An Overview of Glaciers Distribution in the Nepal Himalaya

Shakti P.C., Dhiraj Pradhananga, Wenchao Ma, and Pei Wang


Shakti P.C.


Dhiraj Pradhananga


Wenchao Ma


Pei Wang

Abstract: Glaciers in the Himalayas are the important resource for fresh water. Continuous releases of the water from these glaciers make an important contribution to the drinking water, agriculture, and hydropower supply of densely populated regions in south and central Asia. Glaciers are not only a necessity for the survival of the people living in the low lying areas but also for their prosperity. Therefore, special attention should be given to detail research in the distribution of the glaciers in the Himalayan region and its surroundings.

Physical parameters of glaciers area, length, depth, elevation profiles were analyzed based on the data provided by WGMS and NSIDC (1989), which was updated in 2012. Machhapuchhre, Thyangbo, Cho Oyu, Taweche, Setta, Tingbo and Kanchanjanga glaciers were found as the smallest glaciers in terms of area (<1km^2), mean length (< 2km) and mean depth (40m) in the Nepal Himalaya. Langtang Ngojumba, Barun and Yalung glaciers were found as the largest glaciers in terms of area (>50km^2). Large difference between start and end elevation point of glaciers of Khumbu, Ngojumba, Imja, Langtang indicates coverage area profiles are large and located in steep slopes of the Nepal Himalaya, which may result in linear erosions and avalanches. This paper also discusses about the Glacier Lake Outburst Flood (GLOF) in the Himalayan region.

Key words: Glaciers, Himalayas, GOLF, Nepal

Introduction

Glacier form by accumulation and compaction of snow for many years, compresses into large, thickened ice masses. Special character of glaciers is their ability to move very slowly. Glaciers flow like very slow rivers. Some glaciers are as small as football fields, while others grow to be over a hundred kilometers long. Glaciers are the origin and lifeline of the major river systems, giving the lives of million people relying on freshwater for drinking and crop irrigation across the south and central Asia. Therefore, storage and release of water from glaciers are important for various aspects; hydroelectric power, flood forecasting, sediment transportation, and formation of landforms including scientific fields (Jansson et al., 2003). Glacier itself is an economically valuable deposit because it contains fresh water. Glaciers once covered 30% of the land area of the Earth, and left deposits of diverse shape and composition. Presently, glaciers occupy about 10% of the world's total land area (Lemke et al., 2007), with most located in Polar Regions like Antarctica and Greenland. The largest mountain glaciers are found in the Himalayan region in Asia. The water resources from the Himalayan region drains through ten of the largest rivers basin in Asia, which sustain about 1.3 billion people livelihoods (Xu et al., 2009).

The word Himalaya is derived from two Sanskrit words: 'Hima' meaning snow and 'alaya' meaning abode that is how the Himalayas got their name. The Himalaya range is the highest mountain system in the world. The Himalayan region of Nepal is a barrier between the Plateau of Tibet to the north and the alluvial plains of Nepal to the south (Fig.1). This region is located above 3500m from mean sea level and glaciers covers approximately 33,000 square kilometers in this range alone. Three of the world's major rivers: Indus, Ganges and Brahmaputra originate from the glaciers of this region. The Himalayan Region of Nepal covers nearly 35% of the total area and contains 200 peaks of more than 6,000 meters in elevation and 13 peaks of more than 8,000 meters high, including Mount Everest. Himalayas contain important natural resources of frozen fresh water in the form of snow and glaciers. It is found that about 3,248 glaciers are in Nepal and among them; only 55 glaciers have their own names (WGMS and NSIDC, 1989). Glaciers are highly sensitive to even minor changes in the atmospheric temperature. It is well documented that temperatures in the Himalayas have risen in recent decades (Shrestha et al., 1999) and that glaciers in the region are losing mass especially in the south slope of the central Himalayas (Ren et al., 2006). It is widely accepted that climate change is the main factor behind the accelerated glacier retreat observed in the Himalayas. In the Himalayan range, many glacier lakes exist at the lower end of glaciers. There are about 2,315 glacial lakes, and 20 potential glacial lake outburst floods (GLOFs) sites are located in Nepal (Mool et al., 2001). Several glacial lakes have been formed as a result of glacier retreat which could lead to catastrophic events like GLOF in valley's downstream. The retreating glaciers are the new threats of climate change in the Nepal Himalayas. Empirical and model studies suggest that there will be more new glacier lakes and existing glacier lakes will grow rapidly in the Nepal Himalayas in the future because of climate change (Horstmann, 2004). Peoples who live downstream snow-fed river may be likely to face in any time by loss of millions of dollars worth of property, tourism facilities, trekking trails, roads, bridges and hydropower plants etc.

Mathematically, glaciers are formed when rate of accumulation of snow is higher than rate of ablation and falling snow gets enough time and space to get metamorphosed to form ice. Glacial ice can range in age

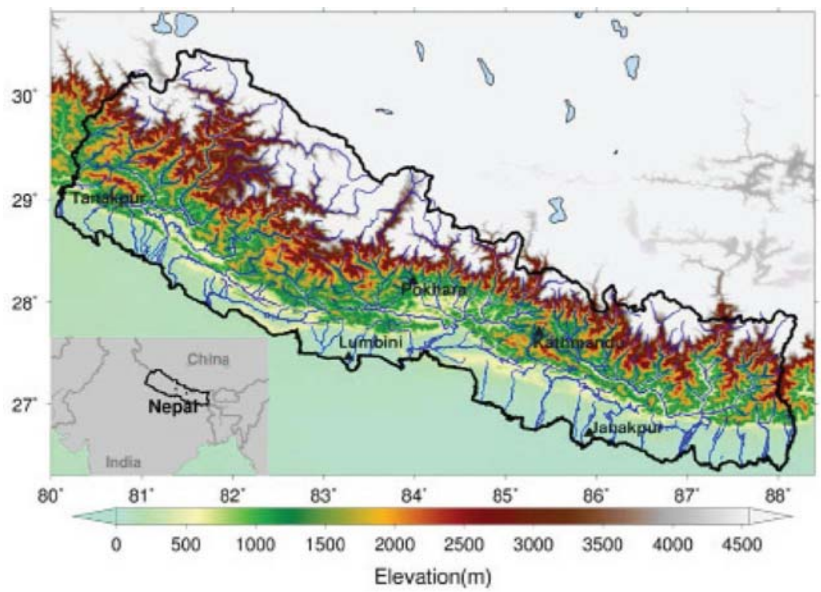

Figure1. Topography and major river networks of Nepal.

online and updating it every few decades. Recent update in 2012 was undertaken by the WGMS that brings the total number of glacier records to over 130,000 around the world. They have provided several glacial parameters for examples: geographical location, area, length, width elevation etc. in ASCII text data format. We first, extracted data only around the Himalaya region and its surroundings. Longitude and latitude have set from 80.00° to 88.40° E and 26.30° to 30.80° N in this study, which covers almost all Nepal Himalaya including neighboring countries (China in the north and India in the east and west). Fig.2 shows the location of glaciers in the Nepal Himalaya and its surroundings. The total numbers of glacier in this selected area are about 28,800. Out of them, there are 3,248 glaciers in Nepal. Glaciers nearby the country's border also are very important because many rivers in the Nepal Himalaya are originated and connected with them. Dense numbers of glaciers are located in the eastern side of Nepal. Only few glaciers have their own name with detail information among the large number of glaciers in the Nepal Himalaya and its surrounding. Out of 3,248 glaciers in Nepal, only 55 glaciers have their names with more parametric information in the data set of WGMS and NSIDC, 1989. Therefore, in this study, we include only those glaciers which have their name in the selected frame. It is found that there are 251 glaciers that have their names in the selected region (Fig. 3). Note that the glaciers close to the Nepal border (Gray symbol in Fig. 3) are important because of the topography. We have named serial numbers to each individual glacier

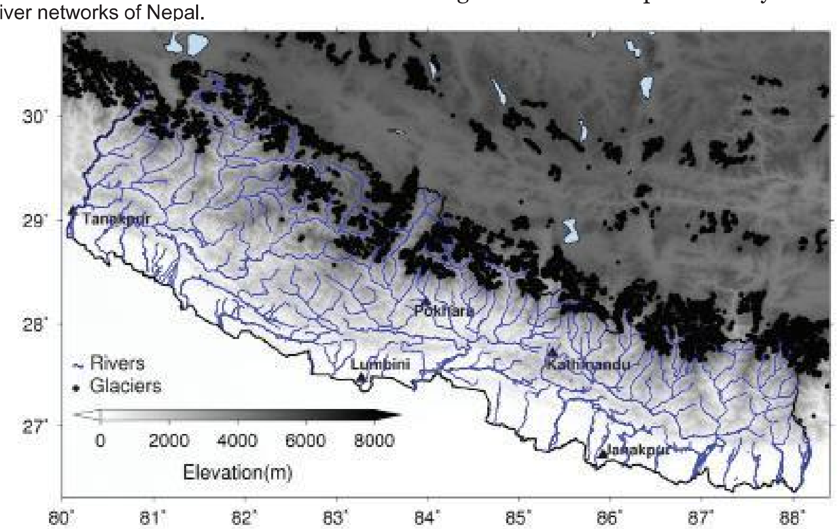

Figure 2. Location of individual glacier in the Nepal Himalaya and its surrounding region.

from several hundred to several hundreds of thousands years, making it valuable for climate research (WGMS and NSIDC, 1989). But, due to remoteness, high mountains, steep slopes and extreme logistical difficulties, detail study on glaciers is being difficult though some research and documentation have been carried by few institutions and on individual basis.

Himalayan glaciers release water steadily throughout the year, which gives a continuous flow to almost all major rivers in Nepal and all these rivers receive flow from numerous tributaries originating in the high mountainous areas with glaciers and snow covers (Fig. 1). Therefore, any change in glaciers mass, volume, depth, length, diameter etc are directly effect to the river system of Nepal. A few glaciers have been studied for their mass balance in the Nepal Himalayas, which is important parameter for monitoring glacier's health and the impact of climate change but, there is not much detail literature and documentation about whole major glaciers together in Nepal Himalaya. This paper highlights the present status of glacier around the Nepal Himalayan region.

World Glacier Monitoring Service (WGMS) collects detail information on measurements of glaciers from different organizations around the world and compiles these regional inventories into one baseline world inventory with the aim to update it every few decades. In 1998, WGMS and National Snow and Ice Data Center (NSIDC) agreed to work together to make the World Glacier Inventory (WGI) widely available in the Nepal Himalaya. Name of glaciers and their corresponding numbers is presented in the Table 1. Area, length, elevation, and depth of these glaciers are discussed separately more detail in the next sections.

Physical Status of Glaciers

Elevation profile

In general, glaciers are located above 4000m from mean sea level in the Nepal Himalaya. There are different zones in the whole body of glacier. Bottom tail of glacier is called ablation zone while above snow line, it is called accumulation zone. Hence, location of zones of glacier

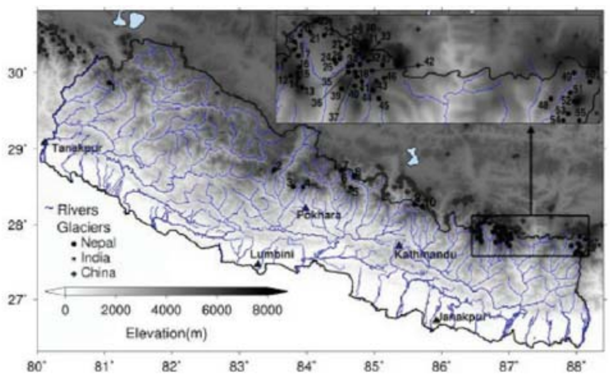

Figure 3. Location of selected individual glacier in the Himalayan region. Glaciers in the Nepal (solid circles) Himalaya are indicated by numbers.

S.No.	Glacier Name	Lon	Lat
1	Kap Chuli	81.08	29.87
2	Dhaulagiri	83.52	28.73
3	Kayamnu	83.81	28.50
4	Machhapuchhre	83.95	28.49
5	Lanjam	84.65	28.49
6	Hindum	84.51	28.71
7	Tarkya	84.53	28.73
8	Sonam	84.69	28.65
9	Chumsundo	85.68	28.27
10	Langtang	85.71	28.24
11	Ripimo shar	86.50	27.91
12	Rolwaling	86.53	27.83
13	Lumdin	86.59	27.77
14	Thyangbo	86.57	27.82
15	Thyangbo	86.57	27.84
16	Langmuche	86.57	27.87
17	Langdak	86.55	27.93
18	Chhule	86.55	27.95
19	Melung	86.55	27.99
20	Bhote kosi	86.85	28.02
21	Lumsamba	86.63	28.04
22	Tingbo	86.84	27.85
23	Cho Oyu	86.67	28.09
24	Cholotse	86.76	27.91
25	Taweche	86.77	27.89
26	Cholo	86.79	27.91
27	Ngojumba	86.71	28.02
28	Khumba	86.83	27.98
29	Lobuje	86.80	27.96
30	Nuptse	86.87	27.95
31	Lhotse	86.92	27.92
32	Imja	86.94	27.90
33	Ombigaichain	86.90	27.88
34	Hungu & Mereal	86.96	27.85
35	Nereyargaip	86.87	27.85
36	Seeta	86.84	27.88
37	Amadabalam	86.86	27.88
38	Nare	86.88	27.82
39	Kyashar	86.80	27.77
40	West Chamang	86.97	27.76
41	Mera	86.91	27.80
42	West Lhotse	86.89	27.93
43	East Hungu	86.99	27.80
44	Inkhu	86.87	27.78
45	West Chamang	87.00	27.72
46	West Barun	87.03	27.82
47	Barun	87.02	27.88
48	Naphunba	87.92	27.72
49	Lhonak	88.04	27.84
50	Kanchenjunga	88.13	27.80
51	Merra	88.02	27.75
52	Kumbhakarna	88.04	27.71
53	Yamatari	88.01	27.65
54	Lasampa	87.98	27.61
55	Yalung	88.07	27.61

Table 1. Location of glaciers in the Nepal Himalaya. G.N. = Glacier number, Lon = Longitude (°) and Lat= Latitude (°).

is different, which is one of the important parameter to see the status of glacier. If end point of ablation zone of glacier is located at lower elevation, retreating probability could be higher and vice versa. Therefore, in this study, we checked the elevation profile of highest and lowest glacier from mean sea level.

It should be noted that mean elevation profile of glacier in the Nepal Himalaya are above 4000m from mean sea level. For example: average elevation profile of Machhapuchhre, Tingbo, Cholo, Setta and Lumdin glaciers found as 4084m, 4755m, 4831m, 4869m, and 4983m respectively. These are the lowest elevations as compared to other glacier in the Nepal Himalaya. Yalung (7436m), Kyamnu (6849m), Khumbu (6523m), Cho Oyu (6500m), and Imja (6431m) are the top five glaciers, located at highest elevation in the Himalaya. Glaciers are generally long. Therefore, elevation profile of start and end point of each glacier is also important to understand slope profile, area etc. Overall, upper parts of glaciers are located mostly around 6000m from mean sea level. The Highest and lowest elevation profile of glaciers in the Nepal Himalaya and its surrounding is shown in Fig. 4. There are some glaciers, which are located at lower elevation (<6000m), specially eastern side of Nepal. Khumbu (8230m), Ngojumba (7897m), Imja (7864m), Yalung (7710m) and Cho Oyu (7590m) are the top five glaciers, at which upper part of glacier located at the highest elevation. Lanjam (3139m), Machhapuchhre (3353m), Sonam (3840m), Kumbhkarna (4115m) and Yamatari (4119m) glaciers have their lowest maximum end points, located at lowest elevations in the Nepal Himalaya. Some lowest points of glaciers around middle zone of Nepal were found below 4500m. In such case probability of melting glaciers and formation of glacier lakes could be higher.

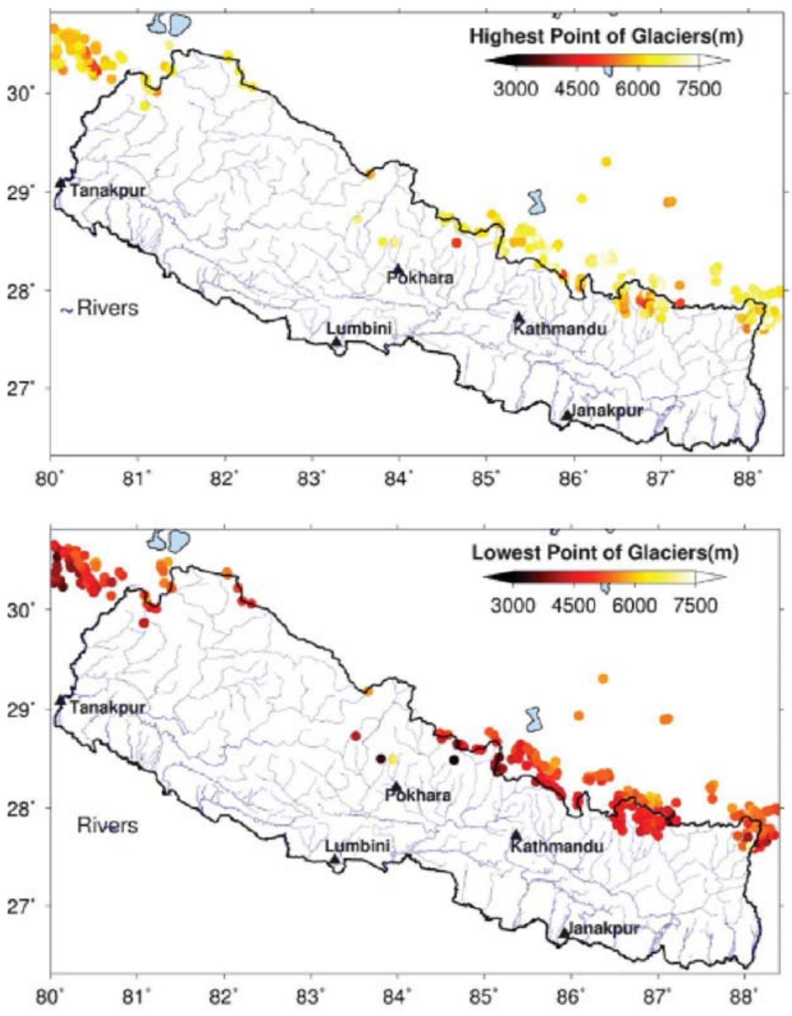

Figure 4. Elevation of highest (up) and lowest (bottom) point of glaciers in the Nepal Himalaya and its surrounding.

Length and Depth Profile

The majority of glaciers in mountain ranges worldwide retreated substantially during the 20th century (Dyurgerov and Meier, 1997). But, there is not exact information about the data especially in the Nepal Himalaya. Generally, length of glacier shows the capacity of bearing of total ice. In this study, mean length of the glacier in kilometers measured along the most important flow line in a horizontal projection. Mean length of glaciers ranged from less than 1 km up to 24 km in the Nepal Himalaya. Machhapuchhre (0.2 km), Cho Oyu (0.8 km), Tingbo (0.9 km) glaciers have less than 1km in their length. Similarly, Yalung (23.5 km), Ngojumba (22.5 km), Rolwaling (22.2 km) glaciers found as top three highest in their mean length in the Nepal Himalaya. Overall, in the far eastern side of Nepal, maximum lengths of glacier are less than 5 km (Fig. 5). Some glaciers have longer maximum length especially in the mid and eastern parts of Nepal. It's interesting that mean length of the glaciers in the eastern part is significantly lesser than that of western and central parts of the Nepal Himalaya.

Depth of the glaciers is other important parameter to describe its nature and content of ice. The physical depth of the glaciers in the Nepal Himalaya is shown in Fig. 5. Mean depth is only be given in the data set if a glacier was actually measured (by drilling or radio-echo soundings) and many of the values in this field have estimated using a thickness-area relation (WGMS and NSIDC, 1989) in meters. Basically, Mountains in the Himalaya region are steep and narrow (Fig.1), physical depth of the glaciers could be very changeable during

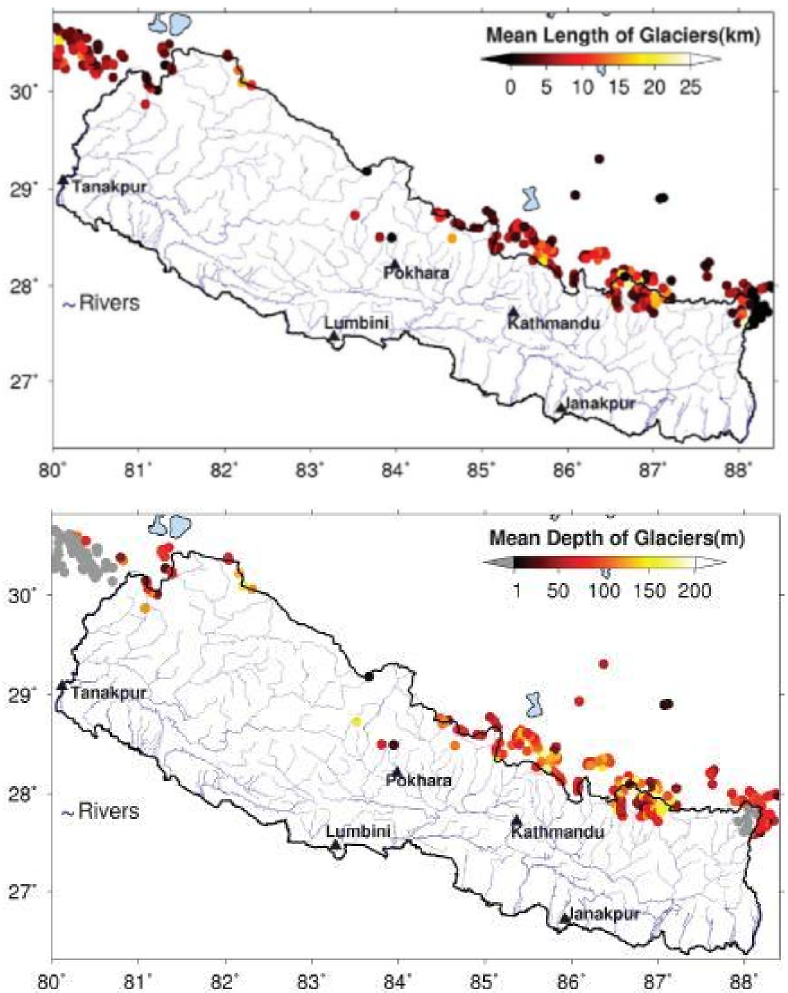

Figure 5. Mean length (up) and mean depth (bottom) of glaciers in the Nepal Himalaya and its surrounding.

their whole length profile. There are missing data especially in the eastern part of Nepal Himalaya and western Indian glaciers (solid gray colors in Fig. 5). In general, variability on the physical depth of glaciers in the Nepal Himalaya is larger. Average depth of glacier in the Nepal Himalaya varies from 20m up to 190m. Machhapuchhre (19m), Tingbo (22m) Cho Oyu (33m), Setta (22m), Thyangbo (37m), and Taweche (39m) glaciers have the lowest depth (<50m). But, Ngojumba (189m), Langtang (177m), Barun (164m), Dhaulagiri (156m) and Khumbu (156m) are the top five highest glaciers in terms of their depth.

Area profile

The total area of the glacier is considered in a horizontal projection in square kilometers (km^2). Though area of mountain glaciers are normally small in term of area coverage due to their topography. In the Nepal Himalaya, areas of glaciers have a large variation. However, some of those have larger area. The deviation of range varies from few km^2 up to about 82 km^2. The total area of Machhapuchhre (0.2 km^2), Tingbo (0.2 km^2), Cho Oyo (0.6 km^2), Thyangbo (0.8 km^2), Taweche (0.8 km^2), Kanchanjanga (0.9 km^2) glaciers have less than 1 km^2. The top five highest glaciers in the Nepal Himalaya are found as Ngojumba (83 km^2), Yalung (82 km^2), Langtang (68 km^2), Barun (53 km^2) and Dhaulagiri (46 km^2). The total area of these 55 glaciers in the Nepal Himalaya is found to be 815 km^2. Regular monitoring of area of glaciers in the Himalayan region would be meaningful to check the variability of their area under changing climate. However, some studies on specific glaciers have shown shrinkage of area annually in the Nepal Himalayas (Fujita et al. 2001, P.C., 2009).

Glacier Retreat and Glacier Lakes

Changing climate is the main factor for net shrinkage and retreat of glaciers and the increase in size and number of glacial lakes. Such changes in glaciers might change the local hydrological cycle for that region. Rapid melting of glacier due to rising in temperature would also trigger slides and avalanche falling in the glacial lake triggering the outburst of the lake (P.C., 2009). Analyses of maximum temperature data from 49 stations in Nepal for the period 1971-94 reveal warming trends after 1977 ranging from 0.068 to 0.128°C /yr in most of the Middle Mountain and Himalayan regions (Shrestha et al., 1999). According to the third assessment report from the Inter governmental Panel on Climate Change (IPCC, 2001) by using current climate change trends, the average global temperature may rise by 1.4 - 5.8°C during the current century seem all too possible which may result less glacier and increase flash floods in mountain region of Nepal. However, uncertainty about the future state of the climate, as well as an incomplete understanding of the processes affecting Himalayan glaciers under the current climate, make any projections of climate change's impact on glaciers uncertain as well (UNEP, 2009).

Nepal has a numerous networks of river channels and most of them originate from snow and glacier cover area of the Himalayan region. There are 6,000 rivers and rivulets flow through Nepal. The sudden failure of a moraine dam on a glacial lake can release a very large amount of water called a Glacial Lake Outburst Flood (GLOF). The released water may destroy property hundreds of kilometers from the source. Speedy rate of retreating glacier and formation of glacier lakes in the Himalaya is warning signal for future GLOF. GLOF can be said a common natural hazard in the Nepal Himalayas.

in the Himalayan region. In the eastern part of Nepal Himalaya, frequencies of past GLOFS are higher as compared with western part. The frequency appears to be more than once every three years, which seems to be very frequent rate compared with other natural disaster now arising in Nepal Himalaya.

There has been some investigation about the potential glacier lakes in the Nepal Himalaya. According to Bajracharya et al., (2007), there are about 2,315 glacier lakes of varies sizes and due to the impact of global warming, 50 lakes are growing and 22 new lakes have been formed after 2000 in the Nepal Himalaya. Fig. 8 shows exact location of potential glacial lakes (solid black circles) in the Nepal Himalaya. Almost all of the glacial lakes are situated at remote and high altitudes of rugged terrains with harsh climatic conditions. Hence to carry out the physical mitigation works on these lakes are expensive and impractical. Therefore, to reduce or minimize loss of life and infrastructures due to future GLOF especially in the eastern part of Nepal could be challenging job.

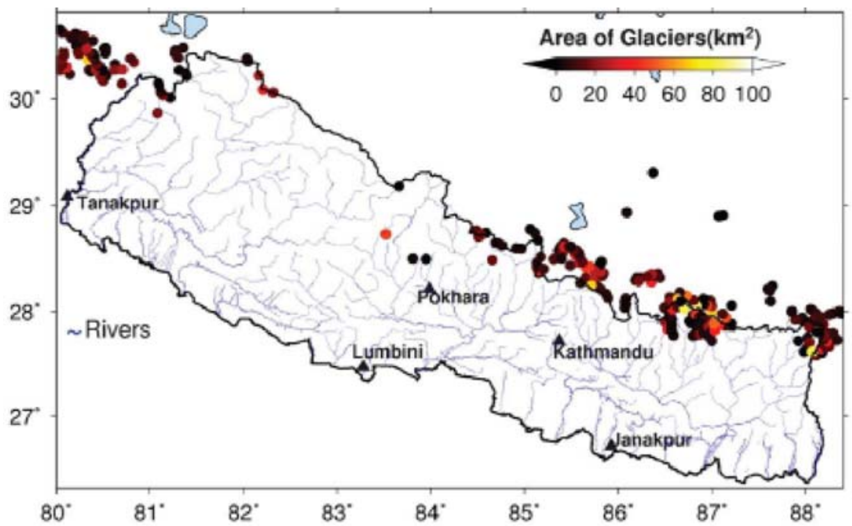

Figure 6. Area profile of glaciers in the Nepal Himalaya and its surrounding.

According to the records of GLOF in the Nepal Himalayas, thirteen GLOFs happened in the thirty years since 1960 (Yamada and Sharma, 1993). The recent GLOF in August 2003 destroyed a loss of life and properties in Madi River (P.C., 2009). Several GLOFs have occurred in Nepal Himalaya and its surrounding, but there is no precise documentation of events because of its occurrence in the remote areas. Nevertheless, some GLOFs events including recent events in the past have reported in many literatures (Yamada and Sharma, 1993, Mool et al., 2001, P.C., 2009). Figure 7 depicts the GLOFs events (solid stars on the map) which happened

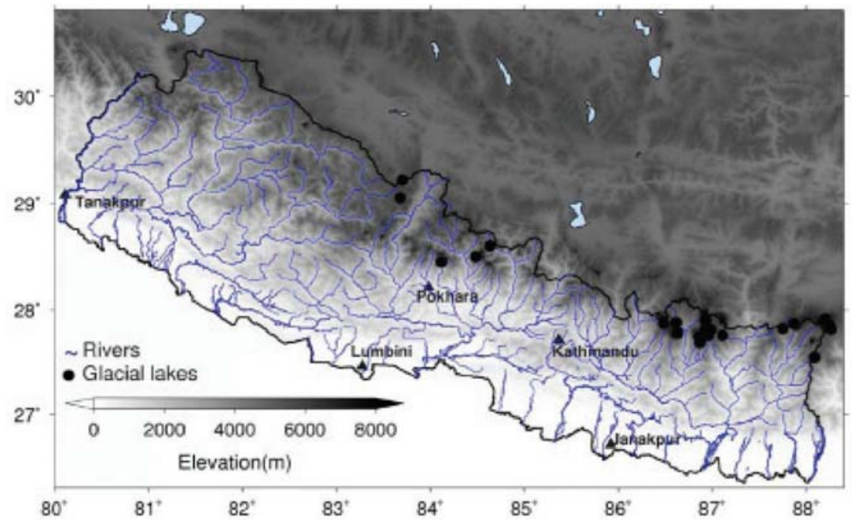

Figure 8. Location of potential dangerous glacial lakes (solid black circles) in Nepal Himalaya

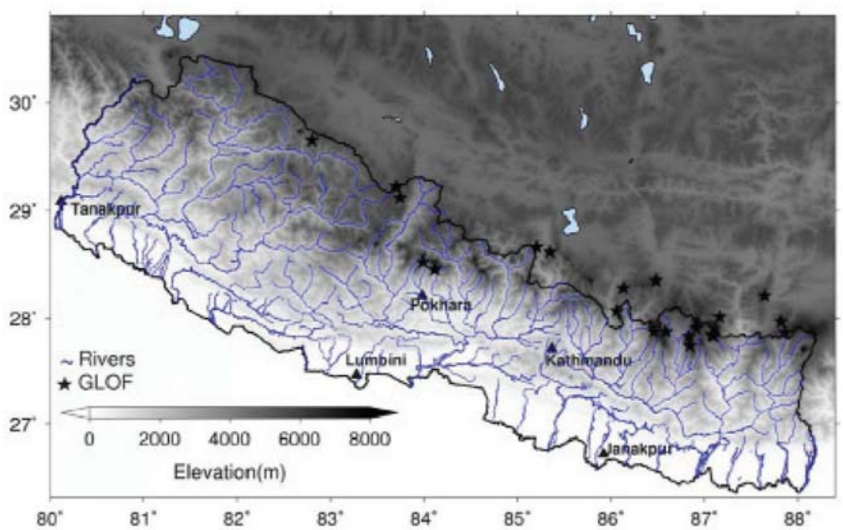

Figure 7.GLOF events in the Nepal Himalaya and its surrounding.

Summary and Conclusion

Glaciers are important natural resources over the Himalaya region which plays a crucial role in the lives of many human beings. Moreover, glaciers are extremely important because they are particularly susceptible to climate change and their loss directly affects human populations and ecosystems. Glaciers are located in very complex topography of the Himalaya region and very few researches have been done on it. The growing population and the expanding infrastructures such as road, bridges and many existing and proposed ambitious hydro-power projects in the river valleys capped by such glacier lakes, have increased the menace of the GLOF hazards in Nepal. This threat implies a serious challenge to the development endeavors. However, the limited studies in the physical status of glaciers, glacier retreat and glacier lakes in the Himalayas in terms of space and time, actual threat and vulnerability of the GLOF events is still anticipatory.

In this study, we focused the distribution of physical parameters of glaciers in the Nepal Himalaya and its close neighboring countries. Machhapuchhre, Thyangbo, Cho Oyu, Taweche, Setta, Tingbo and Kanchanjanga are found as the smallest glacier in terms of area (<1 km^2), mean length (< 2 km) and mean depth (40m) in the Nepal Himalaya. There are three glaciers (Lanjam, Kyamnu and Sonam) whose lowest end point found below 4000m from mean sea level (3139m, 3353m and 3840m respectively) and their maximum point found at 5029m, 6645m and 6564m from mean sea level. In general temperature profile at the lower elevation cloud goes higher as compared with higher elevation. Therefore, retreating rate of glacier and possibilities of formation of glacial lake at the end point of these glaciers might be higher.

Langtang, Ngojumba, Barun and Yalung glacier are found as the largest glaciers in terms of area (>50 km^2). The total area of these four glaciers is close about the country Maldives in South Asia. Yalung, Ngojumba and Rolwaling glaciers found as the longest glacier (>21 km). Ngojumba, Langtang, Barun and Dhaulagiri glaciers have the maximum vertical depth. Most of these larger glaciers in terms of area, length and depth have located higher elevation. But, the difference between the elevation of start and end point of glaciers are also higher. For example: Difference elevation of start and end point of glacier for Khumbu, Ngojumba, Imja, Langtang are about 3.4 km, 3.3 km, 2.8 km, and 2.7 km respectively. If glaciers are located at steep slope and connected with the lakes, a chance of linear erosion, ice avalanches, debris fall and rock avalanches into the lake could assist to generate GLOF in coming days. It is recommended that a careful watch/research should be given to these glaciers to minimize a natural disaster caused by GLOF.

As climate change is still a new concept in Nepal, people are not aware about it so need for the glaciological studies of the Himalayas had been felt since a long time. Nepal does not have sufficient data base, sufficient capacity for international negotiation and lobbying at international level, institutional framework, any specific policy and strategy regarding the climate change. One of the most urgent problems that Nepal faces is lack of technical, human resource, and financial capacities. The Government should also develop the database of spatial distribution of glaciers in details and make a clear vision and strategy on climate change. The most careful attention should be paid to control GLOF in the development of water resources in the vicinity of glacierized areas in the Nepal Himalaya.

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***Shakti P.C., PhD**, is a researcher at Storm, Flood and Landslide Research Department, National Research Institute for Earth Science and Disaster Prevention Centre (NIED), Tsukuba, Japan. His main areas of research are radar hydrology and meteorology. Recently, his research centers on nowcasting of precipitation system for flood forecasting. Besides, he is interested about glaciology of high altitudes.*
Corresponding address: shakti.pc@gmail.com

***Dhiraj Pradhananga**, is a PhD scholar at the Centre for Hydrology, University of Saskatchewan, Canada. His research focuses to snow and glacier melt on water availability under changing climate conditions in the Canadian Rockies*
Corresponding address: dhiraj.pradhananga@usask.ca

***Wenchao Ma**, is a PhD scholar at Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan. Her research field includes calculation and methodology of water age and transit time, as well as environmental isotopes processes within hydrologic cycle.*
Corresponding address: yixisi.1984@gmail.com

***Pei Wang, PhD**, is a researcher at College of Resources Science & Technology and State Key Laboratory of Earth Surface Process and Resource Ecology (ESPRE) for Beijing Normal University, Beijing, China. His interested areas of research are ecohydrology and isotope hydrology. Recently, he is focusing research on ecosystem response to the climate change, in particular, to dynamics of glacier responding to global warming.*
Corresponding address: wangpei7912@gmail.com

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CALENDER OF EVENTS - DAMS AND WATER RESOURCES

02 - 06 September, 2013: 18th International Conference on Soil Mechanics and Geotechnical Engineering Location: Paris, France Organizers: Le Public Systeme PCO Email: secretariat@paris2013-icsmge.org URL: www.issmge2013.org

04 -06 September, 2013, 2nd International Conference on Water and Society, Location: Southampton, UK, website: http://www.environmental-expert.com/events/water-and-society-2013-13522.

08 - 12 September, 2013: Dam Safety 2013, Location: RI, USA, Providence, Organizers: Association of State Dam Safety Officials (ASDSO), Email: info@damsafety.org , URL: www.damsafety.org

08 - 13 September, 2013: IAHR World Congress, Location: Chengdu, China Organizers: China Institute of Water Resources & Hydropower Research (IWHR) Email: iahr2013@vip.163.com , URL: www.iahr2013.org

20 - 25 September, 2014: Dam Safety San Diego, CA, Location: USA, Organizers: Association of State Dam Safety Officials (ASDSO) Email: info@damsafety.org URL: www.damsafety.org

22 - 29 September 2013: Nepal Head works Design in Steep Sediment Loaded Rivers
The workshop will start on Monday 23 September in Pokhara and end on Saturday 28 September 2013 in Kathmandu.

01 - 30 October, 2013: Sustainable Water Resources Development and Management (SWRDAM), Location: Aurangabad, Maharashtra, Organizers: Government College of Engineering, Aurangabad, URT: http://www.geca.ac.in