RESEARCH ARTICLE

Hypsometric analysis of major glaciers of Shigar river basin in the Karakoram mountain range

Siddique Ullah Baig

Abstract: Unique environment and multifaceted mountain geo-dynamics of Karakoram disguise the variations present in the hypsometries (frequency distribution of altitudes). We report hypsometry of mountain glaciers of Shigar river basin (with a 7046 km^2 land-covered area) in the Karakoram, to understand area-elevation relations of glacier environments and effects of magnitude of glaciated-area and location of Equilibrium Line Altitude (ELA). We apply a method based on histogram analysis of glacier hypsometry and a pixel-based regression tool on an updated version of glacier outlines. A big portion of the largest glaciated area (20.63%) of Shiger river basin lies between mixed (high velocity), net accumulation (low velocity) regime of horizontal zone and clean-dusty regime of vertical zone. The smallest glaciated area is found in the extreme ends of the high (in the net avalanche accumulation and low velocity zone and temperature below -18°C) and low (the mostly debris and clean dust-covered ice, net ablation and medium velocity area) altitudes. There are major differences in the hypsometry of the smallest and largest glaciers like except Panmah glacier, large portions of largest glaciers (*e.g.* Baltoro, Biafo and Chogo Lungma) lies at ELA. Smallest glaciated area lies in low altitudes may contribute melt-water significantly to Indus river rise due to their shorter response times as compared to larger glaciers. The high elevation precipitation may sustain the glaciers of this basin whose melt-waters, especially those from largest glaciers, in turn feed the Shigar river. This dependence of the river on glacial and ice melt is manifested in the huge seasonal variation in its flow.

Keywords: Karakoram, hypsometry, Shigar river basin

1 Introduction

Karakorum has the highest portion of the glaciated ice where ∼37% area is occupied by small and large glaciers, compared to 8-12% of the Himalaya and only 2.2% in the Alps[1]. Out of 22862 km^2 land-area covered by Karakoram glaciers[2], glaciated-area is much higher in Shyok (5937 km^2), Hunza (2753 km^2) and Shigar (2374 km^2) sub-basins as compared to other basins of upper Indus[3]. Indus river basin (a lifeline for 200 million Pakistani people living downstream) has various degrees of reliance on melt-water from 3357 glaciers of Shyok, 439 of Shigar, 1384 of Hunza and 968 of Gilgit sub basins.

Hypsometry plays as a major role in understanding glacier dynamics, its response to climate change and is therefore an essential tool for predicting what might happen to glacier ice mass with changing regional temperatures. However, examination of climatic patterns of the Karakoram does not describe size distributions of glacier and hypsometry[4] but hypsometry of glaciated basins tilting towards high altitudes as compared to non-glaciated basins can describe complex mountain dynamics of Karakoram. Secondly, application of hypsometry to gauge the effects of climatic change has become necessary for Karakoram region as fluctuations in glacial ice covered-area is observed due to temperature rise by 2-4°C across the Indus basin, which are a lifeline for the downstream communities of Karakoram.

Hypsometry refers to frequency distribution of altitudes over an area. Proportion of land-area lies under a certain altitude or height above sea level is represented by hypsometric curve. Historically, hypsometry as a tool has been applied to study dynamics of erosion processes of landscapes[5,6] but is influenced by independent variables like drainage-area[7]; lithology[8]; geo-dynamics[4]. Especially, glacier hypsometry, along with its energy-balance characteristics, plays a major role in its response to climate change. It may explain asymmetry of glacial recession under a uniform temperature increase regime and may influence the response of a glacier under different

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climate change modelling scenarios[9]. A valley glacier whose greater part is sitting on a plateau will lose a significant amount of mass even though it is of a large size (ibid). Mostly, glaciers in the Karakoram are mountain glaciers. Ironically, technical development for hypsometric assessment of mountainous glaciers of Karakoram compared to eastern Himalayan glaciers has been slow due to multifaceted topography, challenging logistics, disputed territory and geo-political restrictions associated with information gathering from field-surveys. Therefore, Geographic Information System (GIS) and remote sensing techniques have become a reasonable approach to determine the amount of mass loses at certain elevations.

The hypsometry for glaciers of Alaska was delivered by Kienholz *et al.*[10], which rely on the Shuttle Radar Topography Mission DEM (SRTM), a regional Interferometric Synthetic Aperture Radar (InSAR) Digital Elevation Model (DEM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) GDEM2. Bliss *et al.* (2014)[11] provided the hypsometry for the Antarctic and Subantarctic islands based on a DEM relied on the SRTM DEM, ASTER GDEM2 and maps. Mukhopadhyay and Khan (2016) derived glacier hypsometries for all upper Indus basins watersheds from RGI Version 3.0 in combination with elevation data derived from SRTM while Hakeem *et al.* (2014)[12] used World Glacier Inventory (WGI) updated in 2002, compiled and made available by WGMS (Switzerland) and NSIDC for Shigar basin.

Unique environment and multifaceted mountain geodynamics of Karakoram disguise the variations present in the glacier hypsometries. Therefore there are differences in the effects of magnitude of glaciation and location of Equilibrium Line Altitude (ELA) on individual glaciers. In this paper, we used updated version of RGI[2] for glacier outlines to construct and analyze glacier hypsometric relations of glacier environments of the Shigar river basin (with a covered-area of 7046 km^2) in the Karakoram, a remote region of the world. For this purpose, we applied a simple method based on an analysis of histogram of the (frequencies of altitudes) over glacial-area. Elevation bins are restricted to (*e.g.* 500 m for Shigar drainage basin, 200 m for largest glaciers like Biafo glacier, Baltoro, Chogo Lungma and Panmah). Spatial patterns of glaciated-areas are analyzed based on pixel-based regression tool. Glacial hypsometries, when included with other aspects like Equilibrium Line Altitude (ELA), vertical and horizontal aspects (Wake (1989)[13] helped us to better understand glacier environments of mountainous region. The melting of glaciers and snow of Shigar river basin in summer time is a significant source of water flow in the Indus river system, making it one of the most melt-water dependent rivers of the region. Therefore what happens to the glaciers and how that affects river flows has a huge implication for the country as a whole.

2 Study area

The present study was undertaken on the glaciers of Shigar river basin which lies entirely within the central Karakoram segment of the Hindu Kush-Himalaya region of northern Pakistan (Figure 1). With an area of 7046 km^2 and spatial domain of 35.4°-36.1° N and 74.9°-76.7° E, Shigar is one of the major sub-basins of the upper Indus river. It ranges in elevation from 8611 m at the top of K2 peak to 2775 m above sea level at Shigar Bridge, with an average elevation of 4613 m. Hypsometric curves of the basin show that over 42% of land lies between 4000 and 5000 m above sea level[12,14]. Table 1 shows the major characteristics of the study area. There are 439 glaciers within the basin, including the Biafo and Baltoro glaciers, with the glaciated area being 2374 km^2 (∼33% of total area) and ice reserves estimated to just over 600 km^2[3].

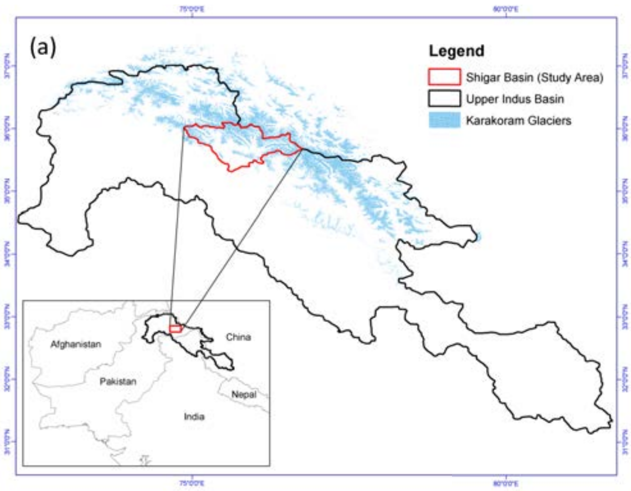

Figure 1. Location of the study area (Shigar river basin)

The climate of Shigar river basin is classified as BWk according to the Kppen-Geiger classification scheme which is a cold desert type climate with a large diurnal and seasonal temperature range. Monsoon winds penetrate only slightly into this region and most of the precipitation originates chiefly from westerly depressions. Most of it is intercepted by the tall mountains and falls on the higher elevations in the form of snow, with 44% of the total concentrated in March-May and a maximum in April[14]. The valleys of the basin are dry with about 400 mm yr-1 precipitation, decreasing south-westward to about 215 mm yr-1 at Sakardu[12]. The high elevation precipitation sustains the glaciers of this region whose melt-waters, especially those from Baltorr, Biafo and Chugolugma glaciers, in

Table 1. Characteristics of the study area

Area	Measured Value
Latitude	35.4° - 36.1° N
Longitude	74.9° - 76.7° E
Drainage area	7319.46 km² (Calculated from ASTER GDEM2 in this study) ~7000 km² (Hakeem et al, 2014) 7046 (Bajracharya and Shrestha 2011)
Glaciated area	2182Km² (calculated using glacier outlines of RGI–V.5.0 in this study) 2120 km² (Hakeem et al. 2014) 2240 km² (Cambell et al. 2004) 2374 km² (Bajracharya and Shrestha 2011) 2431 km² (calculated using WGMS and NSIDC (1999), updated 2012)
Lowest elevation	2718 m
Highest elevation	8572 m
Glacier coverage (%)	29.81 % (calculated by using RGI-V.5.0 in this study) 30% - 39% (Hakeem et al, 2014)

turn feed the Shigar river. This dependence of the river on glacial and ice melt is manifested in the huge seasonal variation in its flow, from a maximum of over 700 m3 s-1 in August to almost 50 m3 s-1 in December-January[14].

3 Material

3.1 Glaciers data

Two sets of glaciers data (*i.e.* Randolph Glacier Inventory (RGI)-Version 5.0 (released in July 2015 and available on http://www.glims.org/RGI/randolph50.html for glacier outlines and database of World Glacier Inventory Services (WGMS) (updated in 2012 and available on ftp://sidads.colorado.edu/pub/DATASETS/NOAA/G01130, updated 2012) for glacier geomorphology were used for this paper. RGI-Version 5.0 contains outlines of glaciers while WGMS covers morphological data of glaciers. Glaciers of Region 14 representing South Asia (West) like sub-region 14-01 (Hidukush), sub-region 14-02 (Karakoram) and sub-region 14-03 (West Himalaya) are entirely new in RGI Version 5.0[2]. Secondly, in this new dataset, glacier outlines covering some parts of the Karakoram region is extracted from the Dresden/Zurich outlines[15]. Thirdly, it has fresh coverage of most of Asian glaciers. However, only glaciers with areas <0.01 km^2 are removed based on the recommendations of the WGI. Glaciers outlines for some parts of Karakoram region, which were not covered in this dataset, were taken from other sources[16,17].

3.2 Topography

ASTER Global Digital Elevation Model Version 2 (GDEM2) (worldwide compiled, arranged and clarified ASTER DEMs)[18] data set of 30 m resolution (available on https://earthexplorer.usgs.gov) is used to study topographic features of glaciers of Shigar river basin. The GeoTIFF format of ASTER GDEM2 was available with geographic coordinates referenced to the WGS84 geoid and a 1 arc-second 30m grid of elevation therefore it easily overlapped Shigar river basin glacier outline GIS layers which were referenced with the same WGS84. The chosen GDEM2 was consistent with four scenes covering the entire Shigar river basin with an accuracy of 17-m at the 95% confidence level, and a 75 m horizontal resolution[19]. GDEM2 contains anomalies and artifacts that may reduce its effectiveness for use in certain applications. Despite this, we preferred GDEM2 for this study although SRTM has a better vertical accuracy than the ASTER GDEM[20] but topographic structures available for Shigar river basin from SRTM website contain several holes or missing data for Karakoram region. Figure 2a shows a map of elevation ranges (m) of Shigar river basin and histogram and hypsometric curve of frequency distribution of elevation ranges (Figure 2b).

4 Methods

To analyze glacier hypsometry (frequency distribution of altitudes), we applied a simple method based on histogram (glaciated-area proportional to the frequency of elevations) over glacier outlines of Shigar river. ELA

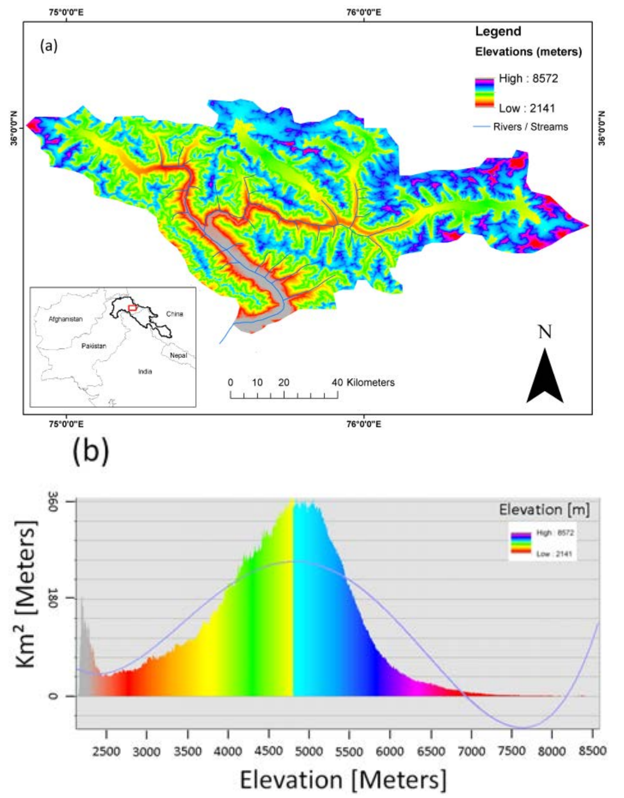

Figure 2. (a)Map of the study area with elevation ranges and (b) histogram of the frequency distribution of elevation ranges, hypsometric curve represents regression pattern of elevations)

for Karakoram from Wake (1989)[13] is positioned over histogram. Elevation bin as class interval is restricted to a 500 m height for Shigar drainage area and 200 m for each largest glacier to minimize a compromise between information concealment due to too large bin size, and loss of information with too smaller size. In this exercise, we found that 500 m elevation bin size is most appropriate for larger mountain areas like Shigar drainage while 200 m for largest glaciers (*e.g.* Baltoro, Biafo, Chogo Lungma and Panmah). Secondly, spatial patterns of glaciated-areas are analyzed based on pixel-based regression tool (CurveFit) with polynomial degree (>1): 5. We focused on four representative largest glaciers based on their respective hypsometric curves and interpretations based on areaaltitude relations model from Wake (1989)[13] for glacier environments in the central Karakoram. Glacier lengths and sizes are calculated to determine ratios between concentration of largest and smallest glaciers.

5 Results and Analysis

5.1 Characteristics of Glaciers

Glaciers outlines of RGI-Version 5.0 cover 2182 km^2 land-area with 345 glaciers as compared to 2374 km^2 estimated by ICIMOD[3] with 439 glaciers. In comparison with ICIMOD, in RGI's Version 5.0 database, 192 km^2 or outlines of 94 smallest glaciers are missing (smallest glaciers with the size ¡ 0.1 km^2 may already been removed based on minimum recommendation of WGI). Mostly, Shigar glaciers adhere to mountain sides therefore doesn't fit in other primary classification pattern given by Rau *et al*. (2005)[21]. Half of glaciers or 51.8% have smallest sizes (< 1 km^2) while only 4 or 1.8% glaciers have largest sizes between (250-640 km^2) and cover 70.25% or 1534 km^2 glacial area of Shigar. Table 2 shows the characteristics (*e.g.* length, land-covered area (in km^2), elevation range and number of tributaries) of largest glaciers. These small glaciers contribute melt-water significantly to Indus river rise due to their shorter response times as compared to larger glaciers. More details about range of glacier sizes starting from 0.045 above 250 and their concentration (number of glaciers) on elevations is shown in Figure 3a. Figure 3b is an illustration of radar graph of glacier sizes and number of glaciers (in percentage). There are far smaller glaciers in the basin than the big ones although it is the four biggest glaciers which occupy more than two thirds of the glaciated area of Shiger river basin. Most of the glaciers are located in the northwest, north and northeast of the basin while only a few small ones are found in the south.

5.2 Glacier Hypsometry

Hypsometry (frequency distribution of altitudes) over glacier outlines of Shigar river basin is shown in (Figure 4a). Location of ELA for Karakoram over histogram (glaciated-area proportional to the frequency of elevations) with a 500m elevation bin as class interval and pixel-based regression pattern of glaciated-area is depicted in the Figure 4b. According to the Wake (1989)[13] model, the largest glaciated area (20.63%) between 4672 to 5024 m lies in the vertical regime of clean-dusty ice and in-between the horizontal regime of mixed zone with high glacier velocity and net accumulation zone with low velocity. Mean annual temperature and precipitation of largest glaciated area is between (-5 and -10°C) and (1800 and 2000 mm) respectively. The smallest is found in the extreme ends of the altitudinal range, *i.e.*, 3.26% between 6372 to 8572 m corresponding to net avalanche accumulation and low velocity zone, where mean annual (temperature) remains (below -18°C) and 4.12% below 2718 to 3805 m is the mostly debris and clean dust-covered ice, net ablation and medium velocity area. Mean annual (temperature) and precipitation of smallest glaciated area is reported to be between 0 and +10°C and precipitation value respectively. The second largest glaciated area (19.50%) lies between 5024 to 5379

Table 2. Geographic location and characteristics of largest glaciers of Shigar river basin

Glacier	Geographic Location (Long, Lat)	Length (km)	Area (km²)	Highest Elevation (m)	Lowest Elevation (m)
Baltoro	76.0-76.7, 35.6-35.9	63	607	7868	3436
Biafo	75.5-75.9, 35.7-36.1	67	406	7131	3041
Chogo Lungma	74.9-75.3, 35.8-36.1	45	245	6940	2757
Panmah	75.7-76.1, 35.8-36.1	40	274	6503	3500

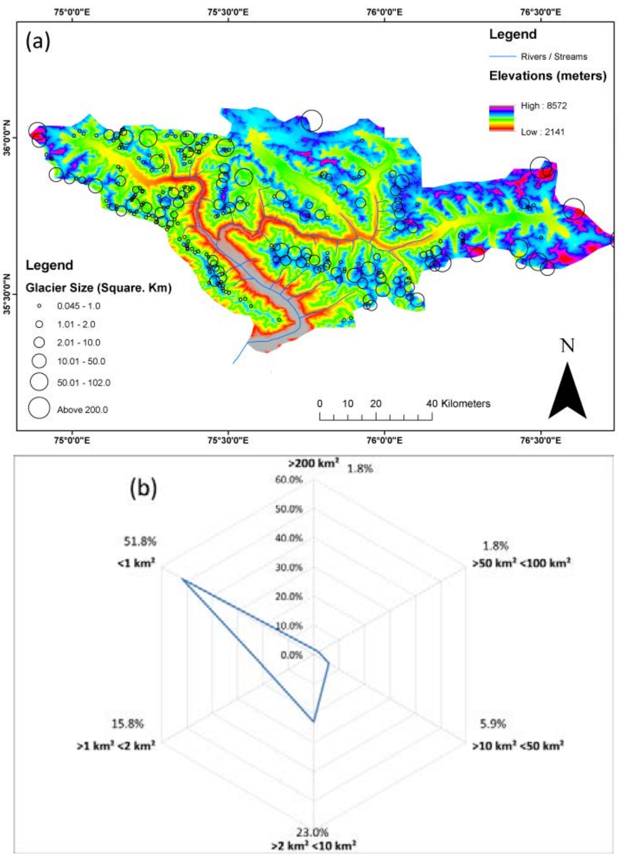

Figure 3. (a) Map of size distribution and (b) concentration of glaciers in the study area and radar graph of distribution of number of glaciers (in %) and size (in km^2)

m in the net accumulation (net freezing) and low velocity zone. Other regions with significant glaciation, 16.63% and 15.50%, lie in the mixed and high velocity zone between 4288 and 4672 m and in the net accumulation and low velocity zone between 5379 and 5793 m respectively. Details pertaining to representative but largest glaciers are described in following sections.

5.2.1 Baltoro Glaciery

Figure 5a shows the hypsometry (frequency distribution of altitudes) over glacier outline of 63 km long Baltoro glacier, one of the largest land glaciers of Karakoram, covering an area of 607.28 km^2 or 27.83% of total glacial ice-area of Shigar river basin. Location of ELA for Karakoram over histogram (glaciated-area proportional to the frequency of elevations) with a 200 m elevation bin as class interval and pixel-based regression pattern of glaciated-area is depicted in the Figure 5b. The largest glaciated area 18.07% between 5321.01 to 5693 m lies in the vertical regime of direct-snow accumulation and the horizontal regime of net accumulation zone and low glacier velocity. Mean annual temperature and precipitation of largest glaciated area is reported to be between -13 °C to -15 °C (cold surface) and 1600-2000 mm respectively. The smallest is found in the extreme ends of the altitudinal range, *i.e.* 3.89% between 6622.01 and 7868 m corresponding to avalanche accumulation and temperature (below -22°C) of vertical regime and low velocity zone of horizontal regime and 6.54% below 3436 and below 4111 m in the mostly debris and clean dust-covered ice and in-between mixed and high velocity of vertical regime and net ablation and medium velocity zone of horizontal regime. Mean annual temperature and precipitation of smallest glaciated area is reported to be between -2 and +5°C and 1000-1500 mm respectively. The second largest glaciated area (17.82%) lies between 4533.01 to 4933 m in the vertical regime of clean-dusty ice while half in the horizontal regime of mixed zone and high glacier velocity and half in the net accumulation (net freezing) and low velocity zone. Other regions with significant glaciation, 16.12% and 14%, lie in the mixed and high velocity zone between 4933.01 to 5321 m and in the net accumulation and low velocity zone and between 4111 to 4533 m (mixed zone and high glacier velocity) and 5693.01 to 6106 m (net accumulation and low velocity) respectively.

5.2.2 Biafo Glacier

Figure 6a shows the hypsometry (frequency distribution of altitudes) over glacier outline of 67 km long Biafo glacier, covering an area of 406.27 km^2 or 18.62% of total glaciated area of Shigar river basin. Location of ELA for Karakoram over histogram (glaciated-area proportional to the frequency of elevations) with a 200m elevation

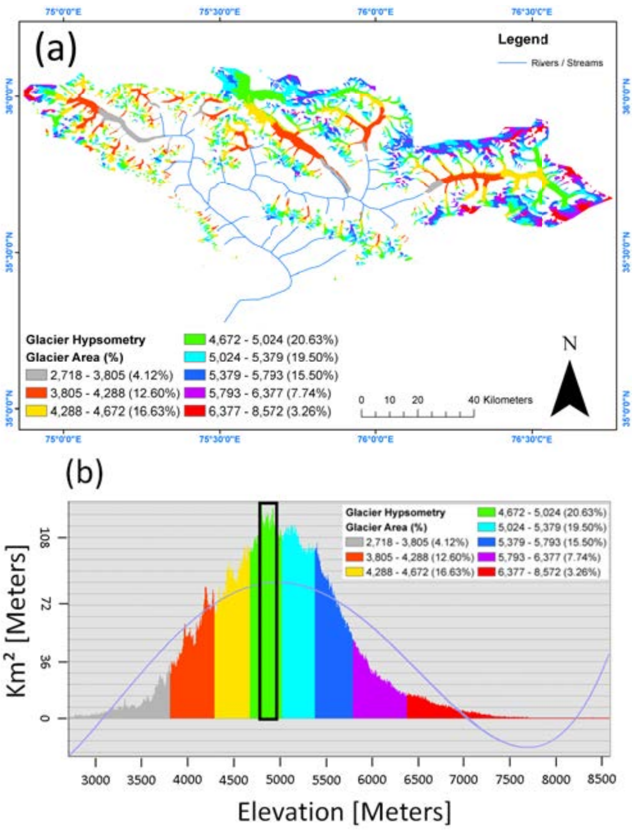

Figure 4. (a) Hypsometry (frequency distribution of altitudes) over glacier outlines of Shigar river basin and (b) location of ELA for Karakoram over histogram (number of pixels of glaciated-area) proportional to the frequency of elevations with a 500m elevation bin as class interval and regression pattern of glacier area represented by CurveFit

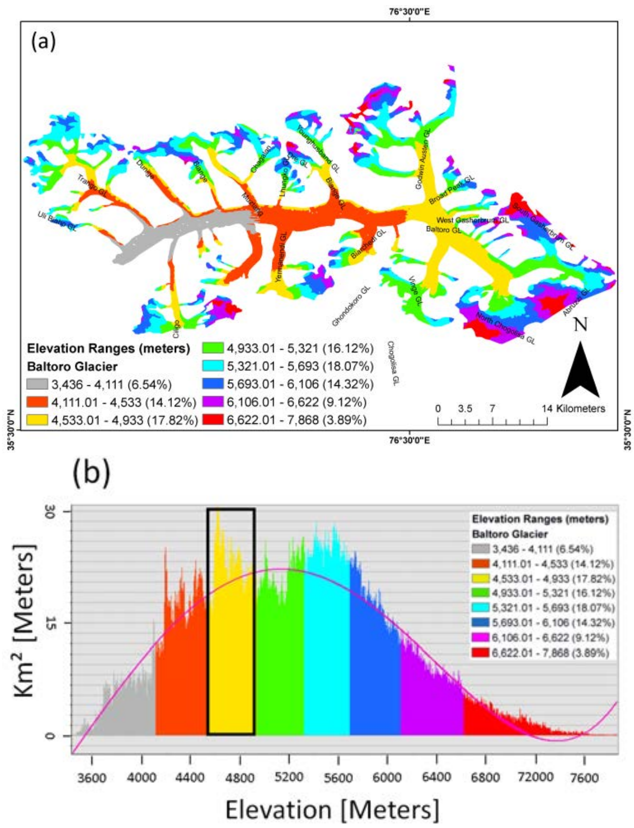

Figure 5. (a) The hypsometry (frequency distribution of altitudes) over glacier outline of Baltoro glacier and (b) the location of ELA for Karakoram over histogram (number of pixels of glaciated-area) proportional to the frequency of elevations with a 200m elevation bin as class interval and regression pattern of glacier area (CurveFit)

bin as class interval and pixel-based regression pattern of glaciated-area is depicted in the Figure 6b. The largest glaciated area (24.71%) between 4240.01 to 4623 m lies in the vertical regime of clean-dusty ice and the horizontal regime of mixed / high glacier velocity / freezing / melting zone. Mean annual (temperature) and precipitation of largest glaciated area is reported to be between -1 to -6 °C and 1500-1800 mm respectively. The smallest is found in the extreme ends of the altitudinal range, *i.e.*, 1.71% between 5956.01 and 7131 m in-between corresponding to (net avalanche accumulation and low velocity zone) and (the direct snow accumulation) and 4.7% below 3041 and 3753 m in the mostly debris-covered ice, net ablation / melting and medium velocity area. Mean annual temperature and precipitation of smallest glaciated area in the high elevation is between (-17 and -25 °C) and while in the low elevation between 0 and +6 °C and 900-1400 mm. The second largest glaciated area (17.92%) lies between 4935.01 to 5210 m in the net accumulation (net freezing) and low velocity zone. Other regions with significant glaciation, half of the 15% and 15.50%, lie in the net ablation / medium velocity and half in mixed / high velocity zone between 37530.1 to 4240 m and in the mixed / high velocity and net accumulation / low velocity zone between 4240.01 to 4623 m respectively. Out of the 63 km, about 51 km of this glacier meet the 49 km long Hispar Glacier (in Hunza Basin) at an elevation of 5128 m and create a 100 km highway of ice.

5.2.3 Chogo Lungma Glacier

Figure 7a shows the hypsometry (frequency distribution of altitudes) over glacier outline of the 45.3 km long Chogo Lungma glacier, covering an area of 245.65 km^2 or 11.26% of total glacial ice area of Shigar river basin. Location of ELA for Karakoram over histogram (glaciated-area proportional to the frequency of elevations) with a 200 m elevation bin as class interval and pixel-based regression pattern of glaciated-area is depicted in the Figure 7b. The largest glaciated area 35.13% between 4271.01 to 4969 m lies in the vertical regime of clean/dusty ice and in-between (in the horizontal regime of net accumulation zone, low glacier velocity) and (mixed zone and high

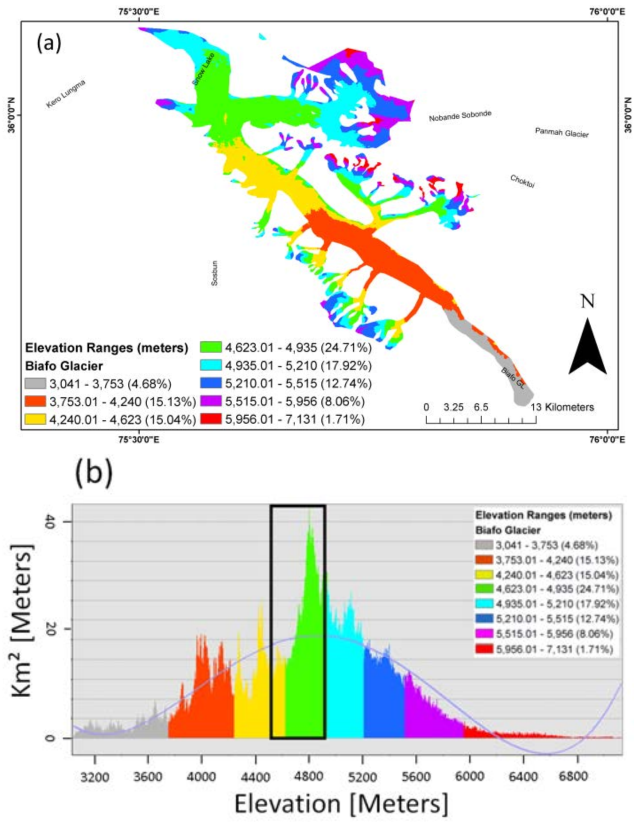

Figure 6. (a) The hypsometry (frequency distribution of altitudes) over glacier outline of Biafo glacier and (b) the location of ELA for Karakoram over histogram (number of pixels of glaciated-area) proportional to the frequency of elevations with a 200m elevation bin as class interval and regression pattern of glacier area (CurveFit)

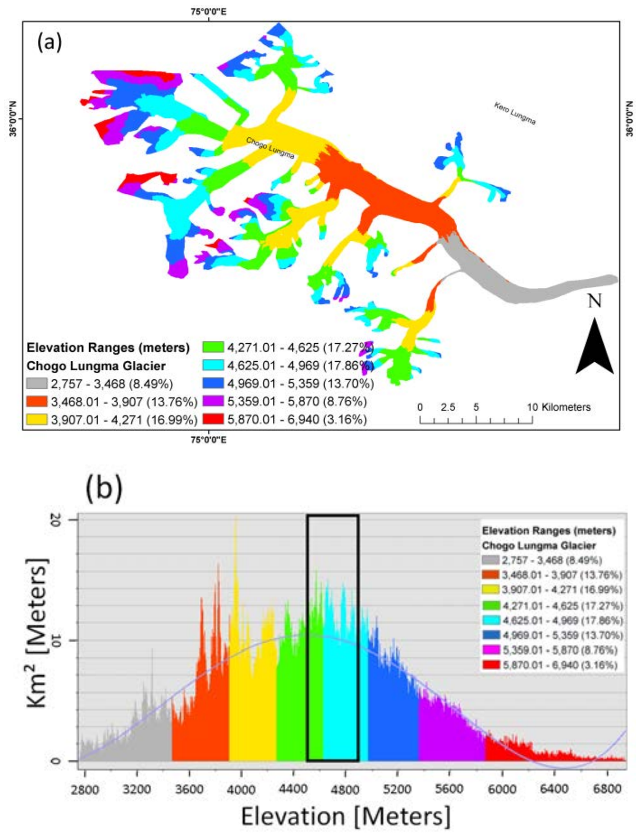

Figure 7. (a) The hypsometry (frequency distribution of altitudes) over glacier outline of Chogo Lungma and (b) the location of ELA for Karakoram over histogram (number of pixels of glaciated-area) proportional to the frequency of elevations with a 200m elevation bin as class interval and regression pattern of glacier area (CurveFit)

velocity). Mean annual (temperature) and precipitation of largest glaciated area is reported to be between (-2 to -8°C) and (1500 and 2000 mm) respectively. The smallest is found in the extreme ends of the altitudinal range, *i.e.*, 3.16% between 5870.01 to 6940 corresponding to direct snow accumulation of vertical regime (temperature -15 to -20°C, precipitation 1000 to 1700 mm) and low velocity zone of horizontal regime while 8.49% between 2757 and 3468 m in the debris-covered ice and net ablation / medium velocity zone (temperature 4 to +8°C, precipitation 800 to 900 mm). The second largest glaciated area (16.99%) lies between 3907.01 to 4271 m in the vertical regime of clean-dusty ice while half in the horizontal regime of mixed zone and high glacier velocity and half in the net accumulation (net freezing) and low velocity zone. Other regions with significant glaciation, 8.76%, lie in the direct snow accumulation of vertical regime and net accumulation and low velocity of horizontal regime.

5.2.4 Panmah Glacier

Figure 8a shows the hypsometry (frequency distribution of altitudes) over glacier outline of the 44 km long Panmah glacier, covering 274 km^2 or 12.60% of total glacial ice of Shigar river basin. Location of ELA for Karakoram over histogram (glaciated-area proportional to the frequency of elevations) with a 200 m elevation bin as class interval and pixel-based regression pattern of glaciated-area is depicted in the Figure 8b . The largest glaciated area (34.59%) between 4877.01 to 5370 m lies in-between in the vertical regime of clean-dusty ice / the direct snow accumulation and the horizontal regime of mixed zone / high glacier velocity and net accumulation / low velocity. Mean annual (temperature) and precipitation of largest glaciated area is reported to be between (-8 to -12 °C) and (1900 and 2100 mm) respectively. The smallest is found in the extreme ends of the altitudinal range, *i.e.*, 4.75% between 5678.01 and 6503 m corresponding to direct snow accumulation of vertical regime and net avalanche accumulation and low velocity zone of horizontal regime (temperature -14 to -21 °C, precipitation 1000 to 1900 mm) and 6.61% below 3500 and 4052 mm in the mostly clean / dusty ice and net ablation and medium velocity area (temperature +2 to -2 °C, precipitation 1100 to 1400 mm). The second largest glaciated area (15.85%) lies between 4626.01 to 4877 m in the clean / dusty ice zone and mostly in the mixed / high velocity zone of horizontal regime. Other regions with significant glaciation, 13.97% and 10.11%, lie in the clean / dusty ice and mixed / high zone between 4351.01 to 4626 m and in the same zones between 4052.01 to 4351 m respectively.

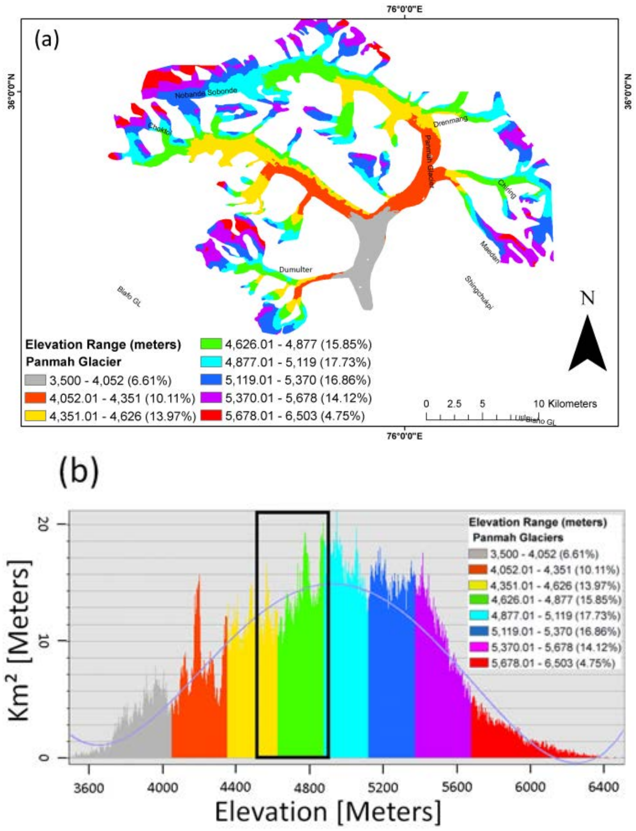

Figure 8. (a) The hypsometry (frequency distribution of altitudes) over glacier outline of Panmah and (b) the location of ELA for Karakoram over histogram (number of pixels of glaciated-area) proportional to the frequency of elevations with a 200m elevation bin as class interval and regression pattern of glacier area (Curve-Fit)

6 Conclusions

It is likely that more than 50% glaciers of Shigar river basin with less than 1 km^2 size contribute melt-water significantly to Indus river rise due to their shorter response times as compared to the four larger glaciers covering 70% land-area. However, a uniform response time cannot be calculated widely across both smaller and larges glaciers under any given climate scenario. Mostly, small glaciers lies close to melting points, therefore, they may recede any time.

There are major chances of glacier erosion because largest glaciated area of Shigar river basin lies at ELA. A big portion of the largest glaciated area lies in mixed zone between net accumulation and ablation covered by clean and debris-covered ice under freezing temperature. Despite high precipitation, due to high glacier velocity at mixed zone, a significant portion of glacier may move downwards due to slope gradient and mountain glaciers. A portion of the smallest glaciated area found in the extreme ends of the high altitudes will remain stagnant because of net avalanche accumulation and low velocity zone and temperature below -18 °C. The remaining 4.12% in the low elevations is the mostly debris and clean dust-covered ice. However, there may be a climatic effect due to its proximity close to net ablation, medium velocity and temperature above 0 °C.

There are major differences in the hypsometry of the largest glaciers. Unlike Biafo glacier, the largest and smallest glaciated area of Baltoro lies above the ELA in the vertical regime of direct-snow accumulation and the horizontal regime of net accumulation zone and low glacier velocity might have longest response time to climatic change but erosion cannot be ruled out. However, significant portions of both Biafo and Baltoro lie below the ELA, mostly debris and clean dust-covered ice and in-between mixed and high velocity of vertical regime and net ablation might have medium response time and sustain longer.

The high elevation precipitation may sustain the glaciers of this basin whose melt-waters, especially those from Baltoro, Biafo and Chogo Lungma glaciers, in turn feed the Shigar river. This dependence of the river on glacial and ice melt is manifested in the huge seasonal variation in its flow.

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