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Recent seismicity of Western Nepal

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ABSTRACT

Geographically, the Himalaya range lies between Namche Barwa in eastern syntaxis and Naga Parbat in western syntaxis. Nepal Himalaya occupies nearly one-third of the 2500 km-long Himalaya range. Geographically, the Nepal Himalaya is differentiated into five stratigraphy, based on the four major tectonic structures, i.e. Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT) and South Tibetan Detachment System (STDS) from South to North. Western Nepal seismicity is controlled by the mid-crustal ramp in the hanging wall of the flat-ramp-flat geometry of the Main Himalayan Thrust (MHT), in contrast to the double-ramp geometry in eastern Nepal. This paper reports the seismic activity in western Nepal, the seismic network, and the earthquake catalogue from 2022 to 2024. Seismic data was acquired under the National Earthquake Monitoring and Research Centre (NEMRC). Western Nepal has a seismic gap of approximately 520 years. Recently, the region has experienced four significant earthquakes: the Doti earthquake (2022-11-08, ML 6.6), the Bajura earthquake (2023-01-24, ML 5.9), the Bajhang earthquake (2023-10-03, ML 6.3), and the Jajarkot earthquake (2023-11-03, ML 6.4). Over 4,800 seismic events were recorded during this period, with a magnitude of completeness (Mc) 2.3 and a b-value 0.75 ± 0.02.

Keywords: Seismicity; Tectonic Structures; Earthquakes; Epicentre; b-value

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INTRODUCTION

Characteristics of Nepal seismicity

In the Nepal Himalaya, seismicity is concentrated along the east-west direction between the lesser and higher Himalaya. In the whole Himalayan range exists an almost continuous midcrustal seismicity belt (Pandey et al., 1995; Kumar et al., 2006; Monsalve et al., 2006; Mahesh et al., 2013; Diehl et al., 2017).. Similarly, a large concentration on the eastern and western sides of the Nepal Himalaya, though some in mid-central Nepal, was affected by the 2015 Gorkha earthquake. According to (Pandey et al. 1999), the seismic activity in the midcrust appears quite diverse with a pitchfork-shaped distribution consisting of three seismic belts: Bajhang in the west, North Karnali in the Northeast, and South Karnali in the southeast. Similarly, on the southern slope of the higher Himalaya range, a narrow and straight band of seismicity. In the eastern side of the Nepal Himalaya, a more complex zone of seismicity spreads between the Moho of the Indian crust and the mid-crustal zone (Monsalve et al., 2006). The primary area of seismic activity is located at the base of the high Himalayan range in the Bajhang region, with depths ranging between 10 and 18/20 km. Most of the seismic activities in Nepal are confined between the Main Central Thrust and the Main Boundary Thrust. In addition, the Bajhang Earthquake 1980 is a 120° dip 60°SE plane; the strikes of the fissures, fractures and that of the active fault coincide with this trend (Singh, 1982). Similarly, the Northern side has scattered seismic activity, whereas the southern side has reached south of Karnali Klippe at depth between 8 – 15 km (Hoste-Colomer et al., 2018). According to (Hoste-Colomer et al., 2018), the spatial distribution of earthquakes compared with the local geology, the earthquakes appear structurally controlled, i.e. the major structures MHT, along with the intersection between Megathrust faults and the contact between lesser Himalayan tectonic slivers. The earthquake pattern in the region shows a structural division of the thrust due to several mid-crustal and frontal ramps, which results in spatiotemporal variations in seismic activity. Given the historical evidence of destructive earthquakes and interseismic locking of the area, it is likely that this zone has the potential to produce both large and great earthquakes on the western side of Nepal. In the Himalaya, crustal deformation occurs on the Main Himalayan Thrust faults (MHT) where the Indian continent converges under the Eurasian continent at a rate of about 20mm/yr (M R Pandey et al., 1999), and MHT reaches the surface at the Main Frontal Thrust fault (MFT) (Nakata, 1989). However, different scientists have published various convergence secular slip rates, such as 21.5 ± 1.5 mm/yr in central Nepal (Lavé and Avouac, 2000) and 19 ± 6 mm/yr in western Nepal (Husson et al., 2004). A total of 1406 local earthquake data were recorded in the seismological centre, Surkhet, in 2022. This research will present the seismic patterns of Western Nepal, seismic gaps and seismo-tectonics of Western Nepal.

Western Nepal seismological networks

The Seismological Centre is located at 28°36'02.16'' latitude and 81°37'21.39'' longitude, Birendranagar, Surkhet, and this is an autonomous centre for recording and processing data received from ten seismic stations. The seismic network of SC covers from west Rukum to Far-western of Nepal, for instance, Mega (West Rukum), Harre (Surkhet), Bhimchula (Surkhet), Gaibana (Surkhet), Pusma (Surkhet), Gainekanda (Surkhet), Badegauja (Kailali), Ghanteshowar (Dhadeldura), Ganjari (Baitadi), and Bayana (Bajhang). The centre is equipped with data processing, an earthquake location facility, the Technical Alert System (TAS) and the Seismic Alert System (SAS). This Data centre covers Karnali and Sudurpaschim province, including the Siwalik to Higher Himalaya rock sequences.

Tectonic setting of Western Nepal

Tectonically, the Nepal Himalaya is divided into four geological structures: the Main Frontal Thrust (MFT), the Main Boundary Thrust (MBT), the Main Central Thrust (MCT), and the South Tibetan Detachment System (STDS). Similarly, Western Nepal also corresponds to the same tectonic structures; the main nucleation of seismic activities occurs in the Main Himalayan Thrust (MHT). According to (Laporte et al., n.d.), Seismicity in western Nepal from 80.8° E to 81.4° E Longitude is controlled by the mid-crustal ramp in the hanging wall of the flat-ramp-ramp geometry of the MHT, whereas from 81.5° to 81.9° E is controlled by a double-ramp geometry of the MHT, as shown in Figs 2 B and C.

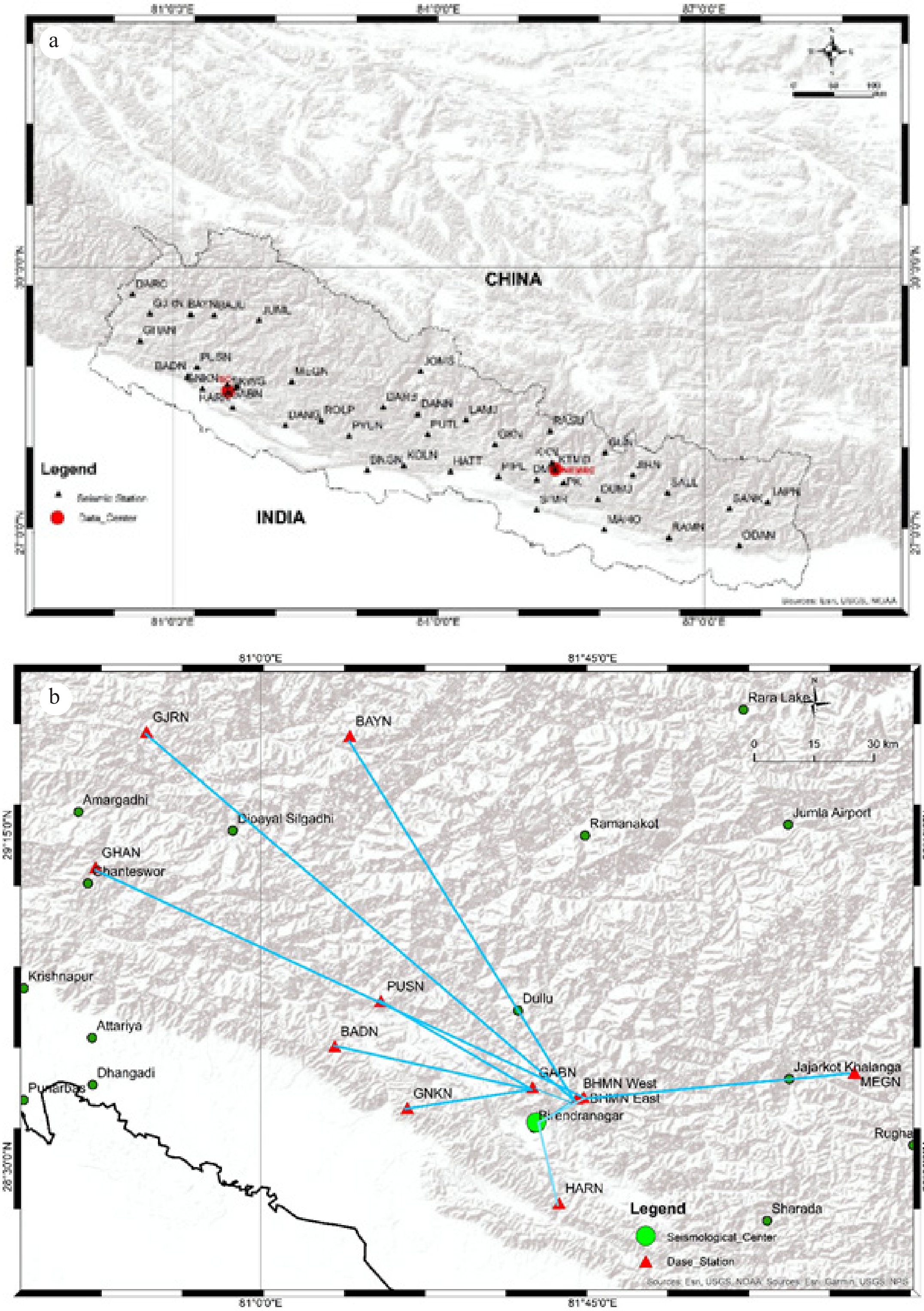
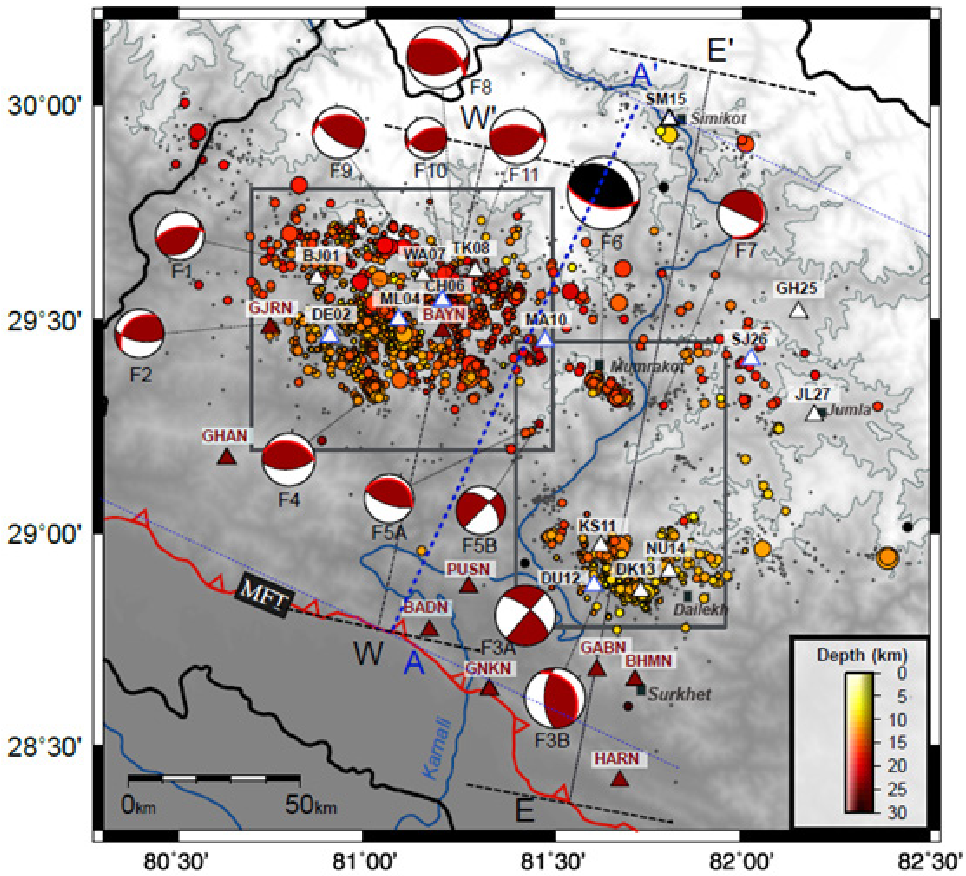


Fig. 1: a) Seismic network of the National Earthquake Monitoring and Research Centre, b) Seismological Centre network system.

a)


30°00'
29°30'
29°00'
28°30'
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81°00'
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F1
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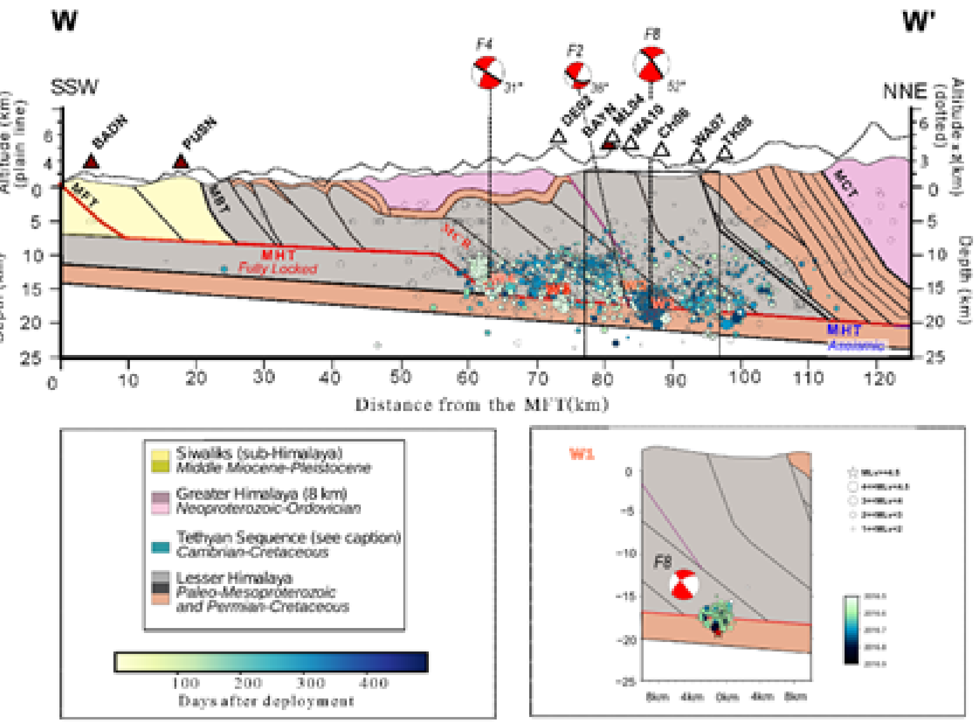
F3A
F3B
F4
F5A
F5B
F6
F7
F8
F9
F10
F11
A
A'
W
W'
E
E'
MFT
SM15
Simikot
BJ01
WA07
TK08
CH06
ML04
DE02
GJRN
BAYN
MA10
SJ26
GH25
JL27
Jumla
Munnakot
GHAN
KS11
NU14
DK13
DU12
PUSN
BADN
GABN
BHMN
GNKN
Surkhet
Dailekh
HARN
Karnali
0km
50km
Depth (km)
0
5
10
15
20
25
30

b)


W
W'
SSW
NNE
F4
F2
F8
Altitude (km) (plain line)
Altitude x 2(km) (dotted)
Depth (km)
BADN
PUSN
DE02
BAYN
ML04
MA10
CH06
WA07
TK08
MFT
MBT
MCT
MHT
Fully Locked
Distance from the MFT(km)
Siwaliks (sub-Himalaya)
Middle Miocene-Pleistocene
Greater Himalaya (8 km)
Neoproterozoic-Ordovician
Tethyan Sequence (see caption)
Cambrian-Cretaceous
Lesser Himalaya
Paleo-Mesoproterozoic
and Permian-Cretaceous
100
200
300
400
Days after deployment
W1

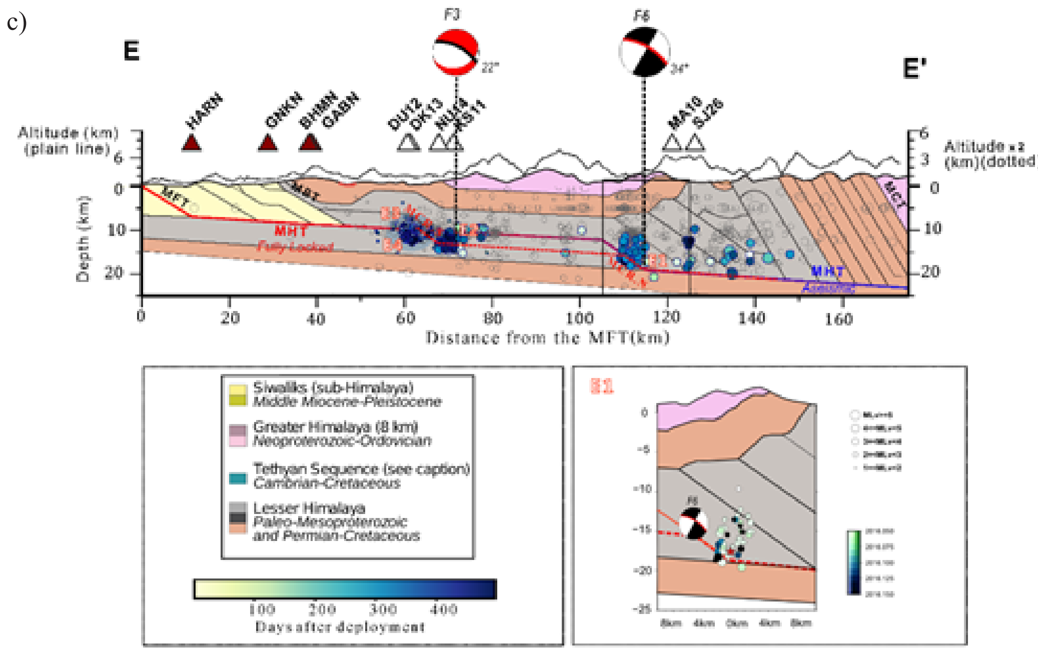


Fig. 2 : a) Seismicity map of Western Nepal from 2014 to 2016 data, b) projection of hypocentres on the Bajhang balanced cross-section, c) projection of hypocentres on the balanced cross-section of Karnali (Source: Laporte et al, 2021).

METHODS AND DATA ANALYSIS

Seismic data

In this study, we analyse seismic signals recorded by the Seismological Centre network (Pandey et al., 1999; Pandey et al., 1995). The Department of Mines and Geology (DMG) collaborate with the Department of Analytical Surveillance Environment (DASE) from France to operate 22 seismic monitoring stations. Among them, 10 seismic stations have been autonomously run in the Seismological Centre Surkhet to cover Karnali and Sudurpachim provinces. Under the 10 seismic networks of SC, 8 stations record the vertical component of seismic activity at short intervals of 1 second (ZM500), while the remaining 2 stations can record seismic activity across a wider range of frequencies, from 0.1 to 120 seconds (broad-band). These seismic stations are telemetered to process at SC into the Jade-Onyx acquisition-treatment software suite. To locate earthquakes routinely, a velocity model with three layers is utilised. This model includes P and S–wave velocities in each layer, which measure (5.56, 6.50, 8.10) and (3.18, 3.71, 4.63) km/s, respectively. The depths of the interfaces between these layers are 23 and 55 km, and they correspond to the Moho discontinuity(Pandey et al., 1995).

Magnitudes and location

The local magnitude (ML) is estimated on the maximum amplitude [A(i)] of the Sg, Sn or Lg seismic phases measured at station i on the 0.3 – 7 Hz bandpass filtered seismic signals following:

$$ML - NSC\,(i) = LOG[A(i)/T] + B[\Delta(i)] + C\,(i)$$

Where T is the period, B is the attenuation law, and C(i) is a station correction term. The attenuation law is expressed as a function of the epicentral distance (Δ) and include a geometrical spreading correction and an anelastic attenuation term such that

$$B(\Delta) = -1.85 + 0.854 \log 10\ (\Delta) + 0.00102\,\Delta.$$

To prevent any distortions caused by source and path effects, only seismic monitoring stations situated beyond a distance of 100 km from the earthquake's epicentre are taken into account for the purpose of calculating its magnitude.

Gutenberg–Richter relations of Western Nepal seismicity

The analysis of seismicity data from 2020 to 2022, as shown in Fig. 3A, reveals a completeness of magnitude of 2.3, indicating that the instruments record magnitudes greater than 2.3. The Central Himalaya is a tectonically very active and high-stress region; therefore, its b-value is 0.75±0.02. Moreover, a value of 4.736 indicates high seismic productivity; thus, we can expect about 1000 earthquakes per year greater than 2.3.

Epicenter map of Western Nepal

Figure 4. Epicenter map of Western Nepal

Table 1. Seismic activity in Western Nepal from 2020 to 2022.

S.N.	ML	No. of Earthquake
1	< 3	4145
2	3 - 4	570
3	4 - 5	88
4	5 - 6	14
5	> 6	3
Total No of Earthquakes		4820

Since 2020, numerous mild earthquakes have struck in western Nepal, as shown in Fig 4. Including the aftershocks and earthquakes, we recorded more than forty-eight thousand events in the SC. We recorded 3 earthquakes with magnitudes greater than 6, followed by 14 events in the range of 5–6 magnitudes, and subsequently 88 events with magnitudes between 4 and 8, followed by 570 earthquakes with magnitudes between 3 and 4. Finally, with less than 3 magnitudes, we recorded 4145 earthquakes as shown in Table 1.

Table 2. Four mild earthquakes in Western Nepal from 2020 to 2022.

S.N.	ML	Doti Earthquake (6.6 ML)	Bajhang Earthquake (6.3 ML)	Jajarkot Earthquake (6.4 ML)	Bajura Earthquake (5.9 ML)
1	< 3	606	544	698	284
2	3 -4	116	156	59	61
3	4 -5	11	28	7	12
4	5 - 6	3	5	1	1
5	> 6	1	1	1	0
Total		737	734	766	358

During the two years in western Nepal, we recorded four mild earthquakes, ranging from 5.9 to 6.6 ML, as shown in Table 2. This data illustrates that seismicity in western Nepal is increasing significantly as compared to the previous period. The Jajarkot and Doti earthquakes are the major disasters and casualties that occurred in Western Nepal. The epicentre density distribution map illustrates that it occurs in the range between 29° and 30.25° latitude and 80.5° and 82.5° longitude, with the density of seismicity in the range between 0.5 and 2.5 as shown in Fig. 5.

DISCUSSION AND CONCLUSION

The continuous monitoring of earthquakes by the Seismological Centre and coordinating with the Central Data Centre (NEMRC/DMG) to prepare a catalogue for research, measurement, and monitoring of earthquakes within Nepal. The active seismic station with the (Pandey et al.) velocity model is used for the measurement of local earthquakes within Nepal and regional areas.

A 2-year earthquake catalogue illustrates that Western Nepal has a significant impact on mild earthquakes. More than four thousand eight hundred events were recorded within two

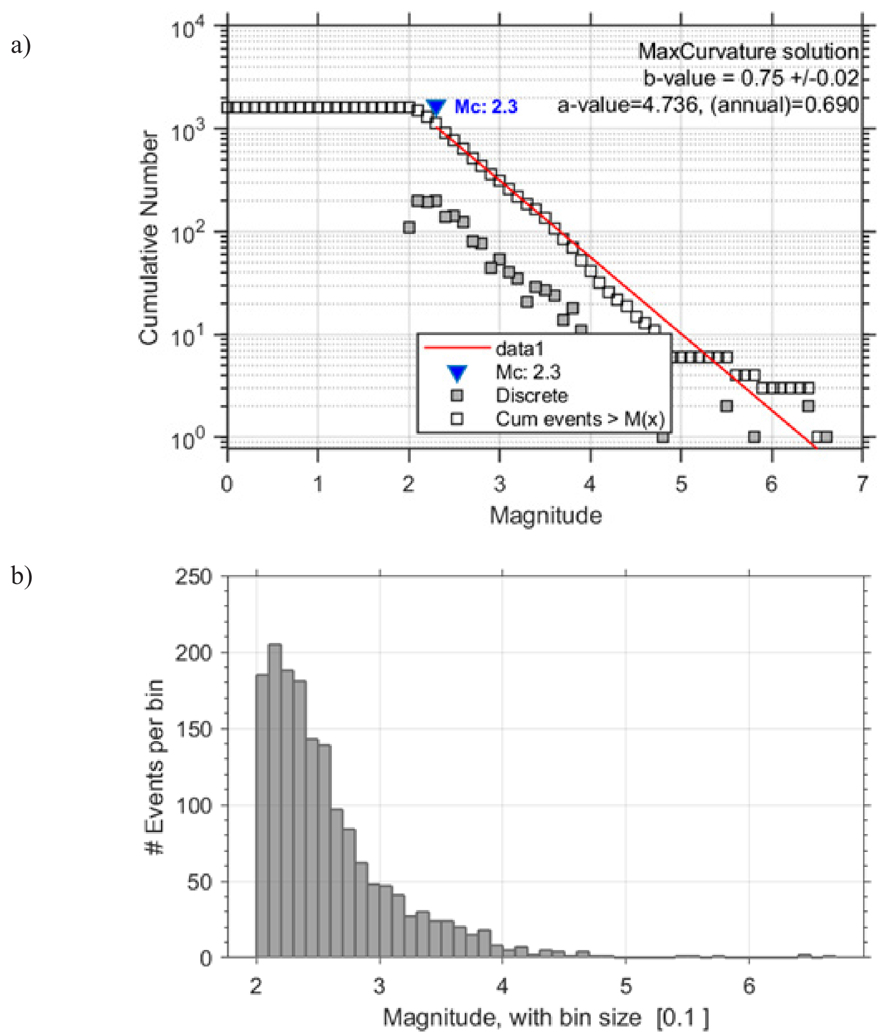


Fig. 3: a) Gutenberg-Richter relation, b) Magnitude vs events.

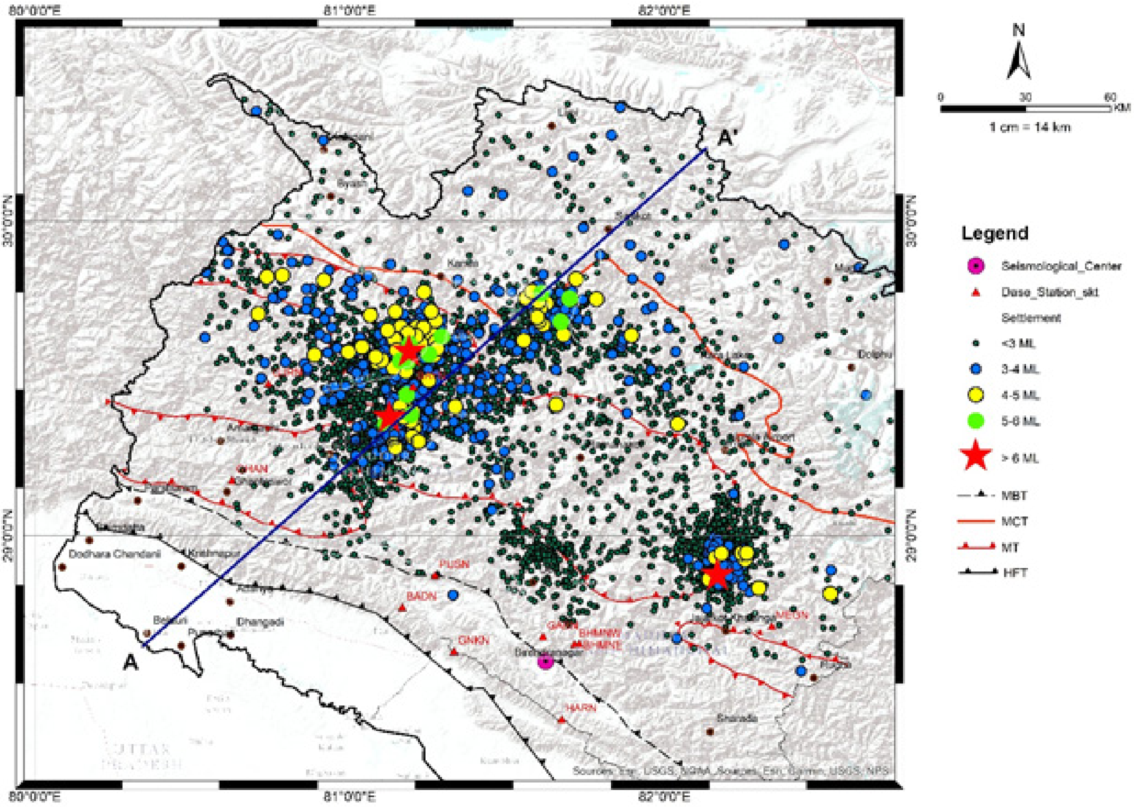


Fig. 4: Epicenter map of Western Nepal.

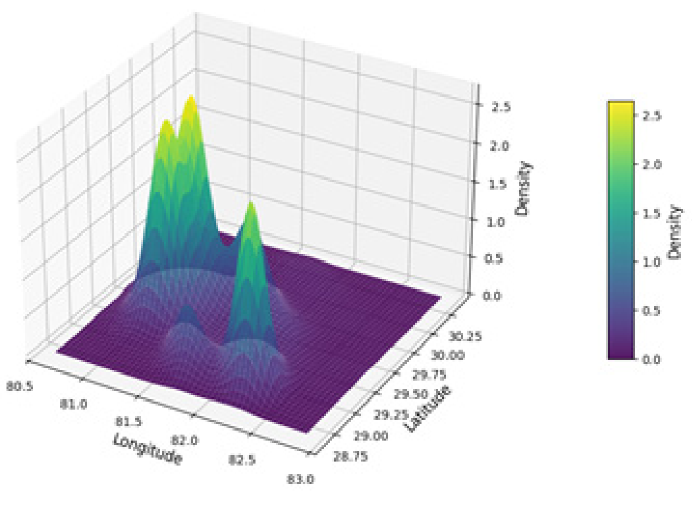


Fig. 5: Seismic density of western Nepal from 2020 to 2022.

years, including four mild earthquake events. According to the magnitude, the Doti earthquake has a greater magnitude than the rest of the other events, though Jajarkot is more disastrous. The completeness of magnitude is 2.3, which is similar to that of (M R Pandey et al., 1999), i.e., the minimum value of the earthquake record by our instruments is 2.3 Magnitudes. Similarly, the b-value is 0.75±0.02, which means Nepal Himalaya is a tectonically very active and high-stress region. Subsequently, in Western Nepal, high-stress-strain building and secular convergence rate is nearly 19±6 mm/yr according to (Husson et al., 2004). The seismicity of Western Nepal indicates that most of the seismicity has occurred in the Mid-crustal regions of MHT, along the Lesser and Higher Himalaya. As the concentration of seismicity around the MCT, the Laporte et al 2021 results are significantly matchable with each other, i.e. Western Nepal seismicity is controlled by the mid-crustal ramp in the hanging wall of the flat-ramp-flat geometry of MHT. Moreover, the range of density in Western

Nepal is between 0.5 and 2.5 from the 29° to 30.25° latitude and 80.5° to 82.5° longitude. The main causes of the increase in the density in these regions are the four mild earthquakes that struck. Since 1505 AD, in Western Nepal, there have been no great and mega earthquakes; a huge seismic gap in Western Nepal. The seismic patterns and energy accumulations within the Himalaya illustrate that there is a high possibility of a great to mega earthquake striking.

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