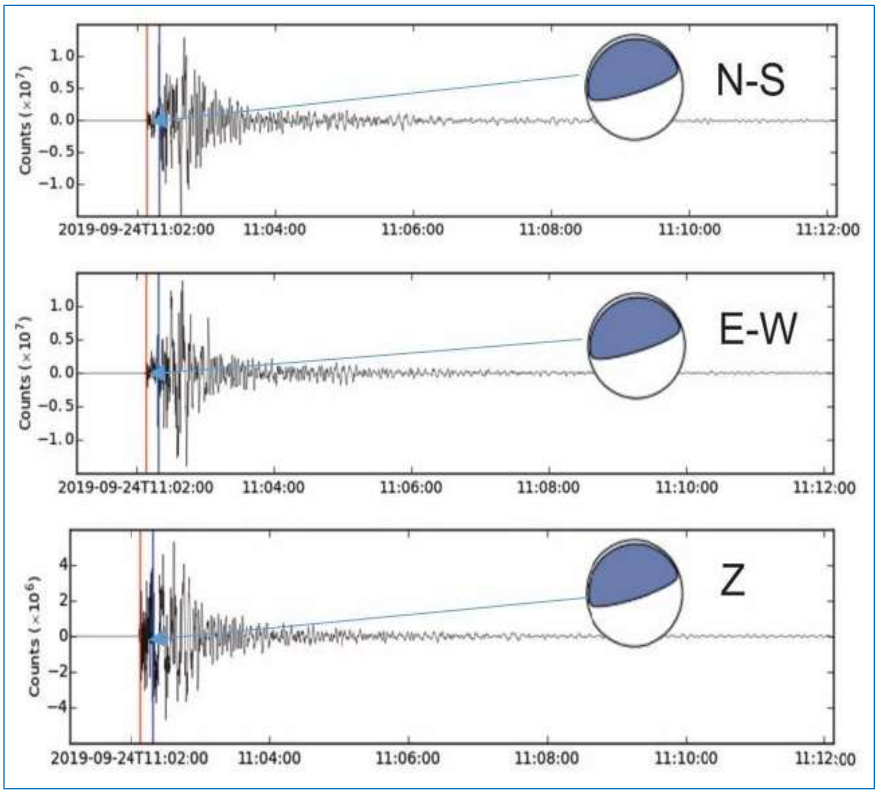

Fig. 6. Seismic waveform of earthquake event 24 Sep 2019 three directional components (E - W), (N - S), Z with P-wave (red) and S-wave (blue). First P-wave polarity arrival upward orientation shows the reverse faulting

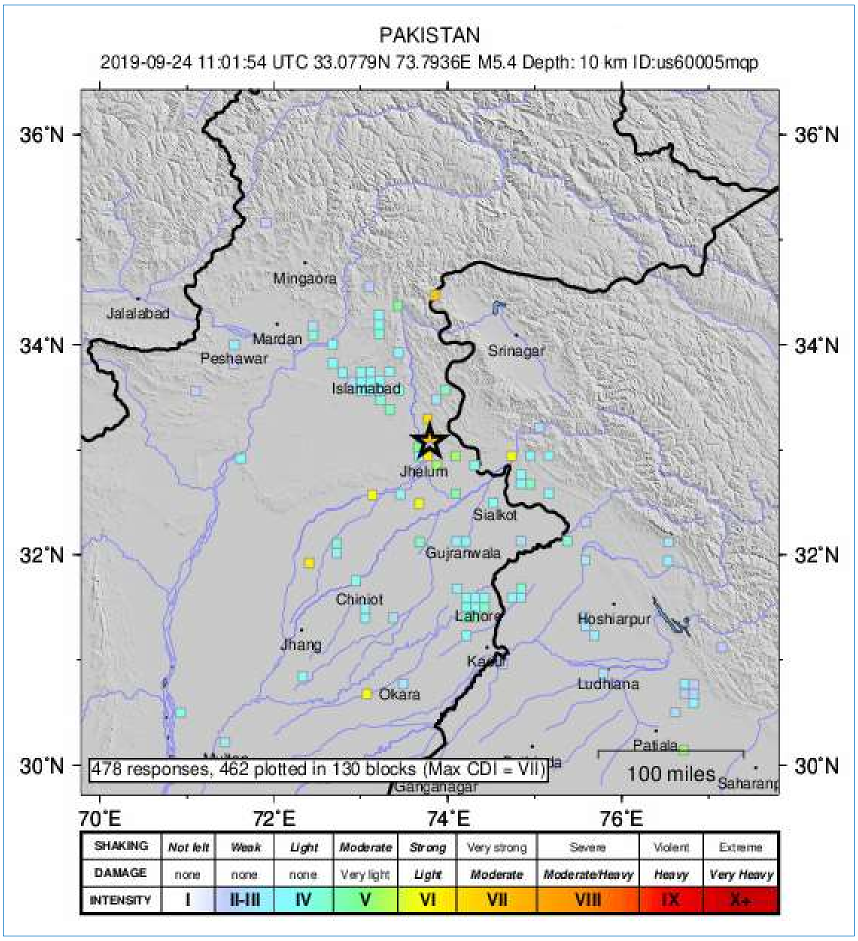

Fig. 7. Intensity map of the earthquake event 24 Sep 2019 (USGS, 2020)

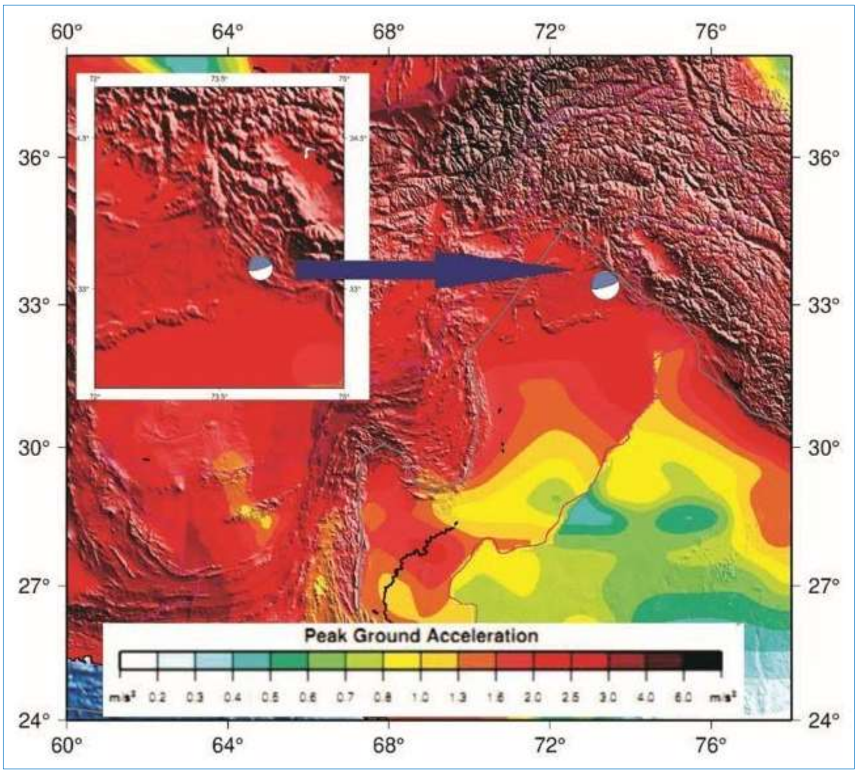

Fig. 8. Peak Ground Acceleration PGA map of the study area at 10 % probability of exceedance for 50 years. Box mention the study area with respect to coordinates and beach ball shows the exact epicenter location of the event by Online GSHAPE (Giardini et al., 1999; Giardini et al., 2003)

Its mean S wave comes after 70 seconds from P waves. P wave faster than the S wave so the scientist used this time difference to locate the earthquake epicenter for triangulation method. Furthermore, above information can also give the velocity of the seismic weaves therefore epicentral distance is 81 km and the time difference is 70 secs so the velocity of the seismic wave during earthquake is 1.15 km/sec.

In (Fig. 7), intensity map displaying the severity and damaged area due to seismic waves after earthquake. Star shows the epicenter location and small square boxes indicate the intensity level as given in the legend. We know that velocity of seismic wave is 1.15 km/sec cover the large area around Mirpur. The MMI scale VI and VII covers the area in Jattalan New Mir-Pur City, Jhelum and near cities. This level shows the light to moderate damages in nearby area due to strong ground motion.

The PGA has been calculated at site with respect to their epicentral location. This PGA map was drawn by the GSHAP in which it is easy to extract the exact value of PGA for any location in and around the Pakistan. In the (Fig. 8), the PGA map of Pakistan contained in the box shows the study area latitude (32^0–35^0), longitude (72^0–75^0) where the beach ball sign locates the focus point of the earthquake event. The global seismic hazard map represents PGA with 10% probability of exceedance in 50 years, corresponding to a return period of 475 years. Result for latitude 33.10° and longitude 73.8° PGA according to GSHAP i.e. for a probability of exceedance 10% within 50 years for the given location is 2.53 m/s^2 for return period of 475 years.

5. Conclusion

To study the seismic parameters around the Jhelum Fault, a recently happened surprising earthquake 24 September 2019 was studied at latitude 33.10°N and longitude 73.8°E in Mirpur City near Jattalan Area. An earthquake catalogue was prepared bounded by latitude (32^0–35^0), longitude (72^0–75^0) included Jhelum Fault. Event occurred about 80 km away from the Jhelum Fault. The seismicity map and focal plane solution shown that there are many fault systems in the vicinity of the Fhelum Fault. The Jhelum Fault is strike slip fault and strike, dip and dip direction values show that this earthquake is due to normal faulting. So, explore this version we have studied the seismicity around the Jhelum Fault. After utilizing the parameters for this event, it is concluded that it was happened due to plane of weakness, overburden pressure or released of accumulated seismic energy from any trap/hidden fault inside crust at shallow depth. The beach ball representation clearly elaborates the normal faulting in the vicinity of strike slip regime. Additionally, this may be a intra plate earthquake that happened due to stresses inside the plate or it may be a place of ancient fault which later deformed by the potholes and cavities during seismic wave. The value of seismic moment (M_0) and energy released have been determined as 2.570x10^{24} dyne/cm, 1.283x10^{20} (ergs) respectively. Surface wave magnitude M_s 5.5 was also obtained. The velocity of seismic waves was 1.15km/sec determined by ($S=vt$) where s is epicentral distance. The MMI scale indicates that this was light to moderate earthquake at VII intensity level. The PGA for study site i-e probability of exceedance 10% within 50 years for the given location is 2.53 m/s^2 and return period is 475 years. PGA value can be used in future construction of high rise building and any other mega project in this area.

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