An Overview on Geology, Tectonic Framework and Geo-Hazards in the Nepal Himalaya

Krishna P. Kaphle¹

¹Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu, Nepal

Author Note
Correspondence concerning this article should be addressed to Krishna P. Kaphle, Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu, Nepal. Email: kpkaphle@gmail.com
Abstract
The article summarizes up-to-date information on the geology, tectonics evolution, structural setup and an overall account of the geo-hazards that frequently impact the Nepal Himalaya. The Himalayan belt terminates at the Brahmaputra River in the east and the Indus River in the west, forming syntactical bands at both ends. Its evolution perceivably synchronised with the northward drifting Indian continent that collided with the relatively passive Eurasian continent during 40 - 55 Ma and gave rise to the Himalayan mountain range and the Tibetan plateau. The timing of collision is considered with the marine transgression of the Subathu Formation of Palaeocene to Lower Eocene age and complete withdrawal and cessation of marine sedimentation of the Tethyan basin in Post-Mid Eocene time. In this process, frontal northern margin of the Indian plate was deformed due to drastic collision and under-thrusting of the Indian craton with Lhasa block of Tibet, giving rise to north-dipping major thrusts, laterally yielding the Tibetan Tethys, Higher Himalaya, Lesser Himalaya, Sub-Himalaya and Indo-Gangetic plain. Nappe, klippe, and active faults played major role in the geo-dynamics of the Himalayan region. MCT, MBT and MFT come off together in a low-angle decollement and comprise as MHT. The cumulative effects of natural and anthropogenic hazards adversely impact the environment and ecosystems, besides causing immense economic loss.

JEL Classification: Q50, Q54
Keywords: Nepal Himalayas, geology, tectonics, thrusts, geo-hazards, climate change

Acknowledgements: I would like to extend my sincere thanks to all the members of the organizing committee of the International Conference on “Recent Developments in Earth & Environmental Science, Natural Resources Management and Climate Change with special focus on Eastern Himalaya” who had invited me as a guest speaker to present this paper. My special thanks go to Prof. Dr. V. C. Tewari, Sikkim University, who kept us informed about the conference program in advance and also about the schedule change due to Covid-19, and continued motivation to present and write this paper. I am indeed so much indebted to Prof. O. P. Varma, senior most Earth Scientist in India, who so critically edited and amended the MS painstakingly for publication. My special thanks also go to Dr. Santa Man Rai for going through the manuscript before final review and his advice to publish it in the Journal of Development Innovations (JDI) in Canada.
1. Introduction

1.1 Location, Physiography and Climate

The Himalayas are the loftiest and the youngest mountain belt on the earth, which extends 2500 km in WNW - ESE orientation and terminate at the Indus River in the western and the Brahmaputra River in the eastern syntaxial bands, becoming convex towards south. Nepal lies in the central part of highly seismic and tectonically active Himalayan belt and occupies almost one-third of the Himalayan range (Figure 1). Out of the ten highest mountain peaks, over 8,000 m high, eight including Mount Everest (the highest peak, 8,848 m), are in Nepal. Nepal is a landlocked mountainous country of 147,553 km² area and flanked by China (Tibet) in the north, and by India in the south. Due to abrupt changes in topography from flat Terai plain to high mountains, there is extreme climatic variation from sub-tropical, temperate, subalpine, and alpine climate within a short distance of 200 km from south to the north (Figure 2). As a result, biodiversity is markedly prominent. Monsoon is very active from mid-June to mid-October, and more than 85% of the total rainfall occurs during this period of the year. Flood and landslide disasters commonly occur during the monsoon season.

Figure 1

Location of the Nepal Himalaya and the Himalayan Region (modified by Kaphle, 2013)

Figure 2

Morpho-geotectonic Divisions from South to North and Climatic Zones in the Nepal Himalaya (modified after Hagen, 1969 and Kizaki, 1994)

Note: Ganges Allv = Ganges Alluvium, HH = Higher Himalaya, HHG = Higher Himalayan Gneiss, MBT = Main Boundary Thrust, MCT = Main Central Thrust, MFT = Main Frontal Thrust, STD = South Tibetan Detachment
1.2 Evolution of the Himalayas

Evolution of the Himalayas perceivably synchronised with the northward drifting of the Indian continent (about 135-150 Ma ago) that collided with the relatively passive Eurasian continent during 40 - 55 Ma. The collision of the two sub-continents and subduction of the Indian plate under the Eurasian plate gave rise to the Himalayan mountain range and the Tibetan plateau (Heim & Gansser, 1939; Gansser, 1964, Dewey et al., 1989; Masce et al., 2012) (Figure 3). The timing of the collision is generally considered with the marine transgression of the Subathu Formation of Palaeocene to Lower Eocene age in the Lesser Himalaya, and the complete withdrawal and cessation of marine sedimentation of the Tethyan basin in Post-Mid Eocene time. The frontal northern margin of the Indian plate was highly deformed due to drastic head-on collision and continued convergence against the Eurasian plate. Underthrusting of the Indian craton with Lhasa block of Tibet gave rise to major thrust structures and regional metamorphism, accompanied by leucogranites and migmatites. Northward movement of the Indian plate and subduction is continuing under the Eurasian plate and the Himalayas are still rising. Convergence between the two continental blocks has remained active, stress has built up, and as a result, thrusting and faulting continually take place. Releasing of the built-up stress creates significant seismicity with large magnitude earthquakes (Mw >8) in the Himalayas and the Tibet plateau (Pandey et al., 1995). Nepal Himalaya (central part of the Himalayan range) lies in the collision zone between the Indian and the Eurasian continents. It is made up of thick tectonic stacking of sedimentary and metamorphic rocks with some granite intrusions (22 – 12 Ma) that resulted from the drastic collision and under-thrusting of the Indian craton below the Lhasa block of Tibet.

Figure 3
Regional Geological Map of the Himalayas showing N-S Major Tectonic Zones (Gansser, 1964)

2. General Geology of the Nepal Himalaya

A number of foreign and Nepalese geologists from the Department of Mines and Geology (DMG), Nepal and universities of Nepal and abroad have investigated the geology and tectonics of the Nepal Himalayas since 1935, mainly from 1961 onward. Because of their research works, the geology, structure, seismo-tectonics and mineral resources of the Nepal Himalaya are well understood, although connected with each other in a complicated manner. In central and western Nepal, there exist quite a few thrust sheets which occupy the cores of the major synclines, forming crystalline nappe and klippe in the Lesser Himalaya as Kathmandu nappe (Hagen 1969;
Stöcklin & Bhattachari, 1977); Dadeldhura nappe (Kaphle, 1992; Bashyal, 1986; Amatya & Jnawali, 1996); Karnali nappe (Fuchs, 1974, 1977); Jajarkot klappe (Frank & Fuchs, 1970); and Kahun klappe (Paudyal & Paudel, 2013). Similarly, there also exist a few tectonic windows like Okhaldhunga, Arun and Taplejung windows in eastern Nepal, where underlying low-grade metamorphic rock units of the Lesser Himalaya are well exposed (Figures 4 & 4a). On the basis of geology and tectonic elements, the Nepal Himalaya can be divided into five distinct morpho-geotectonic divisions (Kaphle, 2013; DMG/ Amatya & Jnawali, 1996; Upreti, 1999), as shown in Figure 4, separated from each other by major prominent thrust/fault contacts from north to south, as presented in the following stratigraphic column:

North

Inner Himalaya (Tibetan - Tethys Zone)  
--------South Tibetan Detachment System (STDS) --------
Higher Himalaya (Higher Himalayan Crystalline Zone)  
--------------------------------- Main Central Thrust (MCT) ---------------------------------  
Lesser Himalaya (Mahabharat Range and Mid Valleys)  
----------------------- Main Boundary Thrust (MBT) -----------------------  
Sub-Himalaya (Siwalik Hills and Dune Valleys)  
-------- Main Frontal Thrust (MFT)/Himalayan Frontal Thrust (HFT) ----

South

Terai Plain (Northern fringe of Indo-Gangetic Plain)

Figure 4


Note: HH = Higher Himalayan Crystalline, LH = Lesser Himalayan Metasediments, MBT = Main Boundary Thrust, MCT = Main Central Thrust, MFT = Main Frontal Thrust, SH = Sub-Himalaya/Siwaliks, STDS = South Tibetan Detachment System, TP = Terai Plain, TT = Tibetan Tethys sediments

Figure 4a

Geological Cross Section of Eastern Nepal (From SSE to NNW)
2.1 Major Tectonic Units

Each thrust forms the boundary line between the two consecutive zones, playing the major role in the geo-dynamics of the Himalayan region. Thrusts progressively are younger towards south from MCT - MBT - MFT, respectively (Figure 4). The Indus-Tsangpo Suture Zone (ITSZ) forms the northern boundary with the Eurasian continent. It is marked by a depression from which headwaters of Indus River originate flowing westwards and the Tsangpo River flowing to the east (Figure 3). On the margin of the Indian subcontinent, foreland sedimentary basin began to develop in the Late Eocene time. The Sub-Himalayan (Siwaliks) Zone is occupied by the Himalayan foreland basin deposits, represented by thick beds of folded and faulted molasses sediments (Mid-Miocene to Pleistocene) and form the Siwalik range as the Himalayan mountain front. It abruptly rises along the MFT which is the youngest and the southernmost thrust that separates the Terai plain with overlying Siwalik sediments.

Terai is the northern fringe of Indo-Gangetic foreland basin which is underlain by over 1000 - 1500 m thick Quaternary sediments overlying the Tertiary molasses deposits, designated as the Siwalik Groups. Below that lies the Pre-Siwalik rocks. The Lesser Himalaya has thrust over the Siwalik rocks of the foreland basin along the MBT. It sharply separates the Siwaliks from the complex Lesser Himalayan zone which consists of predominantly metasedimentary rocks of the Nawakot Group (Proterozoic to Paleozoic), Gondwana Group (Permo-Carboniferous to Lower Cretaceous), and at places fossiliferous sedimentary sequence of the Tansen Group (Upper Cretaceous to Lower Miocene; Sakai, 1983), which is an equivalent to the Surkhet Group further west. At places, the MBT is locally upset by transverse faults. The Lesser Himalayan zone is characterized by stacking of crystalline nappe/ klippe that were transported from far north and now appears as large nappe mass. Kathmandu nappe is represented by the rocks of the Phulchauki Group (Cambrian to Devonian) and Bhimphedi Group (Pre-Cambrian to Early Cambrian) of the Kathmandu Complex (Stöcklin & Bhattarai, 1977; Stöcklin, 1980).

In the Crystalline Nappe of the Lesser Himalaya, quite a few East-West elongated porphyritic two mica granite bodies in the central part and orthogneisses in the periphery (Cambrian to Ordovician age) occur. These granite bodies of various shapes and sizes are named as Dadeldhura granite (470±5.6 Ma, Einfalt et al., 1993) and Khaptad granite in far-western Nepal; Agra/ Simchar granite (500±56 Ma, Le Fort et al., 1983); Palung granite (486±21 Ma, Be Kinsley in Mitchel, 1981); Ipa, Naranthan, Sindhuli, Udaypur granites in central Nepal (Figure 4) and only one known alkaline rock as Ampipal nepheline syenite at Gorkha in Central Nepal (Pêcher & Le Fort, 1977; DMG, 1987; Dhital, 1995). These granites can be correlated with
Champawat granodiorite of 560±20 Ma in age (Trivedi et al., 1984); South Almora granite of Kumau (550 Ma, Trivedi et al., 1984); Dalhousie granite (456±50 Ma), and Mandi granite (507±100 Ma, Jager et al., 1971) of Himanchal Pradesh in India; and Manserah granite (516±16 Ma, Le Fort et al., 1980; Shams, 1983) of Hazara in Pakistan. All these Lesser Himalayan granites resemble in their physical appearance, petrological, geochemical, structural characteristics and age (Kaphle, 1992 & 1994) and also reflect that they have similar magmatic and metamorphic history and their mineral potential.

The Mahabharat Thrust (MT), a southernmost extension of the MCT separates the rocks of the Kathmandu Complex (Pre-Cambrian to Devonian age) from the Lesser Himalayan Nawakot Complex (Late Pre-Cambrian to Paleozoic age, Stöcklin & Bhattarai, 1977; Stöcklin, 1980). In eastern Nepal, Okhaldhunga, Arun and Taplejung tectonic windows are well recorded where underlying low-grade metamorphic rock units of the Lesser Himalaya are exposed due to deep erosion (Figures 4 & 4a). In central Nepal at Ampipal - Champ Bhanjyang area in Gorkha, there exist few exposures of Nepheline syenite bodies (Pêcher & Le Fort, 1977; DMG 1987; Dhital, 1995) in the Kunchha - Gorkha anticlinorium (DMG/Amatya & Jnawali, 1996, Figures 4 & 4b). Nepheline Syenite bodies are intruded in Kunchha Formation but exhibit the same foliation and lineation trend as in the country rocks indicating that they are intruded before the development of foliation in the Kunchha Formation (Dhital, 1995).

Main Central Thrust (MCT) separates the Higher Himalayan crystalline rocks from the Lesser Himalayan metasedimentary rocks (Figure 4). The Higher Himalaya is represented by high grade crystalline rocks metamorphosed under amphibolite to granulite facies of Pre-Cambrian age. The Greater/ Higher Himalayan thrust sheet represents the hanging wall of the MCT. In Nepal, the thrust sheet forms two large open folds: the Great Midland Antiform in the inner zone and the Great Mahabharat Synform in the outer part (Dhital, 2015). The interplay among thrusting, erosion and folding has created a complex pattern of tectonic windows and klippen. In Annapurna-Manaslu Himalaya region the Higher Himalayan crystalline has been divided into three formations by Colchen et al. (1986) as Formation-I, Formation-II and Formation-III from lower section to upper section, depending on the grade of metamorphism and lithology.

Tibetan - Tethys Himalaya is represented by a sedimentary sequence up to 10 km thick of upper Proterozoic to middle Eocene age. It is separated from the Higher Himalayan crystalline rocks by the South Tibetan Detachment System (STDS) to the south. Ordovician limestone in this Himalaya forms some of the highest peaks, e.g., Annapurna and Mount Everest. Ammonite fossils around Damodarkund in the upper part of Kaligandaki valley; Lupra village, north-east of Jomsom Bazaar and Jharkot village, immediate west of Muktinath along the Kaligandaki valley and methane gas seeps through the cracks in the rocks at Muktinath are recorded.

3. Geology of Different Regional Units of Nepal

3.1 Central Nepal (Kathmandu and Surrounding Regions)

Geology of this region has been investigated by a number of geologists from Department of Mines and Geology (DMG), Nepal and foreign geologists for a long time. Auden (1935) was one of the earliest geologists who visited the eastern and central Nepal. Hagen (1969), Talalov (1972) and many Nepalese geologists investigated the Geology and Mineral resources of Nepal. Stöcklin & Bhattarai (1977), Stöcklin (1980) established its stratigraphy and published a geological map of Kathmandu area and Central Mahabharat Range (southern part) clearly showing the rock units in the Kathmandu Crystalline Nappe (KCN) and the Lesser Himalayan Nawakot Complex (Figure 5). Further north, Upeti & Le Fort (1999) and Rai (2001) conducted detail geological investigation and published the map (Figure 5) of the Gosainkund Crystalline Nappe (GCN), an equivalent unit to the Higher Himalayan Crystalline.
Similar to the Kathmandu Crystalline Nappe, there exist Dadeldhura Crystalline Nappe, Karnali Crystalline Nappe, Jajarkot Klippe and Kahun Klippe in the Lesser Himalaya. The MCT carries the Higher Himalayan Crystalline rocks (Pre-Cambrian) over the low-grade metasedimentary rocks of the Lesser Himalaya (Late Precambrian to Paleozoic). North of the MCT, the Higher Himalayan Crystalline rocks (5-10 km thick) form the metamorphic Proterozoic basement that support the Tibetan sedimentary sequence (Cambrian - Eocene) and represents a part of upper crust that has been reactivated due to crustal shortening as a result of continent collision during the Himalayan orogeny.

Figure 5

Geological Map of Kathmandu area, Central Mahabharat Range and Gosainkund Area showing Rock Units in the Lesser Himalaya (LH), Kathmandu Crystalline Nappe (KCN, Stöcklin & Bhattarai, 1977; Stöcklin, 1980; Upreti & Le Fort, 1999; and Gosainkund Crystalline Nappe - GCN, Rai, 2001).

Note: GCN = Gosainkund Crystalline Nappe; KCN = Kathmandu Crystalline Nappe; LH = Lesser Himalaya

Beneath the MCT, the metamorphic grade of the rocks increases upward gradually and northwards (Le Fort, 1975) from muscovite/chlorite grade in the Kunchha Formation, lowermost section of the Lesser Himalaya (Lesser Himalayan Zone) through biotite to garnet-grade in schist to the upper section of the Lesser Himalaya. It is believed that reverse metamorphic isograde resulted from subsequent downward conductive heating from the overlying Higher Himalayan Crystalline to the underlying Lesser Himalaya during the MCT movement (Le Fort, 1975). The Indo-Tibet collision is believed to be still active. Indus Tsangpo Suture zone (ITS) is evidence of the collision zone. Gosainkund Crystalline Nappe (GCN) lies to north of Kathmandu valley and to the Lesser Himalaya (Le Fort, 1975) is represented by high-grade metamorphic rocks (Figure 5) like paragneiss, augen gneiss, garnet-mica-schist, migmaitite, calc-silicate gneiss, marble and quartzite of amphibolite - granulite facies (Rai, 2001).

3.2 Annapurna - Manaslu Himalaya Region

In Annapurna - Manaslu Himalaya region, the Higher Himalayan Crystalline can be divided into three formations (Colchen et al., 1986). Formation-I (Lower part of the section) which is 2-10 km thick and is represented by alternations of quartzo-feldspathic gneiss,
micaceous gneiss and migmatitic gneiss. In this section, kyanite changes to sillimanite, migmatitic leucosomes appear locally. Eclogite-granulite transition are observed in boudins in migmatitic gneiss. **Formation-II** is the middle part, which is up to 3500 m thick. It is represented by calcareous gneiss interbedded with layers of quartzite and marble. **Formation-III** is the upper part which is up to 300 m thick. Large augens of microcline feldspar with plagioclase, quartz and mica are the mineral constituents of the gneiss. The intensity of metamorphism decreases upwards (Colchen et al., 1986; Mascle et al., 2012)., Colchen et al. (1986) studied this area in detail and prepared a geological map and vertical sections. According to them, there exists a Main Central Thrust zone which is marked at the basal part by Lower MCT-I and upper part by Upper MCT-II, which are named as Munsiari Thrust, and Vaikrita Thrust, respectively in the Indian Himalaya. And, actual high grade crystalline tectonic unit, i.e., the Greater Himalayan sequence lies over MCT-II (Arita, 1983). STDS separate the high-grade metamorphic rocks of the Greater Himalayan sequence (Higher Himalayan Zone) from the Tibetan - Tethys sedimentary sequence (Tibetan - Tethys Zone).

### 3.3 Kaligandaki Valley

South Tibetan Detachment System (STDS), a normal fault, separates the fossiliferous Tibetan - Tethyan sedimentary sequence to the north from the Higher Himalayan Crystalline rocks to the south. The Tibetan - Tethyan sedimentary sequence forms some of the highest peaks in the Himalayas. Several intrusions of tourmaline-bearing leucogranite of Tertiary age (22 - 12 Ma) are associated with the crystalline rocks. Tibetan - Tethyan sedimentary sequence is represented by a sedimentary sequence over 10 km thick (Figure 6) of upper Proterozoic to Middle Eocene age (Upreti & Yoshida, 2005). In the source area of Kaligandaki River around Damodarkund and surrounding areas of Muktinath, there exist pyritized ammonites shell molds (Ammonite fossils, locally, known as Shaligram). Rarely floats of such fossils can also be seen in the Kaligandaki River course. At Padukasthan in Dailekh, natural gas seeps are also coming out through the cracks for years, which can also be seen in Jwalamai temple at Muktnath; however, detailed investigations regarding its source rock, reservoir rock, and possible petroleum and natural gas reserves of economic potentiality for extraction and use have not yet been carried out by GON/ DMG. There is a high possibility to find radioactive minerals, high-grade dolomite deposits, gypsum and common salt in Mustang and in some parts of Manang, Dolpa and Lamjung districts (Kaphle, 2020, 2018).

**Figure 6**

*Geological Cross Section from Beni – Kokhethati showing the Major Structures, separating the Lesser Himalaya, Higher Himalaya and Tibetan - Tethys Zones (Upreti & Yoshida, 2005)*

---

*Note: DKT = Dwarika Khola Thrust, MCT = Main Central Thrust, STDS = South Tibetan Detachment System*
3.4 Jajarkot Area, Western Nepal

The Jajarkot Crystalline Klippe forms a synform structure as a whole, cut off by faults on both flanks. It is transported from the MCT zone, lying to the north, covering the older Midlands (Arita et al., 1984). The rock unit of the Jajarkot Crystalline Klippe is divided from bottom to top into: (a) Chaurjhari Formation, (b) Thabang Formation, and (c) Jaljala Formation. Chaurjhari Formation is mainly represented by grey to light greenish mica-schist and garnet-mica schist with minor intercalations of light to dark colored quartzite (Frank & Fuchs, 1970; Fuchs, 1977). The contact between the Chaurjhari Formation and the Thabang Formation is gradational. The Thabang Formation is characterized by the coarse-grained crystalline impure marble, interbedded with mica schist. The Jaljala Formation overlies the Thabang Formation, separated by an unconformity (Paudyal & Paudel, 2013). It is the youngest unit of the klippe and represented by fine- to medium- grained calcareous sandstone and siltstone with some intercalation of gray phyllite.

3.5 Karnali Nappe

Karnali Nappe is represented by high-grade metamorphic rocks. Outcrops of these rocks can be traced along the Karnali and Tila River sections over an area of about 5000 sq. km (Hayashi et al., 1984). Karnali Nappe is separated from its root zone by a few km of intervening Lesser Himalayan rocks (Fuchs, 1974, 1977). The rock unit of this nappe consists of kyanite-sillimanite bearing gneisses, and magmatic augen gneisses (Hayashi et al., 1984), which are quite similar to the rock units of the Higher Himalayan Crystalline zone. In the core of the Karnali Nappe lies an almost 1500 m thick carbonate sequence composed of calcareous biotite-schist with psammitic and pelitic schists.

3.6 Dadeldhura Nappe and Adjoining Areas

Dadeldhura Crystalline Nappe is the eastward extension of Almora Nappe (Bashyal, 1986; Kaphle, 1992, 1994, 1997; Kaphle et al., 1998), which is possibly an equivalent to the Kathmandu nappe (Stöcklin & Bhattarai, 1977). From north, the allochthonous Dadeldhura Crystalline Complex is thrusted over the parautochthonous Bunder Metasedimentary Complex/Bunder Metasedimentary Group (BDR) consisting of low-grade various colored phyllite, quartzite, slate, quartzitic chlorite mica-schist and few minor amphibolite bodies. The Dadeldhura Crystalline Complex (DCC) is bounded by North Dadeldhura Thrust (NDT) and South Dadeldhura Thrust (SDT) (Upreti, 1990; Kaphle, 1992, 1994, 1997). Towards south, the Bunder Metasedimentary Complex (BMC) comes in contact with the Tertiary Siwalik sedimentary rocks separated by the MBT (Figures 4c and 7).

Dadeldhura granite has been emplaced as an intrusion into low-to-medium grade metamorphic rocks (green schist-amphibolite facies) of Dadeldhura Crystalline Group of Pre-Cambrian in age. This group is divided into Sirsegad Formation (SGD), Gaira Formation (GRA), Bherupani Formation (BPN) and Raduwagad Formation (RGD), respectively represented by phyllite, quartzite, slate, sericitic chlorite mica-schist; garnetiferous mica-schist, gneiss, quartz-feldspathic mica schist and amphibolite; phyllite and slate; greenish gray silicified phyllite and sericitic quartzite (Figure 7). The granite body occupies the central part of the nappe and it is divided into (1) Gneissic granite (GGR) towards periphery which is strongly deformed and shows augen structure; (2) massive porphyritic Biotite granite (BGR, biotite dominant) in the inner part, (3) small bodies of Muscovite granite (MGR, muscovite rich) towards core and minor bodies of aplitic (4) Tourmaline granite (TGR) (Kaphle, 1992, 1994).
**Figure 7**

*Geological Map of Dadeldhura and Adjoining Areas, Far-Western Nepal (Kaphle, 1992, 1994, 1997)*

As in central Nepal, Dadeldhura granite is a cordierite bearing two mica granite which is gneissic towards the periphery and massive in the center/core (Kaphle, 1992 & 1994). Few small scattered simple pegmatite/aplite bodies also occur within the granite. Apophysis, greisenization and development of hornfelsic rock at the contact with country rock are observed only in few places, however, xenoliths are quite common. To the north-east side of the syncline, unfossiliferous metasediments of the Damgad Metasedimentary Group (DMG) is separated from Dadeldhura Crystalline Group by a partially developed unconformity, marked by 2-3 m thick...
pebble conglomerate bed. This group is divided into Damgad carbonate (DLL) consisting gray dolomite with bluish gray limestone bands, and Dhanekhola quartzitic sandstone (DQS). Northern exo-contact zone of the Dadeldhura granite with Raduwagad Formation (RGD) is the prospective target for polymetallic mineralization (Cu, W, Mo, Bi and ± Au & Ag) at Bamangaon, and tin mineralization (cassiterite associated with pyrite in quartz veins) at Meddi (Figure 7; Kaphle, 1992, 1994, 1997).

3.7 Pokhara and Kathmandu Valleys

The Pokhara Valley is located 200 km west of Kathmandu City. It is a tectonically controlled valley (Gurung, 1970) and appears as an intramontane basin situated in the middle mountains on the southern foothills of Annapurna and Machhapuchhre Himal in Western Nepal. Bedrocks comprising metamorphic as well as metasedimentary rocks are well exposed on the hillslopes around the basin. Large-scale debris flow, rock and ice avalanche that occurred in the far north mainly in the Annapurna region, have come down along the Seti River and deposited on the floor of the Pokhara Valley (Kaphle & Koirala, 1998; Kaphle, 2002; Kaphle et al., 2008). These valley-fill deposits are the result of three episodes of gigantic debris flow events (Koirala & Rimal, 1996; Hanisch et al., 1996; Koirala et al., 1997, Figure 8), possibly associated with global warming process during Quaternary time (Kaphle & Koirala, 1998) and named them, from bottom to top, as Tallakot Formation (>20,000 years, before present (B.P.); Ghachok Formation (12,000±1000 years B.P.); and Pokhara Formation (750±50 years B.P.) (Koirala et al., 1997, Figure 8). Remnants of debris flow deposits by the side of Seti River and in Pokhara Valley are the evidence of recurrence history of debris flow events at Pokhara.

Karstification is widespread in the form of sink holes (Figure 9), caverns (Gupteshor & Chamere caves) and subsoil pinnacles, mainly in Ghachok Formation (Koirala & Rimal, 1996; Kaphle, 2001). There is high risk of subsidence at these locations, where the overlying soil of Pokhara Formation is thin (Koirala & Rimal, 1996; Kaphle, 2001). Damming of the Seti River during debris flow blocked the tributary streams and developed many lakes, the major ones being Phewa, Begnas and Rupa. In May 2012, flood disaster in Pokhara that occurred due to debris-flow event, caused by huge rock-fall onto a glacier in the Sabche Cirque, a high-mountain from the steep western slope of Annapurna IV Mountain and then transformed into a subsequent debris flow along Seti Khola/ Seti River (Hanisch et al., 2013).

Figure 8

Geology of Pokhara Valley and Three Terraces Deposited by Three Different Episodes of Debris Flow Events in Pokhara Valley as the oldest is Tallakot Formation (TL), Ghachok Formation (GH) and youngest Pokhara Formation (PK), respectively (Koirala et al., 1997)
The Kathmandu Valley is an intramontane basin located in the Lesser Himalayan region in Central Nepal. Bedrocks are exposed mainly on the hill slopes around the basin and only at very few places in the valley floor. The valley-fill sediments comprise of thick semi-consolidated fluvio-lacustrine Quaternary sediment deposits (Figure 10) lying over the basement rocks (limestone, dolomite, slate, marble, schist, phyllite, and quartzite) of the Phulchauki Group of Pre-Cambrian to Devonian age (Kaphle & Joshi, 1998). Drill holes data from different parts of the valley-fill sediments confirm that the maximum thickness of the sediment is up to 570 m at Bhrikutimandap (DMG, 1996). Ground water, sand, lignite and methane gas are currently exploited from different parts of the valley-fill sediments. DMG has already explored 26 km$^2$ of the Kathmandu Valley and proved 316 million m$^3$ methane gas reserves, usable for industrial and household purposes (DMG, 1996).

4. Tectonic Evolution and Structural Setup

4.1 General Statement

Continent drifting started at about 200 Ma before the present. In about 180 Ma, the Indian plate separated from Antarctica and Australia and then started moving northward. At about 135 Ma ago, the Indian continent was a large island situated off the Australian coast. Tethys Sea was located in between the Indian continent and the Asian continent. About 80 - 65 Ma ago, Indian landmass was located just south of the Asian continent and was moving further northward at a rate of about 20-56 mm/year. Eventually, the Indian plate collided with the Eurasian plate at about 55 - 40 Ma ago, as a result, Himalayas was formed. Collision and uplifting of the Himalaya had started in early Miocene. The Himalayan mountain range constitutes the northern plate boundary of the Indian plate that started rising at a rate of about 4 to 15 mm/year.

The Himalayan belt comprises of structural units that are separated from each other by major discontinuities like thrusts and faults. Indus Tsangpo Suture zone (ITS) is the northern boundary between the Indian and the Eurasian plates (Figure 3; Gansser, 1964). Northward drifting of the Indian plate eventually led to the collision with Eurasian plate in Eocene time and closure of intervening Tethys Sea and rise of the Himalayan Range (Mitchel, 1981). Tethys Himalaya (Tibetan - Tethyan sedimentary sequence), a northernmost tectonic unit of the Himalaya was separated from the crystalline basement along the STDS. There also exist some
Blind Thrusts below the Terai plain. Seismic data show a significant seismicity with large magnitude earthquake (>8 Mw) in the Himalaya and Tibet. To the north of the Higher Himalaya and in Tibet, focal mechanisms exist being extension or strike-slip type, with WNW-ESE to E-W extension.

4.2 Major Thrusts and Faults

The Higher Himalaya is over thrusted on the Lesser Himalaya along the MCT which brought the Higher Himalayan crystalline rocks over the Lesser Himalayan metasedimentary rocks. The tectonic evolution of the MCT has a direct bearing on the understanding of the amount of N-S crustal shortening and the upheaval and exhumation history of the Himalaya (Upreti & Le Fort, 1999). The Mahabharat Thrust (MT) separates the rocks of the Nawakot Complex from the rocks of the Kathmandu Complex in the south, where it joins the MCT in the north of Kathmandu and appears as the southward continuation of the MCT (Figure 5).

The Lesser Himalaya is over thrusted on the Siwaliks along the MBT which is a low angle reverse fault that brought the older Lesser Himalayan rocks over much younger Siwalik rocks (Figures 4 & 5). The Sub-Himalaya/ Siwaliks are limited to the north by the MBT and in the south by the MFT (Figure 4). The MFT separates the Siwalik rocks from the Quaternary Terai sediments. All these MCT, MBT and MFT join each other at depth in a flat-lying decollement (Figure 11), known as Main Himalayan Thrust (MHT). Decollement is a major crustal break separating upper and lower continental crusts of Indian plate (Pandey et al., 1995). Compressive deformation in the Himalaya led to the development of foreland sedimentary basins on the northern margin of the Indian Peninsula just after the collision of northward drifting Indian plate and relatively passive Eurasian plate. By Mid-Miocene thrusting, the MCT (Figures 12 & 13a) had emplaced crystalline klippe over the low-grade Lesser Himalayan metamorphic rocks. This led to down warping in front of the advancing thrust-sheets giving rise to deposition of rocks of the Siwalik Group in foreland basin. By the end of Pliocene, all the major structures of the Himalaya had been developed. The MBT juxtaposes the Pre-Siwalik rocks in the hanging wall with much younger deposits of Siwalik Group in the footwall (Figure 13b). Terai, the northern fringes of Indo-Gangetic plain, lies in the northernmost edge of Ganga basin and Purniya basin. The MFT marks the frontal topographic break of the Himalaya. At present main tectonic displacement zone is MFT, which is most active for future earthquake.

**Figure 11**

**Geological Cross Section of the Himalaya (Pandey et al., 1995)**

![Geological Cross Section of the Himalaya](image.png)

*Note: MBT = Main Boundary Thrust, MCT = Main Central Thrust, MFT = Main Frontal Thrust, MHT = Main Himalayan Thrust, STD = South Tibetan Detachment*
4.3 Active Faults

Nakata (1988) has mapped many active faults in different parts of Nepal. Most of these active faults are distributed along the major tectonic boundaries like MCT, MBT and MFT (Figures 12, 13a & 13b), which are associated with the upheaval of the Himalayan range. Quite a few active faults present around Kathmandu include the Kathmandu south fault, Chitlang - Kulekhani fault, Jhiku Kholo fault, Kolpuf Kholo fault and Sunkoshi - Rosi Kholo fault (Figure 12). Beside these, there are few other active faults like Badigad fault (Nakata, 1988; Kizaki, 1994), Falebas thrust and few other thrusts in the Lesser Himalaya and Talphi fault in the MCT zone (Nakata, 1988). Higher terraces along the Kalgandaki Valley are the result of the last glacial epoch about 18,000 yr. B.P. (Nakata, 1988). These active faults frequently trigger earthquakes.
5. Geo-hazards in the Nepal Himalaya

Continuous geodynamics and seismic activities in the Himalayas and the existence of many active thrusts and faults frequently trigger the earthquakes of different magnitude. Micro-seismic activities are intense in the eastern and the far-western Nepal (DMG/NSC, 2006). Major historical earthquakes, namely 1905 Kangara/ India (8 Mw); 1934 Nepal-Bihar earthquake (8.3 Mw); 1950 Assam/ India (8.5 Mw); 2005 Kashmir/ Pakistan (7.5 Mw) and 2015 Gorkha earthquake/ Nepal (7.8 Mw) provide evidences of the active tectonics and warning of the possible future earthquakes in the region. Geo-hydro-meteorological hazards, such as floods and windstorm in Terai; landslides in the Lesser Himalayan and Sub-Himalayan regions are active mostly during the monsoon season. Debris-flow, GLOF and Ice/ rock avalanche in the Higher Himalaya; and earthquakes, draught and windstorm in the Inner Himalaya also trigger frequent disasters (Kaphle, 2013). Alongside, the presence of highly fractured rocks, steep slopes, and haphazard road cuttings, improper infrastructure development, cultivation on high-slope and fossil landslides in the tectonically active zones, and heavy monsoon rains have triggered landslides year after year. Moreover, sink-holes and land subsidence are common, primarily in Pokhara, Hengja and Kusma areas (Kaphle, 2001). The cumulative effects of all these hazards adversely impact the environment and the ecosystems, besides causing immense economic loss. In the following sections, light is thrown on these hazards and some remedial measures are suggested.

5.1 Earthquakes - An Overview

Nepal Himalaya is prone to different types of hazards because of its location in the central part of the Himalayan belt as well as its complex geology, rugged topography, and continued geodynamic activities. The residents of this region, as a whole, are vulnerable to earthquake. Most earthquakes occur to the south of the MCT. The Department of Mines and Geology has well equipped National Seismological Center (NSC) to locate the epicenter of the earthquakes and measurement of intensity (DMG/NSC, 2006). Only the earthquake of >4 Mw are announced through the media. Earthquakes are categorized as Moderate (EQ 6 Mw), Large (EQ >7 Mw) and Great (EQ >8 Mw) (Figure 14). In the world scenario, among 200 countries, Nepal stands at 11th position with respect to earthquake hazards and 30th to the flood and landslide hazard (UNDP/BCPR, UNDP, 2004 study report, UN/ UNCHS, 1993). The Kathmandu Valley is at high risk (called a risk city) and Nepal is as “hot spot” for geophysical and climatic hazards (World Disaster Report, WDR, 2005). Micro seismicity map of Nepal (DMG/NSC, 1998) shows that the earthquakes in the Nepal Himalaya and Tibet region are quite different. Seismic activity appears more intense around 820 longitude in far western Nepal and 870 longitude in eastern Nepal. Past earthquakes listed in Table 1, have destroyed many historical buildings, monuments, temples, houses and infrastructures in the past. 2015 Gorkha earthquake (7.8 Mw) killed about 9000 people, left 28,000 people injured, and 800,000 people affected, and 600,000 houses/monuments collapsed (Figure 15), that is an equivalent to about US $20 billion economic loss (GON/ Ministry of Home Affairs, 2015).

Study of the past earthquakes is likely to help to evaluate earthquake risk and forecasting possible future earthquake occurrence. However, earthquake reoccurrence time is not the same throughout the Himalayas. Historical earthquake scenario in Nepal is shown in Table 1 and Figure 14.
Figure 14

Moderate, Major and Great Earthquakes Scenario in the Himalayan Region (a compiled map from different sources)

Figure 15

Before and After 25 April 2015 Gorkha Earthquake at Kathmandu, Barpak/ Gorkha and Sindhupalchok (Some photographs of damaged village, houses, Dharahara tower and temples etc. were compiled by Kaphle, 2015). EQ, Eq = Earthquake
Table 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Magnitude (Richter scale)</th>
<th>Loss of Lives</th>
<th>Loss of Infrastructure</th>
<th>Total Loss</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1255</td>
<td>East Nepal</td>
<td>&gt;8</td>
<td>No proper record</td>
<td>No proper record</td>
<td>No proper record</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1310 BS</td>
<td>Kathmandu</td>
<td>7.7 Large EQ</td>
<td>No proper record</td>
<td>Many houses, temples collapsed</td>
<td>No proper record</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1373</td>
<td>Nepal</td>
<td>Large EQ</td>
<td>No proper record</td>
<td>No proper record</td>
<td>No proper record</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1505</td>
<td>West Nepal</td>
<td>8.1</td>
<td>No proper record</td>
<td>No proper record</td>
<td>No proper record</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1810</td>
<td>Nepal</td>
<td>&gt;8</td>
<td>No proper record</td>
<td>No proper record</td>
<td>No proper record</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1833 August</td>
<td>Kathmandu &amp; surroundings</td>
<td>7.8</td>
<td>No proper record</td>
<td>30% people affected/ died</td>
<td>30% KTM valley damaged</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1934 Great EQ</td>
<td>Nepal - Bihar</td>
<td>8.3</td>
<td>8519 people died (when total population was only 7,000,000)</td>
<td>80,890 houses collapsed and 207,248 damaged</td>
<td>Huge loss of lives, properties and damage infrastructures</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1966 July</td>
<td>FW Nepal</td>
<td>6.5</td>
<td>24 died</td>
<td>NK</td>
<td>Huge loss in hilly districts of FW-Nepal</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1980 August</td>
<td>FW Nepal</td>
<td>6.7</td>
<td>178 died, 391 injured</td>
<td>NK</td>
<td></td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>1988 August</td>
<td>Udayapur, Eastern Nepal</td>
<td>6.6</td>
<td>721 died and 6553 injured</td>
<td>65,432 houses collapsed and 235,403 damaged</td>
<td>Huge loss in physical structure</td>
<td>EQ catalogue</td>
</tr>
<tr>
<td>2015 April</td>
<td>Barpak, Gorkha District</td>
<td>7.8</td>
<td>About 9,000 died, 28,000 injured, 800,000 affected.</td>
<td>600,000 houses, temples, monuments collapsed/damaged</td>
<td>About US$ 20,000,000,000</td>
<td>DMG/NSC</td>
</tr>
</tbody>
</table>

Note: DMG = Department of Mines and Geology; NSC = National Seismological Centre; EQ = Earthquake, NK = Not known

5.2 Landslides, Debris Flow and Avalanches

Landslide hazards are quite common in mountain/hilly regions in Nepal, mainly during monsoon season due to heavy rainfall and frequently create disasters almost every year. Water infiltration in loose soil and weathered and highly fractured rocks on high angle slope, glide slowly or fall rapidly downwards due to gravity, wedge failure or by toe cuttings. Many landslides, including old landslides, are activated during earthquakes mainly in the Lesser Himalayan and Sub-Himalayan regions. If a huge rock-mass falls suddenly and start flowing along with glacier or water, it causes the debris flow hazard. Debris flow, rock and ice avalanche commonly occur in the Higher Himalayan regions. Pokhara Valley-fill sediments are the result of the three episodes of debris flow events as explained earlier. Human settlement in the flood prone river sides, encroachment to the forest, road sides, haphazard mining activities, old landslides, sinkholes, land subsidence prone areas and slum areas are the main causes of flood and landslide hazards. High intensity rainfall (cloudburst), cultivation on the high angle slope lands, earthquakes, etc., also contribute to trigger landslides. As a result, loss of lives, damage of road, damage or complete destruction of houses, historical buildings/monuments and other infrastructures, cultivated lands, etc., take place. Some of the examples include the Shrawandada
landslide at Butwal (Figure 16; Kaphle & Jnawali, 2003), Laprak landslide (Figure 17; Kaphle, 2013) in Gorkha, and Jure landslide in Ilam, frequent rock falls at Siddhababa – Dobhan section in Butwal – Tansen road, landslides in the catchment area of Melamchi River (2021), etc. More than 2000 landslides were triggered in 7 districts of Central Nepal in 1993. Annually similar landslides occur in different parts of the Lesser Himalaya and Sub-Himalayan regions mainly in monsoon season. Vulnerable areas to landslides should be identified and suitable safety measures must be applied in advance to reduce the losses.

**Figure 16**

*Shrawan Danda Landslide at Butwal (on the left, Kaphle & Jnawali, 2003)*

**Figure 17**

*Laprak Landslide / Gorkha >500 houses are at high risk (on the right, Kaphle, 2013)*

5.3 **Floods**

The flat piedmont plain areas in Terai and lower parts of mid valleys in the midlands and dune valleys in the Sub-Himalaya are susceptible to floods during cloudburst and heavy monsoon rain. Flooding also takes place due to the blockage of the natural flow of drainage system by human activities, landslides debris, and river bank cuttings. It could also be due to unforeseen river surge events caused by sudden dam failure in the reservoir, glacial lakes outburst, landslide dam breakdown, etc. One of the 1993 flood and landslide disasters in the central Nepal washed away Tribhuvan Highway at 20 places and 3 major concrete reinforced bridges on Agra Khola, Belkhu Khola, and Malekhu Khola along Prithivi Highway. Partial damage of Kulekhani dam also created floods in Bagmati River and severe damage downstream in Terai plain. Due to this disaster, 1336 people lost their lives, 408,109 people of 72,091 families were affected, 32,765 houses were collapsed, and infrastructures damaged, costing of millions of dollars (GON/MOHA, 1993). High floods in Sunkoshi River in 2008 (Figure 18), Mahakali River in 2013 (Figure 19), flash flood in Pokhara in 2012 (Figure 20) caused loss of 100s of lives, damages costing of millions of dollars; and landslides and flood (2020) in Nepal killed over 200 people, damaged many houses, infrastructures and cultivated lands. Debris flow event in Seti River in 2013 has swept away Kharapani Bazaar and flooded some parts of Pokhara Sub-Metropolitan City (Figure 21; Hanisch et al., 2013). Recently induced landslide, debris flow and flood events that occurred due to torrential rain on 15th June in the upstream catchment area of Melamchi River, on 16th June 2021, not only destroyed the Melamchi drinking water supply headworks site but also hardly hit by a huge flood that the Melamchi Bazaar in mud and debris up to depth of 10 m and swept away many communities, damaged many settlements and infrastructures at Melamchi Bazaar, Chanute Bazaar, Ganesh Bazaar, Muktitar, Kiul and Talamarang in Sindhupalchok district (Timilsina & Dahal, 2021). It has badly affected more than 1000 people and destroyed over 300 houses, 10 people died, 6 injured, 21 missing; and also destroyed 4 concrete bridges, 6 suspension bridges and few km roads.

Taking into consideration of such bad experiences in the past, it is advised to identify flood and landslide prone areas (in catchment areas & flood plains), analyse the possible amount
annual rain fall (cloudburst), and then prepare the pre-disaster preparedness plan to implement as per required. Conduct detail EIA study and apply suitable precautionary/safety measures in advance like early warning system, immediate response, recovery, rescue and relief operations of displaced people to save lives and protect settlement areas, cultivated land, infrastructures, etc.

**Figure 18**

**Figure 19**
*Flooding in Mahakali River, Darchula, Far-Western Nepal (Kaphle, 2013)*

![Figure 18](image1.png)
![Figure 19](image2.png)

**Figure 20**
*Flash Flood in Pokhara / Seti River in 2012 (on left)*

**Figure 21**
*Flowing Debris along Seti River at Kharapani Bazaar Before and After (Hanisch et al., 2013) (on right)*

![Figure 20](image3.png)
![Figure 21](image4.png)

### 5.4 Land Subsidence, Sink Hole and Karstification

The problem of land subsidence hazard could be seen mainly in the rapidly growing urban areas like Kathmandu and Pokhara. Due to the weak groundmass consisting of loose soft sediments, construction of heavy structures like multi-story buildings, as well as over extraction of the ground water without considering water balance in the aquifers in valley-fill sediments initiated land subsidence at Kathmandu (Joshi & Lamichhane, 2010). Karstification is widespread in the form of sinkholes, cavities, cavern and subsoil pinnacles in Pokhara Valley, mainly in the west side of Seti River, especially in old city area (Figure 8); at Phewa dam site, Davi’s fall (Figure 9); Gupteshor cave; Hengja area and in different parts of Kusma in Parbat district (Kaphle, 2001 & 2013; Paudel et al., 2017). Debris flow deposits in these areas are rich in calcareous constituents like rock fragments, clasts, cementing materials, etc. which are susceptible to solution weathering, sinkholes, cave formation, and that help in land subsidence.
Detail subsurface geological study could guide to find the vulnerable as well as suitable sites for heavy structures.

5.5 Glacial Lakes and Glacial Lake Outburst Flood (GLOF)

There are more than 3000 glacier lakes in the Higher Himalaya regions of Nepal and 27 of them are very dangerous (Mool et al., 2001 & 2005; Bajracharya et al., 2007). They can burst at any time and bring GLOF disaster in the downstream. Snow melting and depletion of snow/ice coverage in the Himalayas is changing significantly and rapidly as a result of global warming and climate change as in other parts of the world. In last 50 years, or so, the effects of glacial retreat are clearly seen in the Himalaya. Due to climate change glaciers are melting rapidly and more glacier lakes are formed, mostly dammed by loosely packed ice core moraine dam. These glacial lakes are always serious threat to the people, their properties and infrastructures located downstream by the side of river valleys due to possible catastrophic GLOF. One of the examples is Dig Tso GLOF in 1985.

Imja glacier lake (Figure 22) in Dudhkoshi basin, Tsho-Rolpa glacier lake (Figure 23) in Tamakoshi River, and Thulagi glacier lake in the upper part of Marshyangdi River are well studied since 1993 (Mool et al., 2001) and have been found prone for possible GLOF hazards. Some precautionary measures were applied in Tso-Rolpa glacial lake by reducing the level of water in the lake. But it appeared quite expansive to reciprocate in other similar glacial lakes.

Figure 22
Imja Glacial Lake in Dudhkoshi Basin at Risk for GLOF (on left)

Figure 23
Tsho-Rolpa Glacier Lake and Settlements in Rolwaling Valley and Downstream of Tamakoshi River (on right)

5.6 Wind Storm and Lightning (Thunderstorm)

In 2018, sudden wind storm with high velocity swept the settlement areas and triggered disaster in Bara and Parsa districts in central Terai. More than 500 houses and cow shades were destroyed completely and over 2000 people became homeless, a number of people injured, and over 25 children, women and old persons lost their lives and 100s of cows, buffalos, goats and chickens were killed. Infrastructures like electricity and phone lines were disrupted for few days. Wind storms, lightning/thunderstorm are common hazards in Nepal mainly in the Terai, the Sub-Himalayan and the Lesser Himalayan regions almost every year during the months of March, April and rarely in May - June. Every year 50 to 80 persons die from such hazards. Early warning system by forecasting hydro-meteorological data, alarm system, etc. must be installed to make aware of the people around.
5.7 Radiation from Natural Radioactive Bodies

Low to medium radioactive sandstone bands exposed at Tinbhangale in Makwanpur (Kaphle & Khan, 1990); sulphide + gold bearing radioactive quartzite band at Gorang in Baitadi; minor scattered autonite in pegmatites at Shivapuri hill to the north of Kathmandu (Kaphle & Khan, 2003; Khadka & Lamsal, 2020), and high radioactive U/Th mineralization in upper Mustang (Khadka & Maharjan, 2019) constitute the sources of natural radiation which can affect the health of the local people, their cattle and wild animals living around. Therefore, special attention must be given to minimize the possibility of health hazard of the people, animals and plants, especially drinking water, fruits, vegetables and food grains cultivated in these areas. No such radiometric survey pertaining to the effects of radiation on health of the local people, cattle, etc. has been done so far. Their detailed studies are urgently called for.

6. Impact of Geo-hazards in Society and Environment in General

Nepal is a mountainous landlocked country with about 30 million population. Continual geodynamic activities in conjunction with complicated geomorphology, complex geology, tectonic frameworks, geological structures like many active thrusts and faults, topographic variation with high angle slopes are the major causes of geo-hazards. At the same time tremendous geographic diversity from highest mountain to the flat plains, climatic variation within the short distance (Figure 2) and hydro-meteorological conditions therein, the country is prone to specific natural hazards like earthquake, flood, landslide, debris flow, rock and ice avalanche, GLOF, thunderstorm, windstorms, hot & cold waves, natural harmful radiations, etc. These natural hazards when combined with anthropogenic hazards like deforestation, haphazard mining, improper road cuttings, cultivation in the unstable slope lands, improper location of settlements and industries as well as discarded solid waste materials, dust, smokes and other harmful chemicals and gases aggravate the situation and degrade the fragile eco-systems. When hazards combined with vulnerability frequently bring the disaster and consequently it will not only damage the infrastructures, settlements, cultivated lands but also damage the natural environment, create the lives at high risk and causes immense economic losses (Kaphle, 2013). As mentioned earlier that in the world scenario, among 200 countries Nepal stands at 11th position with respect to earthquake hazards and 30th to the flood and landslide hazard (UNDP/BCPK, 2004; UN/UNCHS, 1993). The Kathmandu Valley where the capital city is situated is at high risk, and Nepal is as “hot spot” for geophysical and climatic hazard (World Disaster Report, 2005). Major historical earthquakes (Figure 14 & Table 1), like 1905 Kangara/ India (8 Mw); 1934 Nepal-Bihar earthquake (8.3 Mw); 1950 Assam/ India (8.5 Mw); 2005 Kashmir/ Pakistan (7.5 Mw) and 2015 Gorkha earthquake/ Nepal (7.8 Mw) are also the warning sign of the possible future earthquakes in the region. If we analyze all types of hazards/ disasters that occurred in the last 85 years (from 1934 - 2020), attributed to an average annual loss of about 858 lives, damage public & private properties, infrastructures, etc. equivalent to about 5 - 6% of the annual development expenditure of the country.

In addition to various types of hazards, ever increasing trends of world energy consumption correspondingly increasing emission of Greenhouse gases (GHGs) and Chlorofluorocarbons (CFCs) from various sources like burning of fuels, e.g., petroleum, natural gas, coal; use of refrigerators and air conditioners which emit CFCs are thought to be the chief causes of global warming and climate change all over the world including Himalaya region. As a result, the temperature is rising at the rate of 0.06 degree Celsius per year and that causes rapid snow melting, retreating the glaciers, vertical shift of snowline, increase the number of glacial lakes and in their size and water volume, and consequently risk of GLOF is also increasing tremendously in Nepal and in other Himalayan countries. Climate change has also altered rainfall pattern, triggering many landslides, debris flow, floods, etc. and help to rise the sea level.
and submergence of island countries like Maldives. Therefore, it is a worldwide issue and it has to be addressed by world community by following the international treaties and agreements like Kyoto Protocol adopted in 1997 and entered into force in 2005. It was the first legally binding climate treaty to minimize emission of GHGs in the atmosphere and CFCs has to be phase out from our mother planet, the earth. The Montreal Protocol, 1987; The UN Framework Convention on Climate Change, agreed in 1992 and adopted by 197 countries. Sendai Framework for Disaster Risk Reduction 2015 - 2030 was adopted by UN member states in March 2015 at the World Conference in Japan and endorsed by UN General Assembly in June 2015. The UN Climate Change Conference (COP 21) in Paris reached the Paris Agreement/Paris Climate Accords which is another legally binding international treaty on climate change adopted by 192 countries in 2015 and entered into force in November 2016. Therefore, regional cooperation for integrated disaster management is must to reduce the vulnerability from natural and anthropogenic hazards and face the present challenges of global warming and climate change.

Nepal is highly vulnerable to various types of hazards. The Government of Nepal has prepared the national strategy for disaster risk management for building a resilient nation emphasizing on assessment, identification, and monitoring of possible disaster in the country. However, many people in the remote areas are still unaware of such risks. Pre-disaster preparedness and enhancing early warning system as well as early response, recovery, rescue and relief operations and resettlement of displaced people, etc. are still lacking although it should have got high priority.

7. Conclusion

- Geo-genic and hydro-meteorological hazards are the major ones which can bring the disasters at any time in Nepal. Therefore, the disaster risk management plan must effectively focus on pre-disaster and the post-disaster activities to save the lives, properties and infrastructures. Hazards like earthquake, landslide, flood, GLOF, debris flow, land subsidence, sinkholes, etc., must be dealt with during planning, designing and construction phase of settlement area/buildings and all types of infrastructures.

- Continual geodynamics therein and analysis of topographical, geological and geostructures (many active thrusts/ faults), geophysical data, and seismic data from previous earthquakes indicate that the Nepal Himalayas and surrounding regions are frequently suffered from moderate to great earthquakes. Micro-seismic activities are intense mainly in eastern 87° longitude and western 82° longitude, and peak ground acceleration on subsoil type-2 is very high in the western and far-western Nepal, respectively. In general, Nepal is at high risk with respect to moderate to great earthquakes.

- Earthquake specialists believe that even after the 2015 Gorkha earthquake (7.8 Mw) still there is a high risk of another great earthquake of 8.1 - 8.3 Mw which is overdue since the rupture of this earthquake had not reached to the surface and thus strain is not completely released yet. Pre-disaster preparedness and plan for rescue and relief operations should get high priority to minimize the loss. To be safe and minimize the possible loss from devastating earthquake it is advised to construct earthquake resistance buildings in safe land following national building codes, retrofitting of existing weak buildings, and create awareness among the people on how protection from earthquakes can be achieved.

- Govt. of Nepal’s Department of Mines and Geology is regularly publishing geological maps and landslide hazard zonation maps of different parts of Nepal; engineering and environmental geological maps of fast-growing cities of Nepal; and micro-seismicity map and seismic hazard maps regularly, but production of similar flood hazard maps, glacial/
GLOF hazard maps, radiation hazard maps, etc., is still a long cry off. These maps would be very helpful for advance planning, infrastructure development planning, hazard mitigation, disaster risk management, environmental protection, etc., hence need immediate attention of the government.

- Identification of flood, landslide, sinkhole and land subsidence risk areas is called for in priority basis and applied to save lives and properties of the vulnerable communities and public infrastructures. We should prepare at the same time, an effective and comprehensive management plan (long, medium and short-term plans) for disaster preparedness. National action plan ought to be implemented by different concerning central and local government departments/ agencies in close cooperation with UN agencies, donors, INGOs and NGOs, just to make disaster management effective. There is an immediate need of coordination among all the partners and related organizations to investigate the geology and geohazards and also in the development of geotechnologies for the aforesaid studies.

- A comprehensive database (basic information) on disaster management capabilities and the damage/ losses by various hazards/ disasters in Nepal was prepared by Kaphle and Nakarmi (1997) on behalf of Nepal Geological Society and submitted to UNDP Nepal, Disaster Management Secretariat has to be regularly updated and upgraded in every two years, so that such documents could help in preparation of all types of disaster management plan in the country.

References


Department of Mines and Geology (DMG)/ National Seismological Center (NSC) (2006).


