Journal of Urban and Environmental Engineering, v.11, n.2, p.133-141

ISSN 1982-3932
doi: 10.4090/juee.2017.v11n2.133141

Journal of Urban and Environmental Engineering

www.journal-uee.org

ANALYZING SEISMIC ACTIVITIES DURING 1900 TO 2015 TO ASSESS URBAN RISK IN NEPAL HIMALAYAS USING GEOINFORMATICS

Amit Kumar and Arvind Chandra Pandey*

Centre for Land Resource Management, Central University of Jharkhand, Brambe, Ranchi-835205, INDIA

Received 27 August 2016; received in revised form 02 May 2017; accepted 05 July 2017

Abstract: A high magnitude (*Mw* = 7.8) earthquake caused a geological disaster recently on April-May 2015 in Nepal Himalayas and resulted in severe devastation in Nepal as well as neighboring states in India. Looking into its recurrent occurrence with varied intensity, in the present study, the earthquake pattern in Nepal Himalayas was analyzed during the period 1900 to 2015 using United States Geological Survey (USGS) data sources in GIS environment. The result exhibits that the intensity of earthquake events are increased in recent decade in Nepal Himalayas as compared to previous century (1900-2014). The information pertaining to earthquake epicenter, magnitude, depth to hypocenter, demography *etc*. was also analyzed in geospatial environment to deduce its relation with geotectonic settings and possible risk in the vicinity. The earthquake events were also observed at deeper location (more than 40 kms) during 1900-2014 (414 events; 53.9%) as compared to the recent events (2015), where majority of eathquake events (146 events; 85.3%) recorded at below 10 km depth (Janakpur and Bagmati provinces in Nepal). The result exhibits high number of recent events with greater magnitudes in central Nepal during April-May 2015 affecting a very large population above and around their vicinity with varied intensity. The cities located in central Nepal are highly prone to frequent earthquake hazard and induced risk on population of 2 923 621 persons followed by north-western Nepal.

Keywords: Earthquake events; Nepal Himalayas; Urban Risk, Geoinformatics

* Correspondence to: Arvind Chandra Pandey, Tel.: +91 99554 92100. E-mail: arvindchandrap@yahoo.com

INTRODUCTION

The Himalayas, the youngest and most fragile mountain system on the Earth (Nyaupane and Chhetri, 2009) located in Nepal, Bhutan, Pakistan, Tibet and India. The Himalayan ecosystem is vital to the ecological security of these region, which provides forest cover, feeding perennial rivers that are the source of water, hydropower, sustaining biodiversity, providing a rich base for cultivation and sustainable tourism. Simultaneously, climate change adversely influence the Himalayan ecosystem due to increasing temperature, altered precipitation patterns, and drought incidences (Tariyal, 2015). The Himalayas is the most complex newly folded mountain system that separates the northern part of the Asian continent from south-eastern part. The region being a discrete geographical and ecological entity, figures prominently in major biophysical settings of the planet earth. This vast mountain range produced a distinctive climate of its own and influences the climate of much of Asia (Tariyal, 2015).

The entire Himalayan range is highly prone to earthquakes. Historical records reveal that Himalayan system has been regular influenced by the devastating earthquakes. Earthquakes cause significant damage to life and property everywhere in the world every year, which has been rising continuously. Though seismic intensity and magnitude may not have increased over time, the increasing human population concentrated in seismically sensitive zones raised the degree of human vulnerability to potential earthquake events (Kolars, 1982; Chandel and Brar, 2010).

Nepal has the longest division of the Himalaya and occupies the central sector of Himalayan arc. Its Capital, the Kathmandu Valley with a population of 5 million (*ca.*) has been affected by damaging earthquakes in the past several times. The valley was formerly a lake and considerable historical damage in the valley ascended due to seismic amplification associated with thick lake deposits (Paudyal *et al.,* 2012). Earthquakes occur throughout the crustal thickness of the Indian Shield, where the lower crust is consist of dry granulite, responsible for its seismogenic comportment and strength as demonstrated by its relatively large elastic thickness. The crust of the Indian Shield is thin (~35 km) for an Archean shield, and influence to a steady-state Moho temperature that could be as low as ~500 °C. When this shield is thrust underneath the Himalaya in Nepal, the relatively low mantle temperature, together with the high strain rates associated with it adopting a 'ramp-and-flat' geometry, which may be responsible for the mantle micro-earthquakes that accompany other earthquakes in the lower crust (Priestley *et al.,* 2008).

Spatio-temporal variability of seismicity within 300 km area of the main epicenter of Nepal earthquake of 25th April 2015 showed seismic quiescence since 2007 (Prakash *et al.,* 2016). The earthquake affected the human population to a greater degree its vicinity. In Pokhara district (central Nepal), more than 8500 persons died and 20,000 person injuried (NSET Nepal 2015). The massive 7.8 *Mw* earthquake on 25th April 2015 followed by 41 aftershocks within 26 hours and 7.3 *Mw* on 12 May 2015 rocked the Nepal Himalaya almost for a 16 to 18 days, are the largest to have occurred in this region in the past 81 years. The couple of aftershocks were larger than 6.5 *Mw*. The main shock ruptured the frictionally locked segment of the Main Himalayan Thrust (MHT), initiating a positive topography near the locking line and rupturing all the way up dip close to its surface expression near the foothills of the Himalaya. This region had accumulated ~3 m of slip in the past 182 years and converging at a rate of ~18 mm/yr. The close match of the accumulated slip with the coseismic slip of the main event confirms that majority of the convergence between India and Tibet is stored as elastic strain energy and is released by brittle failure in earthquakes. This Nepal earthquake has highlighted that other segments of the Himalayas may have substantial unrelieved elastic tension and may also rupture in similar or greater earthquakes in the future (Mitra *et al.,* 2015). Rai *et al.* (2016) in his study elaborated the damage occurred due the April 2015 earthquake and also discussed the preparedness for future earthquake events.

Looking into its recurrent occurrence with varied intensity, in the present study, the pattern of past earthquakes occurrence during the period 1900 to 2015 was analyzed using U.S. Geological Survey data sources in GIS environment. An attempt has also been made to spatially analyze the patterns of recent earthquake events (April- May 2015) occurred in Nepal Himalayas and its relationship with historical earthquake events (*i.e.,* during 1900-2014) of magnitude more than 4.0 *Mw* Richter scale.

STUDY AREA

In the present study, the Nepal Himalayas and its vicinity were taken into account with reference to the recent earthquake events in the region. The study area covers an area of 5.23 lakh sq. km and lies between 79°37′E to 88°38′E longitude and 26°1′N to 31°4′N latitude, within the elevation ranges from 62 m to 8776 m above sea level (**Fig. 1**). The study area covers Himalayan region of Nepal and India and Tibetan plateau.

Nepal, measures about 25 km east to west stretch and 20 km north to south stretch and serves as the nation's political, economic, and cultural capital with an estimated resident population of 5 million. The population density in urban parts of the valley approaches 13 225 persons/km^2 (Kathmandu

Metropolitan City, 2011). There are 69 urban agglomerations in the vicinity of Kathmandu valley, which are located in Nepal, India and China having cumulative population of 12 815 379 persons in 2011.

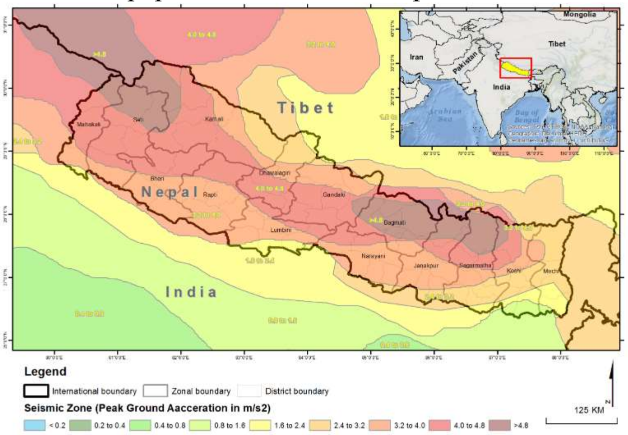

Fig. 1 Map showing the study area with seismic hazard zones.

Nearly one third of the 2400 km long Himalayan range lies within Nepal. Its extension is about 800 Km and starts from west at the Mahakali River and ends at the east by the Tista River. Similar to other parts of the Himalaya, from south to north, Nepal can be also subdivided into the following five major tectonic zones *viz.,* Gangetic Plain, Sub-Himalayan (Siwalik) Zone, Lesser Himalayan Zone, Higher Himalayan Zone, and Tibetan-Tethys Himalayan Zone. Each of these zones is characterized by its own lithology, tectonics, structures and geological history (Dahal, 2006).

METHODOLOGY

The data pertaining to earthquake events was acquired from USGS (http://earthquake.usgs.gov/earthquakes/map) and analyzed with respect to its spatio-temporal occurrence during 1900-2015. The information pertaining to earthquake epicenter, magnitude, depth to hypocenter, elevation, demography *etc*. was analyzed in geospatial environment to deduce its relation with geotectonic settings and possible risk in the area. The ASTER Global Digital Elevation Model (DEM) was acquired from USGS and used to evaluate the epicenter's locations and its relation to hypocenter. Also the population figures were collected from National Population and Housing Census 2011, Govt. of Nepal.

RESULTS AND DISCUSSIONS

Temporal distribution of earthquake events

A total of 767 earthquake events were reported by USGS in and around Nepal Himalayas during 1900-2014 with magnitude of more than 4.0 *Richter Scale*, out of which 326 (42.5%) events were located in the vicinity of Nepal Himalayas. On the other hand, a total of 171 earthquake events occurred in Nepal Himalayas during the month of Jan. to June 2015, mainly during April-May 2015 (**Table 1**). The spatial distribution of recent earthquake (during 2015) exhibits that the majority of earhquakes occurred in Janakpur and Bagmati provinces in Nepal, whereas the same area was less active with reference to earthquake occurance during the last one century *i.e.,* 1900-2014 (**Fig. 2**).

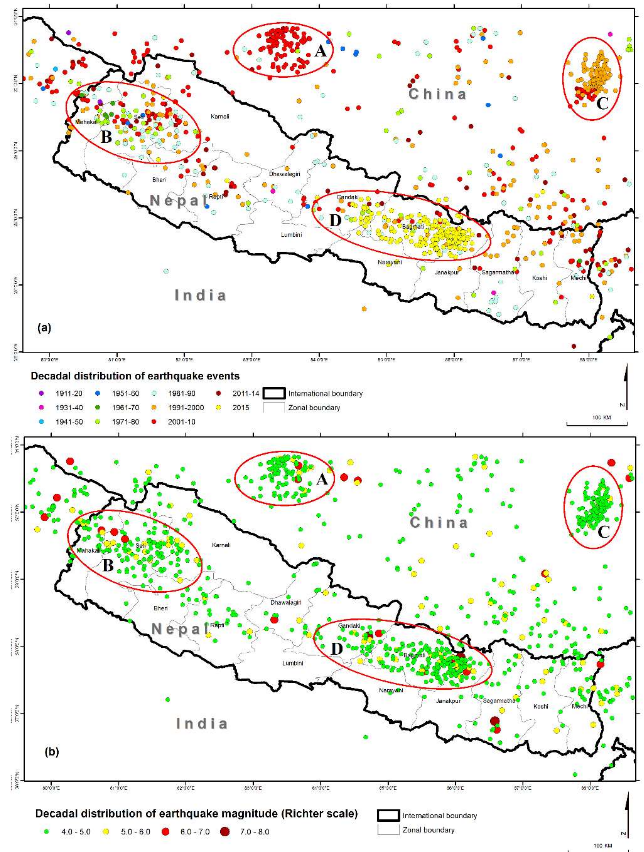

Fig. 2 Map showing earthquake distribution during 1900-2015 (a) decadal occurrences and (b) magnitude variability in various zones (Source: USGS).

The decadal observation exhibits that the earthquake events were very insignificant during the first half of 21st Century (till 1950) (6 earthquake events) (**Tables 1a–b**). During post 1950s period, the earthquake events were increased gradually i.e., 18 events during the decade 1951-60, 61 events in 1971-80, 97 events during 1981-90. The later three decades observed very high number of earthquake events with increasing trend over the deacades *viz*., 233 events during 1991-2000, 278 events during 2001-10 and 245 events during 2011-2015 (till June). The 69.8% (171 events) of earthquake events during 2011-15 period was reported during the year 2015 (till June). This denotes the increasing unstability of underlying plate and thereby higher earthquake events in the region.

The decadal spatial disptribution of earthquakes shows that earthquake events were localized in four zones as exhibited in **Fig. 2** (Major events in Zone A:

Table 1. Comparing the earthquake events occurred during 1900-2014 and 2015

a. Earthquake events during 1900-2014		b. Earthquake events during 2015 (till 30th June 2015)	
Decade/ Period	Earthquake strikes (*Mw* >4.0)	Months	Earthquake strikes (*Mw* >4.0)
1901-10	0	Jan	2
1911-20	2	April	97
1931-40	3	May	58
1941-50	1	June	14
1951-60	18	Total	171
1971-80	61		
1981-90	97		
1991-2000	233		
2001-2010	278		
2011-2014	74		
Total	**767**		

2001-10; Zone B: 1981-91-2000-2010; Zone C: 1991-2000-2010; Zone D: 2015). The zone A, located in south west China was mostly active during the decade 2001-10 and having 4 severely high magitude earthquake events (>6.0 *Mw*), whereas zone C, located in southern China/ Tibet was mostly active during the decade 1991-2000 followed by 2001-2010 period and having two severely high magitude earthquake events (>6.0 *Mw*). The Zone B, located in western Nepal was almost active during last quarter of 20th Centrury and years of 21st Century *viz*., 1961-70, 1981-90, 1991-2000 and 2001-2010. The Zone B had three severely high magitude earthquake events (>6.0*Mw*) within its western margins. In contrast, the zone D, located in central Nepal, was highly active during the year 2015 (April to June), which recorded insignificant earthquake events during the last century (*viz*., 1981-2014) corborating sesmic gap theory. It is also apperant that Zone D was highly active as 4 severely high magitude earthquake events (>6.0*Mw*) occurred in very short span of time during 2015.

Depth to hypocentre

The data pertaining to depth to hypocentre exhibits that majority of earthquake events took place at 30-40 km depth (414 events; 53.9%) followed by that take place at was less than 10km of depth (118 events; 15.3%) during 1900-2014. Whereas, in 2015, majority of eathquake events *i.e.,* 85.3% (146 events) took place (Janakpur and Bagmati provinces in Nepal) below 10 km depth exhibiting highly unstable nature of the upper lithosphere as compared to the lower parts (**Table 1**). During 1900-2014, the earthquake events were also observed at deeper location (more than 40 kms) as compared to the recent events (**Fig. 3**).

The temporal distribution of earthquake exhibits that the region was almost dormant (only 6 events) during the first half of 20th Century (1900- 1950) and located near to the 20 km of depth from the earth surface. At later periods, the earthquake events gradually increased and located mainly at 30- 40 km of depth (414 earthquakes). Moreover, the majority of events during 2015 were located at10 km of depth (146 earthquakes); also few (25 earthquakes) occurred up to 40 km of depth (**Figs 3–4** and **Table 2**). Earthquake of shallower depth indicate reactivation of thrust and fault largely as crustal scale adjustment, whereas at the decolliment surface similar event may be happening at the depth of mostly 35-60 km.

Figure 4 represents the temporal distribution of hypocenter depth of the major earthquake events during the period from 1900-2015. The depth of first major earthquake events occurred on 25th April 2015 was ranging from 4.0 magnitudes (*Mw*) to 7.8 *Mw.* There were 97 earthquake events of more than 4.0 *Mw.* Among these, 03 earthquake events of >6.0 *Mw* occurred between the depth of 10 km to15 km, whereas maximum number of earthquakes (59) was occurred at the depth of 10 km and ranging in magnitude from 4.4 to 5.0 *Mw*.

The aftershocks of the earthquake were recorded on 26th April 2015, where total of 21 earthquake events were occurred, and characterized as moderately high to very high magnitude (ranging from 4.0 to 6.7 *Mw*). Among these, 16 earthquake events occurred at the depth of 10 km, whereas one earthquake event occurred at the depth of 30.68 km**.** The aftershocks were recorded throughout the consecutive months in episodic manner, where magnitude >5.0 *Mw* of earthquake was reported on 27th April 2015 (at the depth of 27 km) and 02nd May 2015 (at the depth of 10km). The 2nd major earthquake event was triggered on 12th May 2015, during which 23

Table 2. Earthquake depth patterns during 1900-2015

Depth KM)	1900-2014	Jan to May 2015
<10	118	146
10 - 20	63	16
20 -30	51	5
30 -40	414	4
40 -60	76	0
60 -80	33	0
80 -100	7	0
> 100	5	0
Total	767	171

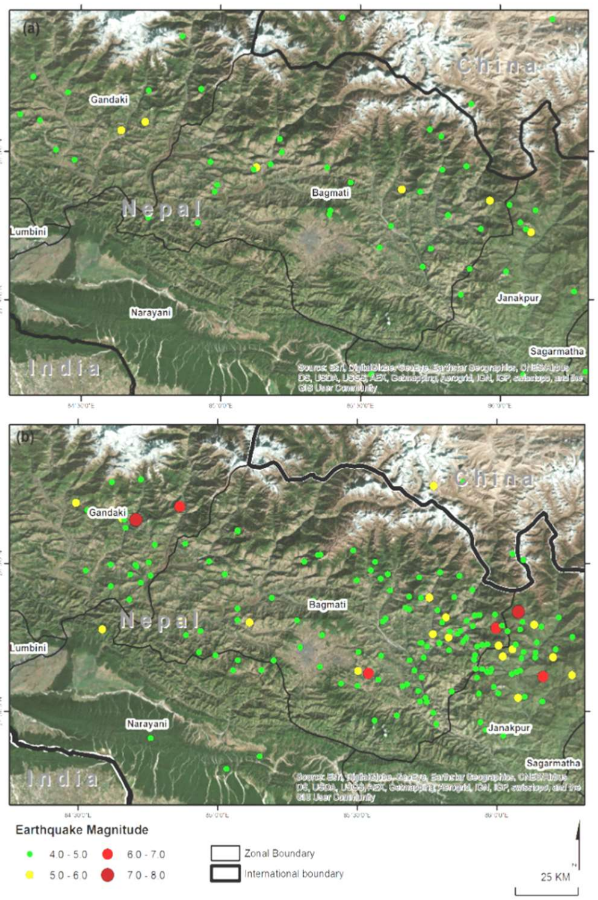

Fig. 3 Map showing earthquake depth to hypocenter (a) 1900-2014 and (b) Jan-June 2015 (*source*: USGS).

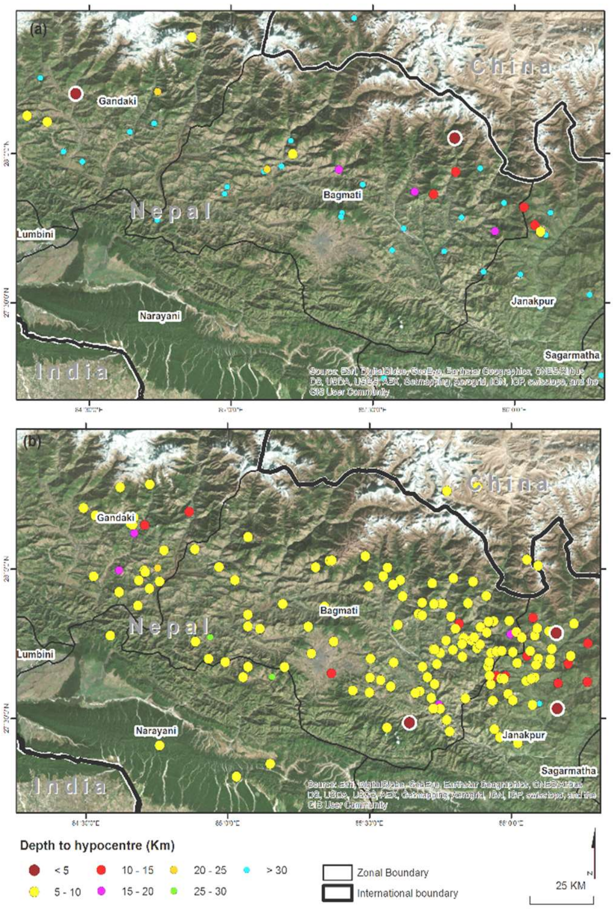

Fig. 4 Map showing spatial distribution of earthquake's magnitude in Nepal Himalayas during (a) 1900- 2014 and (b) Jan-June 2015 (source: USGS).

earthquake events (> 4.0*Mw*) were reported. Among these, 8 events occurred at the depth of 10 km having moderately high (4.2 *Mw*) to high (5.6 *Mw*) magnitudes, whereas 06 events occurred at the depth of 15 km having the high (5.0 *Mw*) to severely high (7.3 *Mw*) magnitudes. Also, deepest hypocenter of the earthquake was at the depth of 25 km having 4.2 *Mw.* The aftershocks were recorded during the entire month and the aftershocks of > 5.0 *Mw* were limited as recorded on 13th May 2015 (5.0 *Mw*) and 16th May 2015 (5.7 *Mw*) at the depth of 10 km. It is to note that the pre-shocks were recorded in January 2015 on 05th and 31st day having moderately high magnitude of 4.2 *Mw* (at the depth of 34.47 km) and 4.8 *Mw* (at the depth of 32.41 km) respectively. The activity at the depth of 32 to 34 km with moderately high magnitude exhibits high activity at the interface of Indian and Tibetan plates during the entire recurrent earthquake activity in the region.

Magnitude

The magnitude-based earthquake distribution during 1900–2014 and January - June 2015 were compared in geospatial environment. The results exhibits that the 85.8% of the activity recorded over the last 100 years occurred in the short period of 6 months, which further corroborates high rate of convergent plate movement in the region (**Figs 5–6**). The spatial distribution of earthquake events indicate that the majority were concentrated in the east and north-east to the Kathmandu city, *i.e.,* in Sindhupalchok, Dolakha and Kavre Palanchok districts.

The magnitude of earthquake events indicate that the moderaly high magnitude earthquakes (4.0–5.0 *Mw*) occurred at a maximum followed by high magnitude earthquakes (5.0–6.0 *Mw*) during 1900–2015 (**Table 3**).

The very high magnitude earthquake were occurred mainly during 1988 and 2011. On the contrary, very high and severely high magnitude earthquakes were very few during 1900-2015 but having very high and devastating impacts. It is to note that earthquake >7.0 *Mw* occurred in 1916 and 1934 during 1900-2014 period, and later in the year 2015

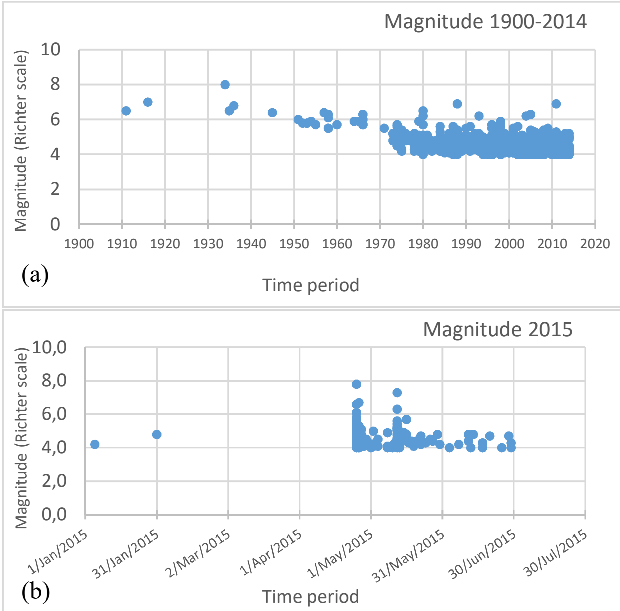

Fig. 5 Temporal distribution of earthquake and its relation with magnitude in Nepal Himalayas, occurred during (a) 1900 to 2014 and (b) 01st Jan. to 30th June 2015.

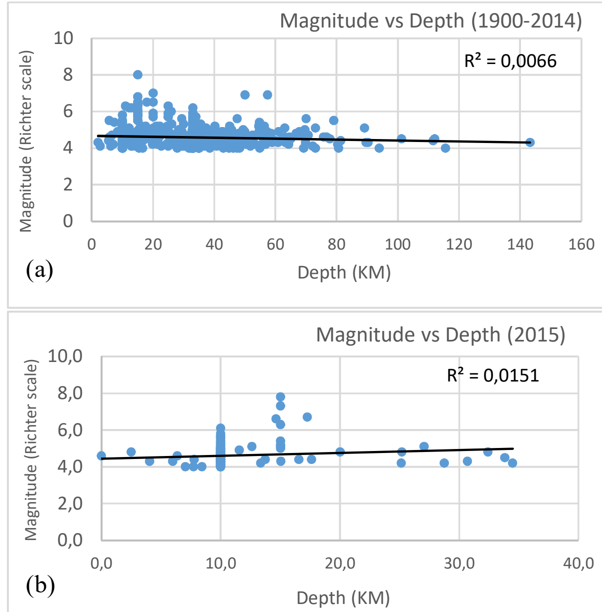

Fig. 6 Magnitude and depth of earthquake events in Nepal Himalayas occurred during (a) 1900 to 2014 and (b) January to June 2015

Table 3. Earthquake magnitude classes during 1900–2015

Magnitude	Class	1900–2014		Jan to June 2015		1900–2015
		Numbers	%	Numbers	%	% of total
< 4.0	Moderate	0	0	0	0.0	0
4.0–5.0	Moderately high	660	86.0	145	84.8	85.8
5.0–6.0	High	90	11.7	20	11.7	11.7
6.0–7.0	Very high	15	2.0	4	2.3	2.0
> 7.0	Severely high	2	0.3	2	1.2	0.4
Total		767		171		

on 25th April (7.8 *Mw*) and 12th May (7.3 *Mw*).

The frequency of depth (hypocentre) vs elevation (epicentre) of earthquake centres during 1900 to June 2015 in the Nepal Himalayas and vicinity. The results exhibits a specific location of earthquake events concentration along the plate *i.e.,* 10 km (±3km) and 30 km (± 3km). The graphical representation of earthquake depth *vs.* magnitude represents that there is no significant correlation between these two variables. Although the correlation during the 2015 was more posivite relationship as compared to the period 1900-2015 (**Figs 6a–b**).

Relief based distribution of earthquake events

The earthquake epicenters were overlaid on ASTER Global Digital Elevation Model (GDEM) and satellite image to deduce relationship of epicenter's elevation and frequency of earthquake events. It was found that majority of earthquake events (epicenters) have took place at 5 to 6 km of elevation (264 events) followed by 1 to 2 km of elevation (215 events), 4 to 5 km of elevation (166 events) and 2 to 3 km of elevation (129 events). On the contrary, the earthquake events were limited at >1 km of elevation (83 events), 3 to 4 km of elevation (61 events) and >6 km of elevation (17 events; **Table 4**).

The historical record of Himalayan earthquakes seems largely incomplete. Seismic networks along the Himalaya are currently inadequate to understand the details of seismic release, or the geometries of future slip and potential of earthquake prediction. Geological investigations of liquefaction in regions south of the Himalaya that could provide estimates of the timing of historic and pre-historic great earthquakes remain to be undertaken (Bilham *et al.,* 1995).

The recent high magnitude earthquakes in Nepal in pre-monsoon seasons created a condition of high landslide activated during monsoon seasons in Nepal Himalayas as well as high flood hazards. This may be attributed to the conditions of subsurface change during post-earthquake activity as well as development of

Table 4. Earthquake events at various depth

Elevation (km)	Earthquake events
> 1	83
1 to 2	**215**
2 to 3	**129**
3 to 4	61
4 to 5	**166**
5 to 6	**264**
> 6	17
Σ	**935**

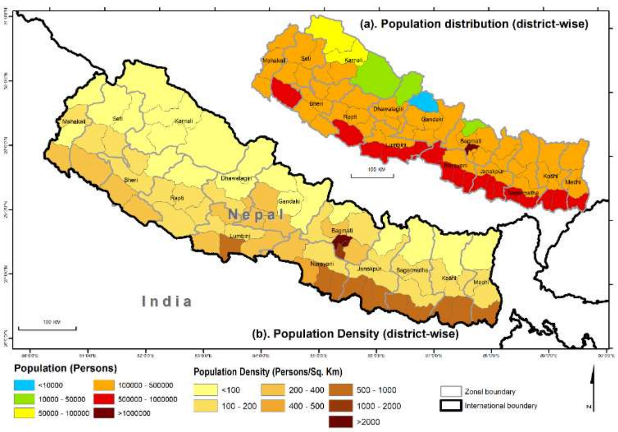

Fig. 7 Demographic status of Nepal (a) district wise population distribution, and (b) district wise population density map (Source: National Population and Housing Census 2011, Govt. of Nepal).

cracks in the bunds along the major rivers draining the region from south of Nepal Himalayas in the earthquake affected zones.

Demography and urban risk

The demography information of Nepal was collected from National Population and Housing Census 2011, Govt. of Nepal and analyzed in GIS environment. It exhibits that the districts located in the south Nepal are highly populated as compared to middle and north-western districts except Kathmandu (**Figs 7a–b**). The population distribution map of Nepal exhibits that the majority of central districts (Mahakali, Seti, Behri, Rapti, Dhalwagiri, Gandaki, Bagmati, South of Karnali and northern parts of Narayani, Janakpur, Sagarmatha, Koshi, and Mechi districts) have popualtion ranginging from 1 to 5 lakhs. On the contratry, the north-western parts of Nepal (Northen parts of Karnali, Dhalwagiri and Gandaki districts) are less populated (less than lakhs population). The southern aprts of Nepal is densely populated having population between 5 to 10 lakhs and covering southern parts of Seti, Rapti, Lumbini, Narayani, Janakpur, Sagarmatha, Koshi and Mechi districts. The Kathmandu city located in Bagmati district is having maximum population (> 10 Lakhs) and population density (> 2000 persons/km²).

The population distribution and density in Nepal is generally controlled by physiography of Himalayas. The location of urban area in Nepal Himalayan region is highly populous and severely affected by the earthquake events in different levels. The earthquake events highly affect the urban centres and induce higher risk due to its high population (**Figs 8a–b**). The cities located in central Nepal (Kathmandu, Dhading, Bhaktapur, Gorkha, Bharatpur, Ramechhap, Hetauda, Charikot, Damauli, Bahrabise, Bhimphedi, Okhaldhunga, Kodari, Landtang urban centres) are highly prone to frequent earthquake hazard and induced risk on population of 2 923 621 persons followed by north-western Nepal (Almora, Pithoragarh, Surkhet, Daileki, Jajarkot, Dandeldhura, Darchula, Dhangarhi, Simlkot, Chainpur, Silgadhi, Jumla, Sallyan, Kalapani, Chisapani, Gamgadhi, Nachani urban centres) having population of 2 385 946 persons. Also the earthquake events near south (Bhojpur, Sindhuli, Mahendranagar, Rajbiraj, Okhaldhunga urban centres) and east Nepal (Darjling, Siliguri, Dhankuta, Taplejung, Damakc, Kalimpong, Gangtok, Khandbari, Kakarbhitta, Ilam, Mangan urban centres) asserted impact on 3 656 105 and 2 872 787 population, respectively.

The total death tolls, injured population and fully/ partially damaged buildings (Govt./ private) during April-May 2015 Nepal earthquake (DNF, 2015) were used to map the total affected population and damaged buildings at district level in GIS environment. The total damages assessment in conjugation with major urban locations provided an insight of earthquake impact on the urban regions. The Kathmandu region was severely affected, where 1222 persons died and 4634 injured (total 5856; **Fig. 8a**). The districts in the vicinity of Kathmandu (*viz*., Nuwakot, Sindhupalchok, Lalitpur, Kavrepalanchok) were higly affected (2000-5000 population). The Gorkha, Dhading, Rasuwa districts were moderately high affected (500-2000 population), and influenced the urban popualtion of Landtang, Dhading, Gorkha cities. The Dolakha, Solukhumbu, Sindhuli, Makwanpur, Chitwan districts were modeately affected (100- 500 population) and influences the urban popualtion of Charikot, Namche, Lukla, Salleri, Bharatpur, Hetauda, Bhimphedi cities. The majority of districts in central, western and eastern Nepal (Rolpa, Rukum, Kaski, Lamjung, Tanahu, Nawalparasi, Parsa, Bara, Rautahat, Sarlahi, Dhanusa, Ramechhap, Okhaldhunga, Bhojpur, Sunsari, Morang, Taplejung) were less affected (>100 populations) and influenced the urban popuation of Pyuthan, Pokhara, Damauli, Birganj, Gaur, Janakpur, Ramechhap, Okhaldhunga, Bhojpur, Mahendranagar, Biratnagar, Damak Cities.

The total affected buildings indicates that Kathmandu, Kodari, Bahrabise, Gorkha cities were severeley afftected with building damage/ loss of government and private nature, located in severely (> 50000) buildings affected zone of Bagmanti and Grokha

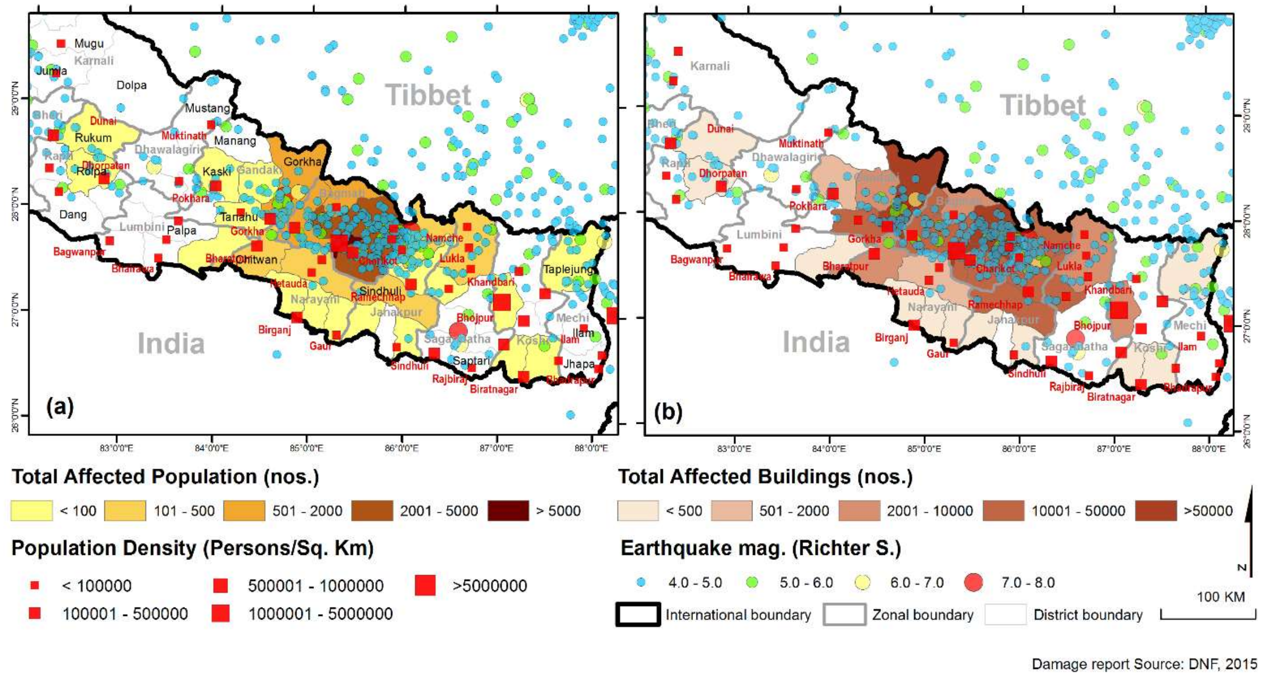

Fig. 8 2015 Earthquake footprints in urban regions as deduced from (a) district wise total affected population, and (b) districe wise total affected buildings.

provinces (**Fig. 8b**). The Damauli, Dhading, Charikot, Ramechhap, Okhaldhunga cities were highly afftected located in high (10000–50000) building affected zone of Bagmanti, N. Janakpur and S. Gandaki provinces. The Landtang, Namche, Lukla, Salleri, Bhojpur, Bhaktapur, Bharatpur cities were moderately high affected cities located in moderately highly (2000-10000) building affetced zone of Central Gandaki, N. Bagamti, W. Narayani, N. Sagarmatha and Koshi provinces. The Bhimphedi, Hetauda, and Pokhara cities were moderately low affected, which are located in the zone provinces of moderelay low (500-2000) building affected zone of N. Narayani and W. Gandaki. The Birganj, Gaur, Janakpur, Pyuthan, Jajarkot, Mahendranagar, Biratnagar, Damak cities were less affected, which are located in less (>500) building affected of zone of S. Narayani, S. Janjakpur, N. Rapti, S. Koshi and N. Mechi provinces.

Conclusion

In the present study, the Nepal earthquake events of April-May 2015 were analyzed at various levels to understand the patterns in spatio-temporal dimension, past century events and urban risk. The result indicated that the majority of earhquakes occurred in Janakpur and Bagmati provinces in Nepal druing April-May 2015, which was less active during the last one century *i.e.,* 1900-2014. The earthquake events were also observed at deeper location (more than 40 kms) during 1900-2014 as compared to the recent events (2015), where majority of earthquake events (146 events; 85.3%) recorded at below 10 km depth. Although, the technological limitation to observe and record the earthquake data by USGS during early periods of 20th Century may be possible cause to record fewer events as compared to recent periods. The results exhibits high number of recent events with greater magnitudes in central Nepal during April-May 2015 as compared to previous century (1900-2014) affecting a very large population above and around their vicinity with varied intensity. The cities located in central Nepal are highly prone to frequent earthquake hazard and induced risk on population of 2 923 621 persons followed by north-western Nepal having population of 2 385 946 persons. Also the earthquake events near south and east Nepal asserted impact on 3 656 105 and 2 872 787 population respectively. The Kathmandu region was severly affected, where 1222 persons died and 4634 injured. The districts in the vicinity of Kathmandu were higly affected (2000-5000 population) followed by Gorkha, Dhading, Rasuwa districts, which were moderately high affected (500-2000 population). The nearly insignificant proportion of earthquake events of moderate to moderately high magnitude in Nepal Himalayas over a decade also supports the seismic gap theory. The study also indicates the gap areas in Nepal Himalayas that is not active with reference to any significant earthquake since 1900 and may be a vulnerable location of major earthquake events due to the continual northward movement of Indian plate.

Acknowledgment The authors would like to express their gratitude to USGS (http://earthquake.usgs.gov/),

from where the earthquake data were downloaded and used in the present study.

REFERENCES

Bilham, R., Bodin, P. and Jackson, M. (1995) Entertaining a great earthquake in western nepal: historic inactivity and geodetic tests for the present state of strain. *Journal of Nepal Geological Society,* **11** (1), 73-78.

Chandel, V.B. S. and Brar, K.K. (2010) Seismicity and vulnerability in Himalayas: the case of Himachal Pradesh, India. *Geomatics*, *Natural Hazards and Risk*, **1**(1), 69-84

Dahal, R.K. (2006). *Geology of Nepal*, Online Available at: www.ranjan.net.np

DNF (Dalit NGO Federation) (2015) Waiting for "Justice in Response". Compiled report on Earthquake event occurred in Nepal during April-May 2015.

KMC (Kathmandu Metropolitan City Office) (2011). Kathmandu Metropolitan City. Online Available at: http://kathmandu.gov.np/ (Date of access: 21.04.2016)

Kolars, J. (1982). Earthquake-Vulnerable Populations in Modern Turkey. *Geographical Review*, **72**, 20–35.

Mitra, S., Paul, H., Kumar, A., Singh, S.K. Dey, S. and Powali, D. (2015) The 25th April 2015 Nepal earthquake and its aftershocks. *Current Science*, **108**(10), 1938-1943

NSET (National Society of Earthquake Technology) Nepal. (2015) Gorkha earthquake: Intensity maps. Online Available at: http://www.nset.org.np/eq2015/intensity_maps.php

Nyaupane, G. P. and Chhetri, N. (2009) Vulnerability to Climate Change of Nature-Based Tourism in the Nepalese Himalayas, *Tourism Geographies: An International Journal of Tourism Space, Place and Environment*, **11**(1):95-119.

Paudyal, Y. R., Bhandary, N. P. and Yatabe, R. (2012) Seismic Microzonation of Densely Populated Area of Kathmandu Valley of Nepal using Microtremor Observations. *Journal of Earthquake Engineering*, **16(**8), 1208-1229,

Prakash, R., Singh, R. K. and Srivastava, H. N. (2016) Nepal earthquake 25 April 2015: source parameters, precursory pattern and hazard assessment, *Geomatics, Natural Hazards and Risk*. doi: 10.1080/19475705.2016.1155504

Priestley, K. F. and Jackson, J. A. and McKenzie, D. P. (2008) Lithospheric structure and deep earthquakes beneath India, the Himalaya and southern Tibet. *Geophysical Journal International*, **172** (1), 345-362.

Rai D.C., Singhal V., Raj S. B. and Sagar S. L. (2016) Reconnaissance of the effects of the M7.8 Gorkha (Nepal) earthquake of April 25, 2015, *Geomatics, Natural Hazards and Risk*, **7**(1), 1-17.

Tariyal, K. (2015) Vulnerability Assessment in case of changing climate in Himalayan region. *Journal for Studies in Management and Planning*, **1**(5), 441-449.