Monitoring and Estimation of Glacial Resource of Azad Jammu and Kashmir Using Remote Sensing and GIS Techniques

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Abstract

The agriculture and hydropower development in Pakistan is heavily dependant on the snow and glacial resource of Upper Indus Basin. Baseline information of this resource is essential for future management of water resources and economic development of the area. The satellite remote sensing and Geographic Information System (GIS) techniques were utilized for developing base data of glacial resource of Azad Jammu and Kashmir (AJK). The study revealed that there are over 224 glaciers containing ice-reserves of about 4.9 cubic km mainly in the Neelum valley district of AJK area. The glaciers predominantly belong to Cirque and Mountain types. Average thickness of the glaciers is about 24m. The glaciated area stretches over 109 sq km i.e. about 0.8% of the total Kashmir area. The coverage of glaciers and lakes is dominant over 4000-4500 m elevation range.

There are altogether 76 glacial lakes that cover an aggregate area of about 545 ha in the study area. Majority of these lakes belong to Erosion and Cirque types. The image interpretation techniques of remote sensing helped in identification of glaciers and glacial lakes in the high mountainous terrain of the Kashmir area. In order to conserve glacial resources for future use, their regular monitoring is required for effective water resource management and development especially in context of probable increase in global warming in this part of the Himalayan region.

Keywords: Glacial resource, remote sensing, Cirque, global warming, Neelum valley, Kashmir

Introduction

The glacial resource of northern Pakistan represents a unique resource of fresh water vital for agricultural, industrial, and hydropower generation. A major part of the snow and ice mass of the Pakistan's Himalayan region is concentrated in the watershed of the Indus basin. The glaciers of Kashmir lie in Mangla watershed which is drained by Jhelum River contributing about 16 percent flows to the Indus River system. The glacial environment is an important economic component of tourism and an influential factor in high mountain ecology. The glaciers, which consist of a huge amount of perpetual snow and ice, are found to create many glacial lakes. These glaciers as well as glacial lakes are the sources of headwater of our main Indus river system. Glaciers react very sensitively to climate fluctuations, and thereby provide some of the clearest evidence of ongoing climate change. For these and other reasons they have been selected among the essential climate variables (ECVs) in the terrestrial domain within the Global Climate Observing System (GCOS 2004).

Studies have revealed that the rate of Himalayan glaciers melt is increasing and that they are receding faster than in any other part of the world (Eccleston, 2008). According to Kaul (2005), there are 6500 glaciers in the Himalayan regions in India and out of which 3136 glaciers are in the mountain belt of Jammu and Kashmir. Of the major 327 glaciers in the Himalayas, 60 are in Kashmir and Ladakh. Due to their subsequent depletion, annual flows would be much lower which would inevitably affect the performance of dams. Half a billion people in the Himalaya-Hindukush region and a quarter billion downstream who rely on glacial melt waters could be seriously affected (Gilani, 2010). Glacier thinning and retreat in the Himalayas has resulted in the formation of new glacial lakes and the enlargement of existing ones due to the accumulation of melt water behind loosely consolidated end moraine dams that had formed when the glaciers attained their Little Ice Age maxima (ICIMOD, 2011). A detailed glacier inventory is critical to assess these changes and to model their future evolution (Paul, 2010). A comprehensive overview of the World Glacier Monitoring Service (WGMS) database was given by WGMS (2008).

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Kashmir, part of Himalayas, is one of the regions where little information is available on overall glacier extent or changes. There is also a need of repeated detailed inventories to assess the glacier changes over entire mountain ranges of Kashmir. Monitoring of glacier resource can be much facilitated by the effective use of satellite remote sensing (RS) technology. The RS technology is found to be one of the best tools for identifying such glacial lakes and offers strong advantages for rapid and qualitative hazard assessments of glacier lakes (Raj, 2010). The present work is aimed at developing baseline information of the existing glacial resource i.e. glacial ice mass and lakes, for future resource conservation and management. This would provide base for future resource monitoring and risk mitigation of climate induced hazards in this part of the Himalayan region.

Rasul et al. (2011) using satellite imageries and in-situ data have discussed another aspect related to root deposition on the low elevation glaciers. It results into accelerated rate of snow / ice melting developing glacial lakes near the terminus. They have also disclosed by analysis of meteorological data that warming trend is rising to higher elevation causing an upward shift of snowline. As a result, several animal species have moved to higher elevation and likewise the indigenous plant species. Snowline shift has also given rise to melting and hence formation of new glacial lakes and expansion of existing lakes. Resultantly, Glacial lake outburst Flooding (GLOFs) have also increased.

Geographical Setup and Physiography

The State of Azad Jammu and Kashmir comprises of 13,297 sq km area within longitudes 73° - 75° and latitudes 33° - 36° in the Himalayan region of Pakistan (Figure 1). It is a fascinating land of people, languages and culture. The elevation ranges from 360 meters above sea level (masl) in the South to 6325 masl in the North. It consists of 10 districts: Muzaffarabad, Neelum, Sudhnutti, Bhimber, Poonch, Mirpur, Bagh, Kotli, Havaile (Kahuta) and Hattian. Muzaffarabad, the state capital of Azad Kashmir is located at a distance of 138 km from Rawalpindi and about 76 km from Abbottabad at the confluence of the Jhelum & Neelum Rivers. The majority of the rural population depends on forestry, livestock and agriculture for its subsistence. The area under cultivation is around 171,332 ha (almost 13% of the total area), out of which 92% of the cultivable area is rain-fed. The major crops are maize, wheat & rice while minor crops include grams, pulses, oil-seeds and vegetables. Major fruits are apple, pears, apricot and walnuts.

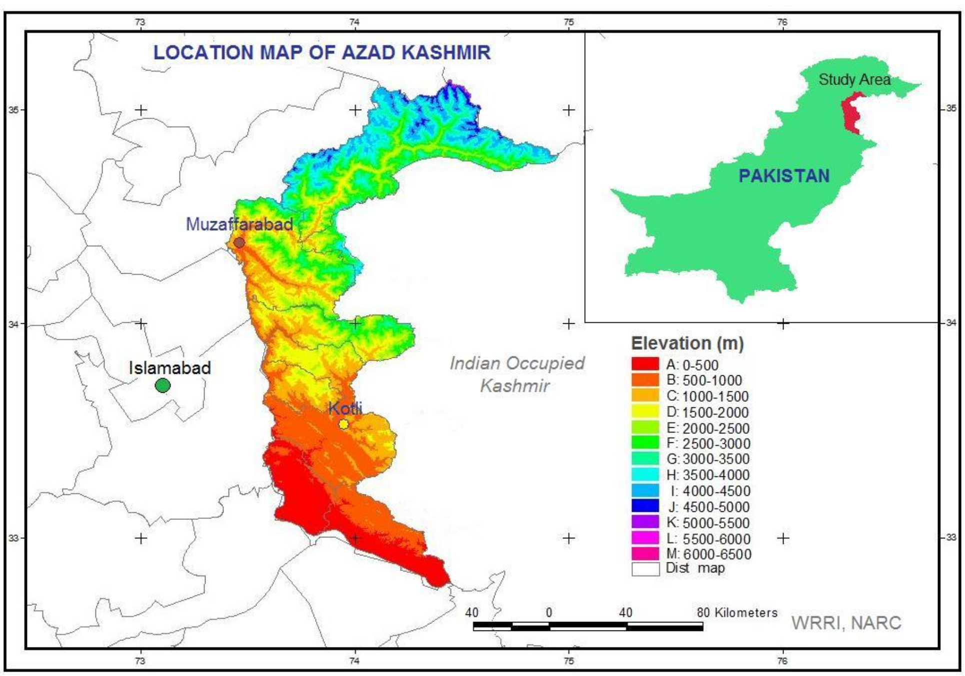

Figure 1: Location map of AJK indicating various elevation ranges

The state's area consists of valley plains, hills in the southeast and south, and high mountains in the west, northwest and north. The area is full of natural beauty with thick forest, fast flowing rivers, winding streams, snow-covered peaks and wheat-scented valleys like Neelum, Jhelum, Leepa, Rawalakot, Banjosa, Samahni & Baghser. Main rivers are Jhelum, Neelum and Poonch. The climate is sub-tropical highland type with an average yearly rainfall of 1300 mm and with maximum and minimum temperatures of 45.2°C and -2.6°C, respectively.

The glaciated area in Kashmir lies mainly in the Lesser and High Himalayas. The Lesser Himalayas are located in the north of Siwaliks and rise within 1,800-4,600 m range. The High Himalayas starts from 4600 m elevation with an average height of about 6,000 m and remain covered under snow throughout the year (Kaszmi and Jan 1997). Among total glaciated area of about 15,040 km^2 in the Upper Indus Basin of Pakistan (Roohi, 2005), 7.5% area lies in the Himalaya while the rest in the Karakoram and Hindukush Ranges. The Himalaya range comprises of Jhelum, Astore and Shingo river basins, and some parts of Indus sub-basin east and south of the Indus River contains ice reserves of about 76 km^3. The territory of Azad Kashmir lies mainly in the western part of Jhelum River basin. The permanent snow and glacial ice in Kashmir predominately exist in the Neelum valley district situated in the north and northeast part of Muzaffarabad. Here the significant glaciers are Saranwali, Shonthar, Parbat, Dewarian, Rati Gali and Mianwitch. A fair weather road opens the valley to tourists up to KeI which is a base camp of mountaineering activities up to "Sarawali Peak" (6325 m). From Kel, a way leads to Gilgit-Baltistan area via Shountar Pass at 4,420 masl. The snowline in Kashmir is around 1200 masl in winter and at 3300 masl in summer.

(http://www.ajk.gov.pk/index.php?option=com_content&view=article&id=21&Itemid=24)

Material and Methods

The glacier margins and exact boundaries between glaciers and seasonal snow are delineated on panchromatic mode and compared with other individual bands as well as in different color composite bands of Landsat-7 ETM image data for the year 2001. The panchromatic band of the image has 15 m resolution. The classification of glaciers is adopted from the morphological classification of glaciers by the World Glacier Monitoring Service (WGMS) defined by Muller et al. (1977). The glaciers were classified based on their physical characteristics like its form, frontal condition, longitudinal profile, source of nourishment and activity of tongue etc. The coding system is based on the subordinate relation and direction of river progression according to the World Glacier Inventory. The area and mean length of each glacier was measured using spatial functions of ILWIS GIS software. Some of the physical characteristics of glaciers were verified from the reference data available in literature and existing topographic maps. The orientations of accumulation and ablation zones are determined in eight cardinal directions. The zone of accumulation is found in the upper parts of the glacier and is still covered by the remnants of the previous winter's snow. The zone of ablation is below this and is characterized by older dirtier ice, from which the previous winter's snow has melted. An equilibrium line, marked by where the amount of new snow exactly equals the amount that melts that year separates these two zones. To estimate the ice reserve, the thickness of a glacier was estimated using following equation as adopted by Chaohai and Liangfu (1986) and Mool et al. (2001) and was multiplied by area of the glacier.

$$H = -11.32 + 53.21F^{0.3}$$

Where,

H = mean ice thickness in meter and
F = area of glacier in square kilometer

The elevation data of the study area was derived from 90 m digital elevation model (DEM) data retrieved from Shuttle Radar Topography Mission (SRTM). For the ease of relief measurements, the elevation is categorized into zones of 500 m interval and assigned alphabetic code for identification i.e. A-Zone starts from 0 to 500 masl; B from 500 to 1000 masl and so on. The study area lies mainly within A-M range of elevation zones (Figure 1). The distribution and characteristics of glaciers and glacial lakes were studied under various elevation zones.

Results and Discussion

The glaciated area in Azad Kashmir stretches over 0.8 percent area within G-M range of elevation zones. There are 224 glaciers of various types identified in the area, which contain ice-reserves of about 4.9 cubic km (Table 1 and Figure 2). Major types of glaciers are Cirque, Valley, Niche, Mountain, Ice apron and Ice cap which have distinct physical characteristics and association with the surroundings. Majority of glaciers belong to Cirque type (i.e. 89 numbers) followed by Ice-apron glaciers (43 numbers). Cirque glacier occupies a separate, rounded, steep-walled recess on a mountain while Ice apron is an irregular, usually thin ice mass plastered along a mountain slope (Mool, 2001; Roohi, 2005). About, 50 glaciers are Mountain type and 3 are Valley type glaciers that contain about 50% and 30% of the total ice reserves of the study area. The adjoining part of the Valley glacier at the headwater is characteristically a Mountain glacier, but due to its continuation into a Valley glacier, the whole ice mass are considered as a Valley glacier. The large Valley glaciers of Kashmir are Sarawali and Shonthar which have mean lengths of about 8 and 7 km and contain ice-reserves of about 0.488 and 0.534 km^3 respectively. The former is the largest in length and the later in surface area and ice-reserve. Both the glaciers are oriented in the southward direction and drain ultimately into Shonthar Nala joining Neelum River near Kel. Generally, the hanging glaciers formed over the mountains slopes are taken typical Mountain glacier. They can cause avalanche due to their susceptible condition. They are mainly nourished by snow and drift snow at the headwater and by snow and ice avalanches at the lower valley. There are 31 Niche type glaciers containing about 0.134 km^3 ice reserve. Niche glacier is formed in a V-shaped gully or depression on a mountain slope. There are few Ice cap glaciers which possess less than 0.02 km^3. Ice cap glacier is usually formed on mountain’s peak and possesses radial flow. Although small sized glaciers (area less than 50 ha) are higher in numbers but they contribute lesser ice reserves than the large sized glaciers (area >400 ha) as shown in Figure 3.

The thickness of glaciers ranges between 5 and 82 m with average thickness of about 24 m. About 53% of the glaciers have thickness greater than 20 m while only 5% have thickness more than 50 m. Most of the glaciers are oriented on the western and southwestern aspects of the mountains (Table 2). Generally, the concentration of Cirque and Mountain type glaciers are higher on the western aspect than on other aspects. The Ice apron and Niche types are dominant over southwestern aspect. The glacial area is dominant on the southern aspect due to presence of large sized Valley glaciers on this aspect (Figure 4).

Table 1: Summary of various types of glaciers found in Azad Jammu and Kashmir

Glacier Type	Number	Area (km^2)	Length (km)	Ice Thickness (m)	Ice Reserve (km^3)
Cirque	89	23.06	54.48	1895	0.681
Ice apron	43	6.68	19.85	801	0.153
Ice cap	8	0.95	2.85	133	0.017
Mountain	50	51.63	53.66	1754	2.464
Niche	31	5.49	19.94	594	0.134
Valley	3	21.72	16.77	240	1.459
Total	224	109.53	167.55	5417	4.908

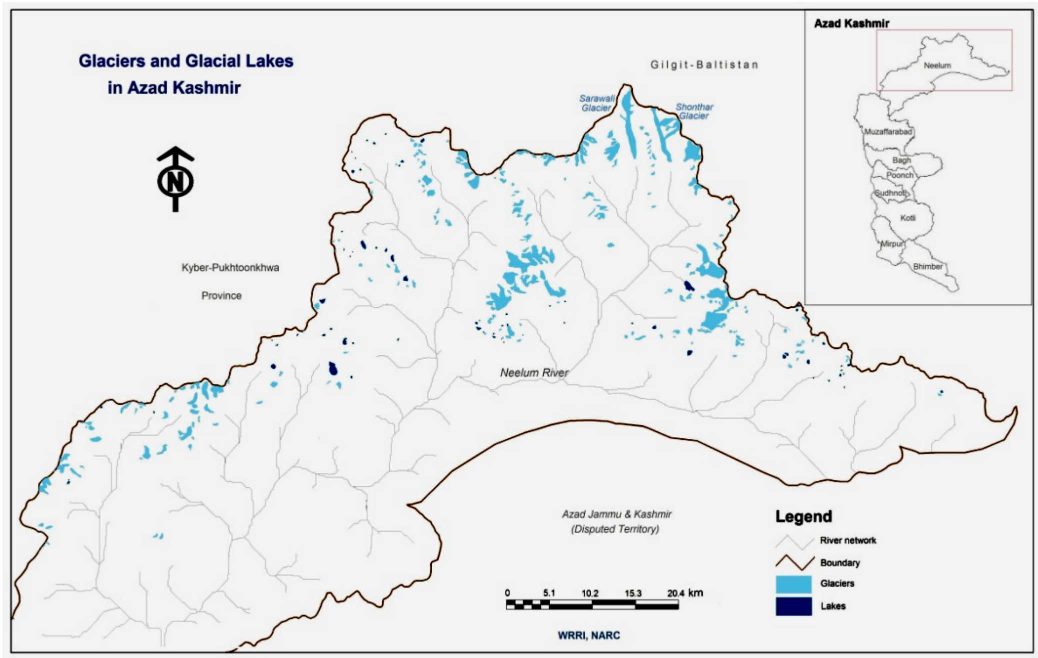

Figure 2: Glaciers and Glacial Lakes in Azad Jammu and Kashmir

About 87 glaciers covering 50% of the total glaciated area and over 63% (i.e. 3.104 km^3) of the total ice reserves of the AJK lie in the catchment of Shonthar Nala entering Neelum River along with other adjoining tributaries near Kel. The aggregate length of these glaciers is about 80 km. In other catchments like of Surgun Nala (joining Neelum River near Sharda) and Jagran Nala (entering Neelum River near Kundal Shahi), the glaciers are 60 and 35 in numbers containing about 21% (i.e. 1.048 km^3) and 10% (i.e. 0.497 km^3) of the total ice reserves of Kashmir.

Table 2: Aspect-wise distribution of glaciers and ice reserves.

Aspect	Number.	Area (km^2)	Ice Thickness (m)	Ice Reserve (km^3)	Ice Reserve %
N	29	9.17	658	0.321	6.5
NE	18	6.27	424	0.229	4.7
E	30	7.88	643	0.251	5.1
SE	24	5.51	475	0.161	3.3
S	26	26.86	717	1.299	26.5
SW	41	15.96	915	0.454	9.3
W	44	22.09	1136	1.114	22.7
NW	12	15.79	449	1.079	22.0
Total	224	109.53	5417	4.908	100.0

Table 3: Various types of glaciers over different aspects

Glacier Aspect / Type	Cirque	Ice apron	Ice cap	Mountain	Niche	Valley
N	14	6	1	6	2	-
NE	8	6	-	2	2	-
E	13	5	4	5	3	-
SE	11	5	-	3	5	-
S	6	3	2	7	6	2
SW	13	10	1	9	8	-
W	19	6	-	14	5	-
NW	5	2	-	4	-	1
Total	89	43	8	50	31	3

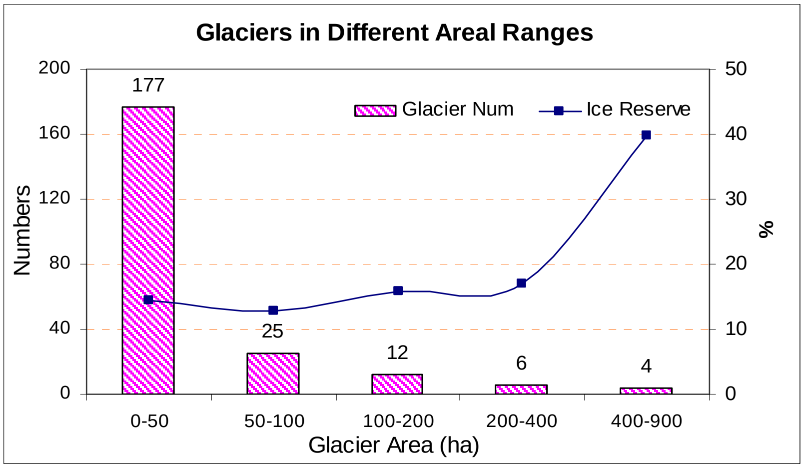

Figure 3: A few large size glaciers contributes significantly to the total ice reserves of AJK

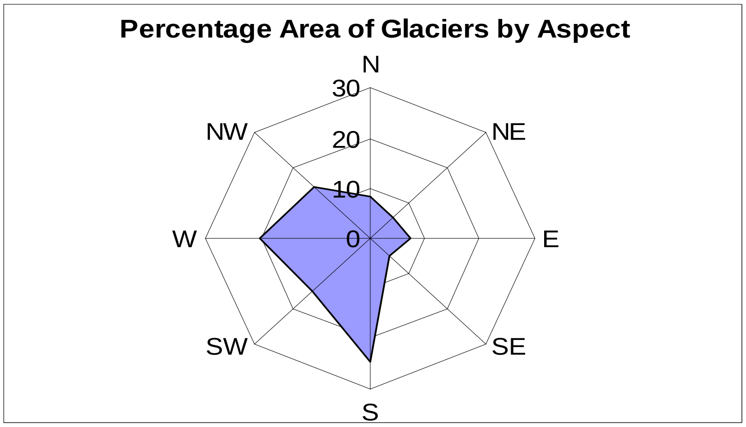

Figure 4: Glacial area is dominant over southern aspect of AJK

Glacial Lakes

In the last half-century, several glacial lakes have developed in the Hindukush-Himalayas and the Tibetan Himalayas. The glacial lakes are formed on the glacier terminus due to the recent retreating processes of glaciers (Meyer et al. 1993). The water in the lakes was accumulated from the melting of snow and ice cover and by blockage of the end moraines of glaciers. Most of these lakes are located in the down valleys close to the glaciers.

Altogether 76 glacial lakes are identified mainly in the Upper Kashmir area, among which 40 are major lakes having greater than 2 ha surface area. On the basis of physical characteristics of the lakes and their surroundings, six types of glacial lakes are identified. Most of the lakes belong to Erosion type (40 numbers) covering a total surface area of about 115.3 ha (Table 4). These lakes are usually formed in depressions eroded by the receding glaciers long before due to climatic change or so. Next major type is of Cirque lakes (15 numbers) which covered a total surface area of about 251.4 ha. Cirque lakes normally formed within eroded parts of mountain's slopes, may be cirque type and trough valley type, generally stable in condition. End moraine-dammed and Lateral moraine dammed lakes are 8 and 7 in numbers having surface coverage of about 128.4 and 10.4 ha, respectively. As a glacier tongue thins and retreats, meltwater traps in the trough between the glacier terminus and its end moraine resulting in formation of an end-moraine dammed lake (ICIMOD, 2011). Lakes may also accumulate along the glacier margins, between the lateral moraine and the valley side, which are termed as Lateral moraine-dammed lakes. Some of the renown lakes are Chittakatha (71.3 ha and 1.2 km long) and Dharian (103.7 ha and 1.7km long). The former drains in Shonthar Nala while the later into Doanrian nar that joins Neelum River from the westward. Most of the glacial lakes have natural drainage system i.e. water flows out in the form of streams.

Majority of the lakes are concentrated on the SW and N aspects (Table 5). The lakes area is maximum on the W while minimum on the SE aspect (Figure 5). The largest lake on the western aspect has an area of about 103.7 ha. Minimum lakes are oriented towards SE and NE directions. Erosion lakes are dominant on the SE and S aspects (Table 6). The end-moraine dammed lakes are equally dominant on the N, SW sides while Cirque lakes on the N, E, and W sides of the mountainous area.

Table 4: Summary of various types of glacial lakes in AJK

Lake Type	Number	Length (km)	Area (ha)	Largest Lake (ha)	Smallest Lake (ha)
Cirque	15	6.45	251.37	103.66	0.79
End Moraine	8	3.60	128.38	71.32	1.43
Erosion	40	7.54	115.31	11.86	0.38
Lateral Moraine	7	1.15	10.37	2.71	0.79
Valley	5	1.48	35.87	30.44	0.72
Block	1	0.24	3.76	3.76	3.76
Total	76	20.44	545.04	223.74	7.87

Table 5: Aspect-wise distribution of glacial lakes

Aspect	Number	Length (km)	Area (ha)	Largest Lake (ha)	Smallest Lake (ha)
N	13	4.45	126.39	30.44	0.72
NE	6	1.26	31.03	20.21	1.30
E	11	2.19	43.09	24.07	0.79
SE	6	1.24	22.12	11.79	0.54

S	10	2.52	33.85	11.72	0.38
SW	14	2.77	47.60	12.46	0.53
W	9	3.50	143.40	103.66	0.44
NW	7	2.52	97.56	71.32	1.16
Total	76	20.44	545.04	285.65	5.86

Table 6: Distribution of various types of glacial lakes over different aspects

Aspect/Lake Type	Block	Cirque	End Moraine	Erosion	Lateral Moraine	Valley
N	-	3	2	4	2	2
NE	-	1	1	2	2	-
E	-	3	1	4	2	1
SE	1	1	-	3	-	1
S	-	1	1	8	-	-
SW	-	1	2	9	1	1
W	-	3	-	6	-	-
NW	-	2	1	4	-	-
Total	1	15	8	40	7	5

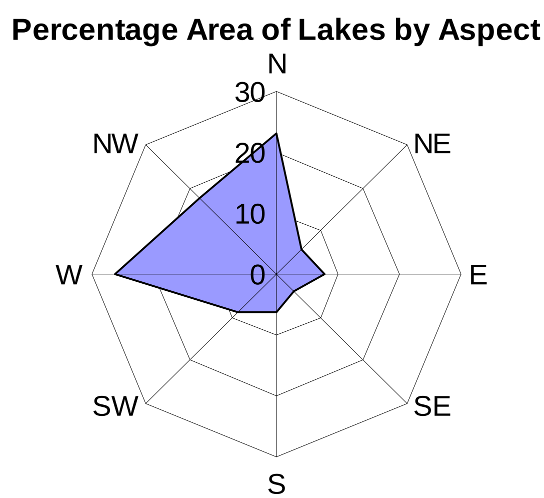

Figure 5: Lakes area is dominant over western aspect of AJK

Glacial Environment by Elevation

The glaciers environment is dominant in the 4000-4500m (Zone: I) elevation range as maximum of about 49% glaciated area (Figure 6) and 61% of the glacial lakes area lie within this zone. It is interesting to note that 2nd maxima of the glaciated area lies above this zone (i.e. within Zone: J) while of lakes area below this zone (i.e. within Zone: H). About 115 partial or full glaciers and 55 glacial lakes lie within 4000-4500m range, while 89 glaciers and 3 lakes only in the 4500-5000m range and above this no lake exist (Figure 7). The elevation above 4000-4500m range seems behaving as snow accumulation zone of the glaciers. Generally, a glacier is maintained by accumulation of snow at high altitudes that is balanced by ice loss due to melting at low altitudes (IPCC 2007). This melting of glacial ice mass discharges into streams or lakes downstream. The surface coverage of two large glaciers i.e. Sarawali and Shonthar indicates influence of topography and surrounding environment. Maximum coverage of about 38% of Sarawali glacier falls in 3500-4000m range while 33% of Shonthar glacier in the 4000-4500m range (Figure 8). In 4500-5000m, the Sarawali and Shonthar glaciers have 21% and 23% coverages respectively. There is a gradual decrease in glacial area of Sarawali upward 5000masl. Although Shonthar indicates a similar trend but there is an increase in coverage (25%) within 5000-5500m range likely due to mergence of branch glaciers from the surrounding.

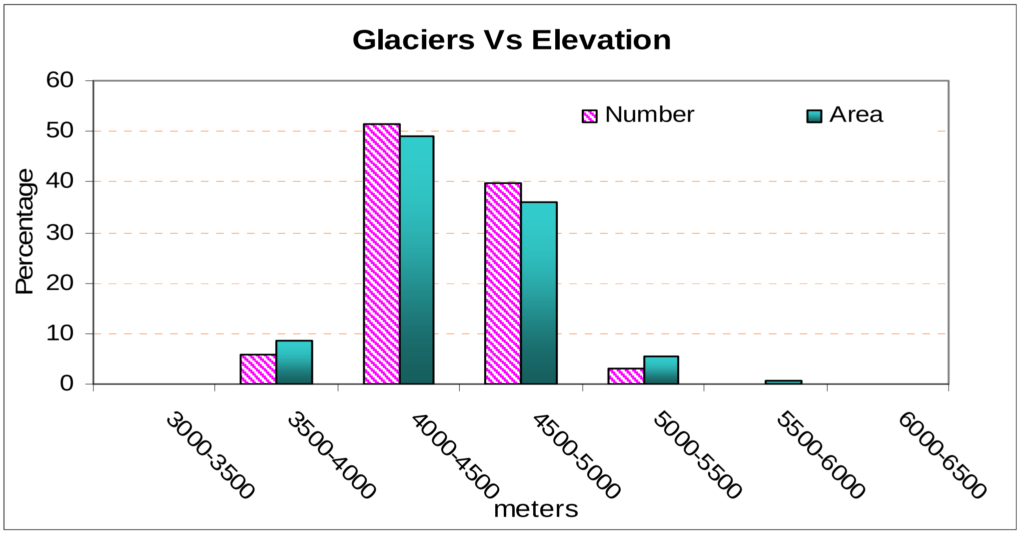

Figure 6: Glaciers numbers and coverage (%) over different elevation ranges

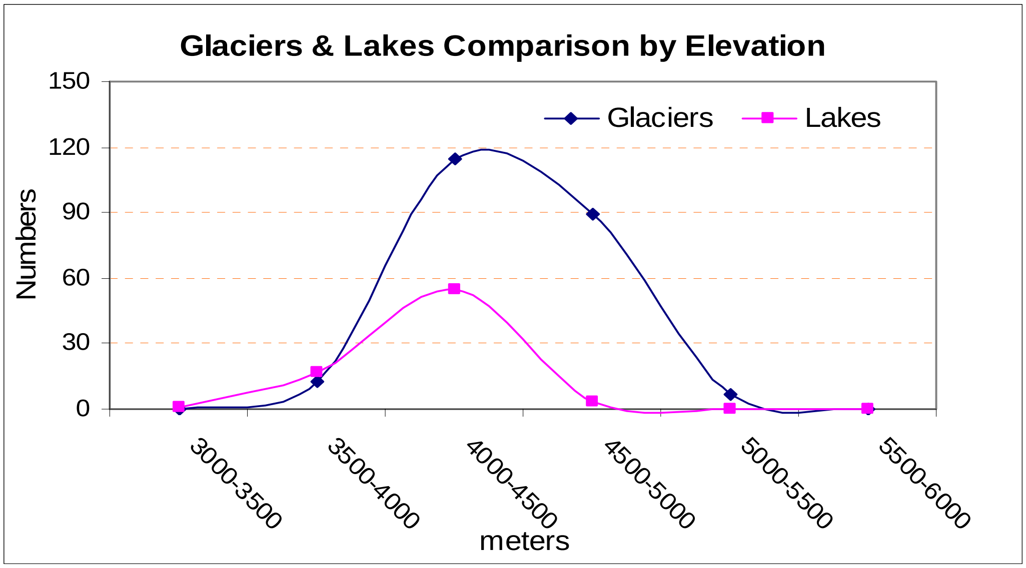

Figure 7: Distribution of glaciers and lakes over different elevation ranges

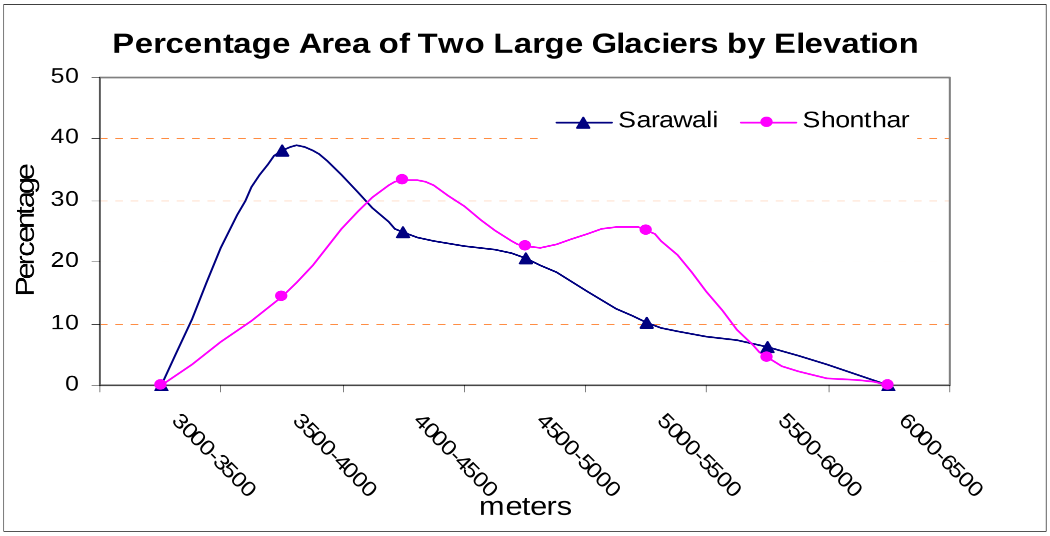

Figure 8: Surface area of Sarawali and Shonthar glaciers is high below 5000 masl

Conclusion

The glaciated area of Azad Jammu and Kashmir comprises of 224 glaciers containing ice reserves of about 4.9 km^3. It constitutes over 0.8 percent of the AJK area and 3 percent of the Neelum district area. About 49% of the glaciated area and 61% of the glacial lakes area lie within 4000-4500m elevation range. Majority of the glaciers belong to Cirque type (i.e. 89 numbers) followed by Ice-apron type glaciers (43 numbers). The glacial coverage is relatively higher on the southern and western aspects. Among 76 glacial lakes identified in the AJK, about 53 percent lakes belong to Erosion type and 20 percent to Cirque type. The presence of high number of Erosion type lakes in this area is indicative of receding of glaciers likely due to global environmental changes in the past. The generated information and database of the glacial resource would provide base not only for resource conservation and management but also for studying climatic change impacts on glacial environment in this region in future. The monitoring of glaciers and lakes can be much facilitated by using high resolution remote sensing data coupled with frequent field observations. Being part of the Himalayan region exposed to global climate change risk, there is a need to monitor behavior of the glaciers and glacial lakes, and compile their inventories on regular basis to ensure effective water resources management in future.

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