Natural Science, 2014, 6, 733-740
Published Online June 2014 in SciRes. http://www.scirp.org/journal/ns
http://dx.doi.org/10.4236/ns.2014.610073

The Complex Phenomenon of Glaciers of Nubra Valley, Karakorum (Ladakh), India

R. K. Ganjoo[1], M. N. Koul[2], I. M. Bahuguna[3], Ajai[3]

[1]Institute of Himalayan Glaciology, c/o Department of Geology, University of Jammu, Jammu, India
[2]Department of Geography, University of Jammu, Jammu, India
[3]Space Applications Centre, Ahmedabad, India
Email: ganjoork@rediffmail.com

Received 1 April 2014; revised 5 May 2014; accepted 16 May 2014

Abstract

The Nubra valley nestled in the Karakorum Mountains of Ladakh houses about 600 glaciers of various dimensions out of which 114 glaciers were monitored in the first phase of study. The study of 114 glaciers suggests that small-sized glaciers outnumber the large-sized glaciers. Almost 52.6% of the studied glaciers are of the size less than 5 km and 31.5% of the total glaciers are between the size of 5 and 10 km. The 84 glaciers out of the 114 glaciers have been monitored on short-term basis between the time period 1989 and 2001 whereas 30 glaciers have been monitored on long-term basis between 1969 and 2001. The monitoring of the glaciers is based on the study of Survey of India topographical sheets of 1969 and satellite imageries of time series between 1989 and 2001. The monitoring of thirty glaciers shows that 17 glaciers have lost their area between 1969 and 2001. The loss in area is from 2150 km^2 in 1969 to 2026 km^2 in 2001. The study of eighty-four glaciers on short-term basis between 1989 and 2001 suggests that 26 glaciers have retreated, 25 glaciers have advanced and 33 glaciers show no change during the time period. The changes in the glaciers of Nubra valley are varied and complex.

Keywords

Nubra Valley, Indus Basin, Karakorum Himalaya, Ladakh, Siachen Glacier

1. Introduction

Geologically, the Karakorum and Hindu Kush are two different mountains formed out of the same crustal fold that passes through western Tibet in a northwest-southeast direction. The trough below the Karakorum Mountains is drained by Shyok, Gilgit, Hunza and Kunar rivers, whereas Nubra river rises in the Karakorum itself. All

How to cite this paper: Ganjoo, R.K., Koul, M.N., Bahuguna, I.M. and Ajai (2014) The Complex Phenomenon of Glaciers of Nubra Valley, Karakorum (Ladakh), India. *Natural Science*, **6**, 733-740. http://dx.doi.org/10.4236/ns.2014.610073

these streams are tributaries to the Indus River. The Karakorum Mountain is more arid and less wooded than the rest of Himalaya. The hard granitic rocks and precipitous slopes of Karakorum Mountains discourage formation of soil, and whatever meager precipitation is received, flows down rapidly.

The Karakorum Mountain separates two great basins of the Indus and Tarim. The Karakorum-Hindu Kush Mountain forms crucial watershed between the three principal drainage basins of Central Asia—The Indus, the Tarim and the Amu. All streams originating in northern, northwestern and northeastern slopes of Karakorum and Hindu Kush Mountain flow either east into Tarim or to west into Amu Darya (Oxus), barring the Shyok, Gilgit and Kunar rivers that forms the headstreams of River Indus.

2. Climate

Karakorum and Pamir Ranges have the maximum precipitation due to winter westerly winds that bring moisture from the Mediterranean, Black and Caspian Seas. The air masses influence the glacier formation both on regional and local scale.

Nubra valley holds special geographical significance for the study of climate change, if any. The valley lies far away from the effect of South West Indian Monsoon (SWIM) that has largely been identified as the moisture carrier for the rest of Himalaya. The moisture laden SWIM brings down the precipitation in the form of snow in most of Himalaya that nourishes the glaciers. On the contrary, the Karakorum Mountain receives a major contribution of snow through Westerlies during the winter season. Hence, the depletion or growth of glaciers of Karakorum Mountains is related to the weakening or strengthening of Westerlies rather than SWIM.

The winters of Nubra valley are harsh, severely cold, extremely dry and long extending from September to May. The minimum temperature starts falling below freezing point from September with peak winter months from December to March. Wide range of fluctuation in winters is due to the Western Disturbances (WD). Major proportion of precipitation, received during the winter season, is in the form of snow fall that begins by November with increase in frequency from December to March. Improvement in temperature starts from late April onwards. May is a transitional period of winter and summer season with bright days and cool nights that are common of this month. Freeze and thaw conditions prevail at low altitude ranges up to 4000 meters. The period from June to August records high mean monthly temperature. July is considered to be the hottest month in Nubra valley. The temperature remains remarkably high and constant whereas night temperature fluctuates facilitating the freeze and thaw action that leads to physical weathering. The summer precipitation is mainly in the form of little rain and snow that occurs in the upper reaches of mountains and glaciated areas. The overall tendency of precipitation in the summer season in Nubra valley is very low. The climate of Nubra valley is transitional between that of Central Asia and the monsoonal land of South Asia. It varies considerably with latitude, altitude, aspect and localized relief, e.g. rain shadow caused by high mountain masses such as Karakorum. The southern arms of the mountains certainly act as an effective barrier to moisture in the subcontinent.

3. Methodology

The broad approach for the present study is to generate map based on multi-temporal Landsat and IRS LiSS III satellite data. The data provides glacier-wise details related to glacier identification number, name (only in few cases), glacier location, measurements of dimensions and orientation. The geo-coded multi-temporal satellite data on 1:50,000 scale for a period of July to end of September are used in the present study. The multi-temporal data is available for 1989 and 2001. The multi-temporal satellite data is projected atop the Survey of India (SOI) 1969 topographic sheets of the scale 1:50,000. Only five SOI topographic sheets of the Nubra valley were available that covered 30 glaciers. The study herein, therefore, carries intensive and extensive examination with respect to change in area and length of 30 glaciers since 1969. The change in the behaviour of rest of the glaciers (84 in number) is only for a period of 1989 to 2001.

Most of the glaciers in Nubra valley are located in remote and treacherous terrain that are inaccessible or lack motorable roads. Siachen is the only glacier in Nubra valley that is well connected with rest of Ladakh region by all weather motorable road.

4. Glaciers of Karakorum Mountains

The greatest concentration of glaciers occurs in Karakorum Mountain and the western Himalaya which have the longest glacier (Siachen glacier) outside the Polar Region. There is important contrast in the seasonal relationship between precipitation and ablation along the Himalaya. In the east, there is significant snowfall in summer, much of which is immediately lost by melting. In the western Himalaya and Karakorum Mountain, in contrast, the dominant input of snow into the glacial system occurs in winter. A second reason why glaciers are larger in the west is that the terrain in the accumulation zone is much broader than in the eastern Himalaya. Glaciers in Karakorum Mountains are of continental interior type. The accumulation zone of the glaciers in Karakorum Mountain lies in high altitudes (4500 m asl or above) that provides drier environments for glaciers throughout.

One hundred and fourteen (114) glaciers of Nubra valley undertaken for studies are divided into seven classes of 5 km interval each (**Figure 1**) based on the length of glacier. Almost 52.6% of the glaciers are of the size less than 5 km and 31.5% of the total glaciers are between the size of 5 and 10 kms in the Nubra valley, suggesting that Nubra valley is occupied by a large number of small glaciers. The glaciers in Nubra valley are distributed in all directions. More or less equal number of glaciers is oriented to east (16), west (15), southeast (14), northeast (13) and southwest (13).

Eighty-four glaciers out of 114 glaciers are selected for short-term monitoring between 1989 and 2001, the time series for which the satellite imageries of the area are available. The change in the area of 84 glaciers could not be monitored from 1969 due to the non-availability of Survey of India (SOI) topographic sheets covering these glaciers.

The 30 glaciers out of 114 glaciers have been monitored in detail with respect to the change in their area for the period between 1969 and 2001. The selection of 30 glaciers for their detail study on change in area since 1969 was primarily because of the availability of SOI topographic sheets covering these glaciers in the Nubra valley. The SOI topographic sheets of 1969 have been used as the base for comparison with the satellite imagery data of 1989 and 2001. The 30 glaciers of the second section are discussed as case study to highlight the causative factors for change in the behavior of glaciers in Nubra valley.

4.1. Short-Term Monitoring of Glaciers between 1989 and 2001

In all 84 glaciers are selected for the short-term monitoring between the period 1989 and 2001. The monitoring in change of the area of these glaciers has been on the basis of the availability of IRS satellite imageries for 1989 and 2001. The study shows that 25 glaciers have gained the area from 1989 to 2001 (**Figure 2**). Fair percentage (24%) of the glaciers in this category is oriented to east, followed by northwest and west directions that are represented by 16% glaciers in each of these directions. Twelve percent of glaciers of this category are in southeast direction, followed by 8% each in north-northwest and southwest directions, whereas 4% each of glaciers are in northeast, south-southeast and south-southwest directions.

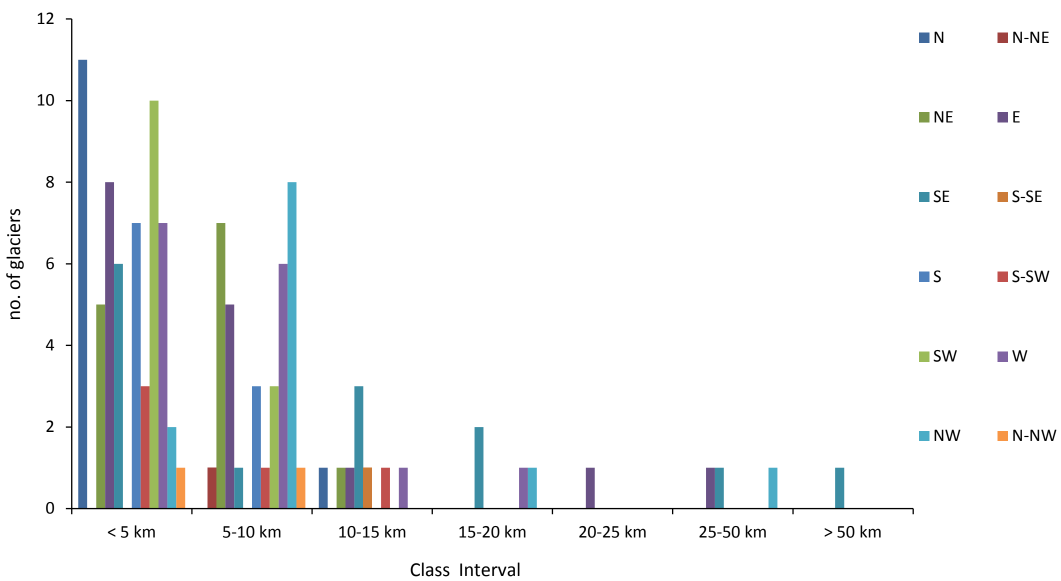

Figure 1. Glaciers with size range and orientation in Nubra valley.

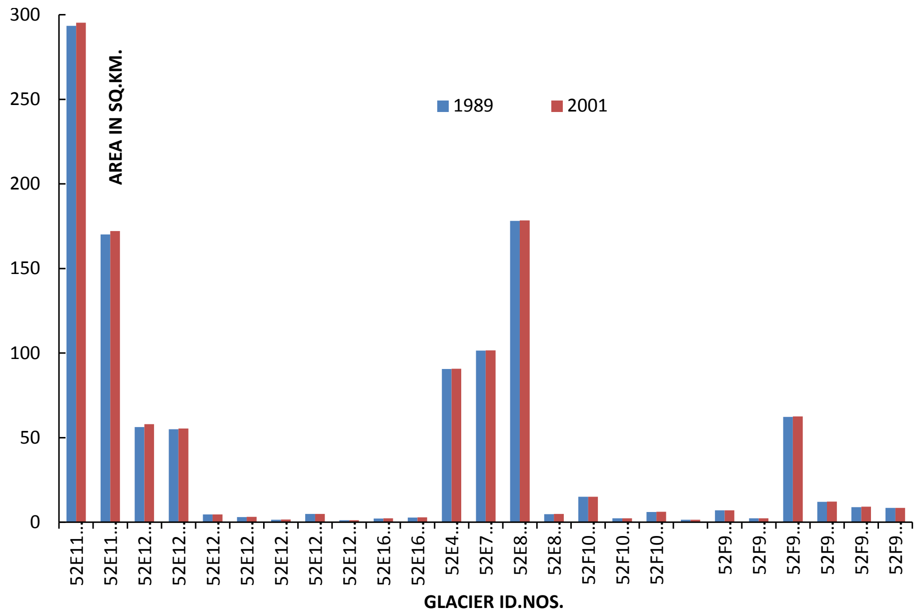

Figure 2. Glaciers in Nubra valley showing gain in area (1989 to 2001).

Twenty-six glaciers, out of 84 glaciers in Nubra valley (**Figure 3**), show vacation of area from 1989 to 2001. The dominating orientation of glaciers in this category is in southeast (23%), followed by northeast (19%). Equal percentage (15% each) of glaciers belonging to this category is oriented in south and east directions. Besides, 8% each is represented by north, south-southwest and southwest directions, whereas 4% of glaciers are oriented north-northeast.

Thirty-three glaciers do not show any change in their area between 1989 and 2001, based on the study of satellite imageries (**Figure 4**). Dominating percentage of glaciers belonging to this category are oriented in west (31%) followed by north (15%). The other directions represented by this category are northwest (12%), northeast (9%), east (9%), southeast (9%), south (6%), south-southwest (6%) and southwest (3%).

4.2. Long-Term Monitoring of Glaciers between 1969 and 2001

Thirty glaciers are identified for long-term monitoring between the period 1969 and 2001.The comparative monitoring of the glaciers marked on the SOI topographic sheets of 1969 with multi-temporal LiSS satellite imageries of 1989 and 2001 presents a complex behaviour of the glaciers. Only three out of thirty glaciers show gain in the area for past almost three decades (**Table 1**). The glaciers are equally spread in three different directions of northeast, southwest and northwest. The glaciers belonging to this category show increase in their length, such as the glacier id. No. 52E3 006 shows an increase in length from 2829.5 m in 1969 to 3088.4 m in 1989 and finally to 3344.1 m in 2001. The increase in the maximum length of glaciers suggest gradual advance of glacier from 1969 to 2001 through 1989.

Eight of the thirty glaciers in Nubra valley show gain in area in two decades from 1969 to 1989 and subsequently from 1989 to 2001 glaciers vacate the area (**Table 2**). About 49% of the glaciers in this category are oriented north and 25% of the glaciers in this category are oriented southwest, whereas 13% each are oriented west and southeast.

The glaciers (e.g. 52E3 005, 52E3 008, 52E4 008) show shift in the position of snout from higher to lower elevation from 1969 to 1989 suggesting increase in the length of the glacier and consequent gain in the area. Subsequently, the snout of these glaciers has shifted back uphill in 2001 from its position in 1989 leading to decrease in the length of the glacier and consequent vacation of the area.

Further, five of the thirty glaciers in Nubra valley show vacation of area from 1969 to 1989 and subsequently from 1989 to 2001, the glaciers show gain in area (**Table 3**). An equal percentage of the glaciers (*i.e.* 40%) are oriented northeast and southwest, whereas 20% of these glaciers are oriented east.

The snout of the glaciers (such as 52E3 002, 52E4 013, 52E4 001) has shifted their altitudinal position be-

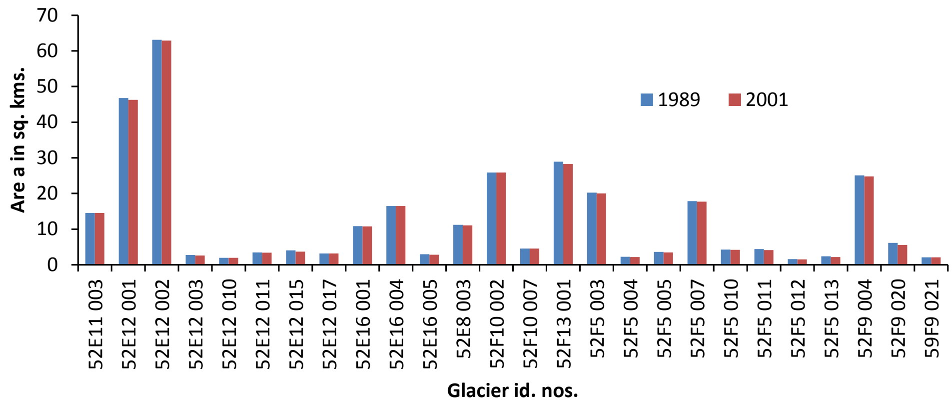

Figure 3. Glaciers showing loss in area between 1989 and 2001.

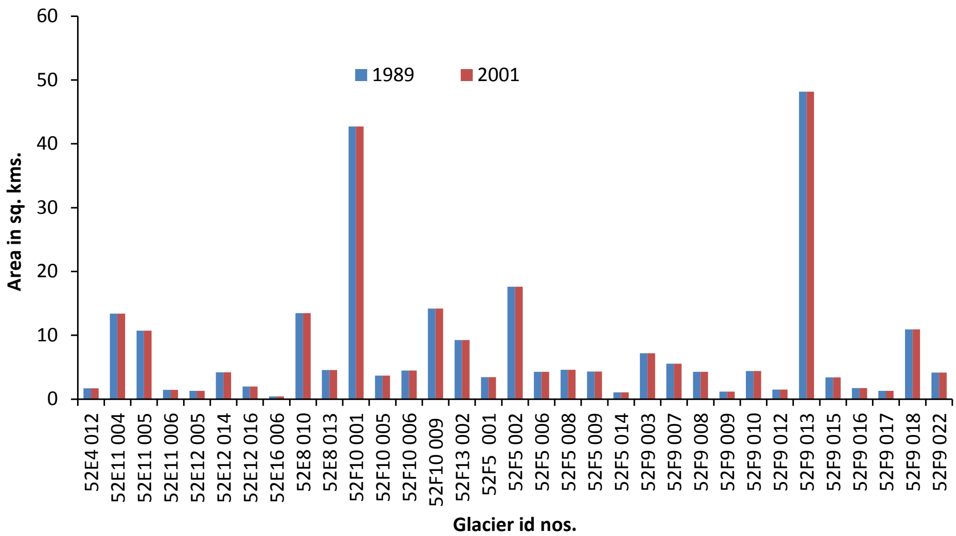

Figure 4. Glaciers showing no change in area between 1989 and 2001.

Table 1. Glaciers showing gain in area between 1969 and 2001.

Glacier ID No.	Orientation	Area (sq. km)		
		1969 (SOI)	1989 (Landsat)	2001 (LiSS)
52E3 006	SW	1.313	1.344	1.386
52E4 003	NE	35.431	45.221	45.309
52E8 007	NW	3.236	3.338	3.368

tween 1969 and 2001. In the process, the snouts of the glaciers have moved up the mountain slope between 1969 and 1989, leading to the vacation of area. Subsequently, between 1989 and 2001 the position of snouts has moved down the mountain slope leading to the gain in area of the glaciers. The glacier ID No. 52E4 001 has shifted the altitudinal position of its snout up the mountain slope considerably from 4610 m asl in 1969 to 4642 m asl in 1989 and again moved down the mountains to 4510 m asl in 2001, that it is much down the altitudinal position occupied by snout in 1969.

Seven glaciers including the Siachen glacier (largest in Indian Himalaya) out of 30 glaciers in Nubra valley show constant vacation of area from 1969 to 2001, for almost three decades (Table 4).

About 30% of glaciers in this category are oriented in south and equal percentage (14%) of glaciers are oriented in all other directions, e.g. north, northwest, southeast, southwest and west.

Table 2. Glaciers showing gain in area between 1969 and 1989 and subsequent vacation of area between 1989 and 2001.

Glacier ID No.	Orientation	Area (sq. km)		
		1969 (SOI)	1989 (LiSS)	2001 (LiSS)
52E3 005	SE	0.896	0.987	0.578
52E3 008	SW	0.541	0.954	0.852
52E4 008	N	0.851	0.884	0.853
52E4 009	N	1.518	1.684	1.604
52E4 014	SW	1.020	1.509	0.939
52E8 008	N	1.940	2.183	1.966
52E8 011	N	0.981	1.123	1.075
52E8 015	W	2.480	3.243	3.217

Table 3. Glaciers showing vacation of area between 1969 and 1989 and subsequent gain in area between 1989 and 2001.

Glacier ID No.	Orientation	Area (sq. km)		
		1969 (SOI)	1989 (LiSS)	2001 (LiSS)
52E3 002	SW	8.476	5.220	5.404
52E4 001	NE	9.529	8.824	8.971
52E4 002	NE	30.570	28.302	28.323
52E4 005	E	5.378	4.341	4.410
52E4 013	SW	0.698	0.489	0.592

Table 4. Glaciers showing area vacated (1969-2001).

Glacier ID No.	Orientation	Area (sq. km)		
		1969 (SOI)	1989 (Landsat)	2001(LiSS)
52E3 001*	SE	994.993	932.907	930.377
52E3 003	S	0.713	0.682	0.353
52E3 004	S	1.834	1.392	1.209
52E3 007	SW	2.119	1.949	1.914
52E4 007	N	1.043	0.907	0.903
52E8 004	NW	10.830	9.372	9.342
52E8 005	W	5.337	4.544	4.337

*Siachen glacier.

The constant shift in the altitudinal position of snout of the glaciers from 1969 to 2001 have lead to the vacation of area and correspondingly decrease in the maximum length of glaciers during the same period. The glaciers such as 52E3 003, 52E3 004, 52E3 007 and 52E8 004 show gradual movement of the snouts up the mountain slope from 5080 m asl to 5245 m amsl, 5080 m amsl to 5208 m amsl, 4780 m amsl to 5020 m amsl and 4875 m amsl to 5140 m amsl, respectively.

In all, three glaciers out of 30 glaciers in Nubra valley show gain in area from 1969 to 1989, with no change in the area of glaciers in subsequent years (**Table 5**).

Table 5. Glaciers showing gain in area between 1969 and 1989 followed by static position of glaciers between 1989 and 2001.

Glacier ID No.	Orientation	Area (sq. km)		
		1969 (SOI)	1989 (LiSS)	2001(LiSS)
52E8 002	S	16.504	17.295	17.295
52E8 006	NW	4.277	5.091	5.091
52E8 009	N	5.688	11.181	11.181

Interestingly, the glacier ID No. 52E8 009 shows a gain in area by almost 100% from 1969 to 1989. The glaciers are equally (33% each) distributed in north, northwest and south directions.

Four (glacier ID Nos. 52E4 006, 52E4 010, 52E4 011 and 52E8 012) out of 30 glaciers in Nubra valley, show vacation of area in first two decades from 1969 to 1989 and later, *i.e.* from 1989 to 2001, there is no change in the area. Almost 50% of the glaciers in this category are oriented in southwest and the rest are equally distributed in northwest and east directions.

5. Discussion and Conclusions

Nubra sub-basin forms a part of Indus basin and houses more than 600 glaciers (Space Applications Centre 2011). The glaciers cover an area of 2178.84 km^2 of which 1263 km^2 is accumulation area and 915.84 km^2 is the ablation area. The percent accumulation area is highest in the Indus basin as compared to the Ganga and Brahmaputra basins. This indicates that the glaciers of the Indus basin are having larger feed area and hence are relatively more stable as compared to the other two basins. Indus basin has high mean accumulation and low mean ablation area (Space Applications Centre, 2011) [1], as a consequence of the dominance of Westerlies rather than South West Indian Monsoon. This phenomenon causes the basin to be more stable compared to Ganga and Brahmaputra basins.

The monitoring of 114 glaciers of the Nubra sub-basin suggests that 39 glaciers (34%) have shown gain in the area, 43 glaciers (38%) have vacated the area and 32 glaciers (28%) do not show any change in their area. The snout of the majority of large glaciers (84% of the 114 glaciers) is facing south-east. The long-term monitoring of 30 glaciers from 1969 to 2001 reveals that the area of these glaciers has decreased from 1157 km^2 (1969) to 1097 km^2 (2001). The glaciers have vacated maximum (56 km^2) of the area between 1969 and 1989 and only 4 km^2 between 1989 and 2001 suggesting the slowing down in the rate of retreat of the glaciers in Nubra valley since 1990.

Further, the snouts of the glaciers facing NW do not show any change in their area between 1969 and 2001. However, the glaciers oriented NE show a marginal increase of 2.5 km^2 in their area between 1989 and 2001 compared to the area of 12.31 km^2 between 1969 and 1989. Change in the area of glaciers (gain or vacation of area) is irrespective to the size of the glaciers. Glaciers as large as Siachen show vacation of area (though nominal), and glaciers as small as glacier ID No. 52E3 008 (maximum length 1.8 km) shows an overall increase in the maximum length of the glacier.

The changes in the glaciers of Nubra valley are varied and complex. Some glaciers show change in length with respect to area whereas some glaciers show variation in area and not in length. In absence of intensive weather data from the Nubra valley, it would be premature to conclude upon the causes for such complex and varied changes. However, it is beyond doubt that glaciers of the Nubra valley do not show much change in their length and area between 1989 and 2001 compared to the time period 1969 to 1989.

The studies on the behavior of glaciers in other parts of Himalaya-Karakorum undoubtedly suggest that the rate of retreat of glaciers has decelerated in past three decades (Copeland, *et al*., 2011) [2] to the extent that some of the glaciers have begun to stabilize and/or advance (Hewitt, 2005) [3] (Mayer *et al*., 2006) [4] (Barrand and Murray, 2006) [5]. The monitoring of snouts of 2018 glaciers in Himalaya and Karakorum for the period 2001-2010/11 with the help of satellite imageries has further revealed that 1752 (86.8%) glaciers are stable in their position, 248 (12.3%) glaciers have shown retreat in their snout positions whereas 18 (0.9%) glaciers have advanced (Bahuguna, *et al*., 2014) [6] confirming the erratic behavior of glaciers with respect to latitude, elevation and climatic/weather variation from region to region.

The complex topographic setting, altitudinal variation from glacier basin to glacier basin, impact of monsoon in high altitudes, variation in various parameters of micro-climate (Koul and Ganjoo, 2010) [7], increase and/or decrease in the cloudiness, encroachment of human population to the interiors of high altitude of Karakorum-Himalaya (Owen and Dortch, 2014) [8] can be some of the factors in the erratic movement of the glaciers.

Acknowledgements

The authors express thanks to the Ministry of Environment and Forests, Government of India and Space Applications Centre, Ahmedabad for the financial support to the undertake the present study.

References

[1] Space Applications Centre (2011) Snow and Glaciers of the Himalayas. Space Applications Centre, Ahmedabad.

[2] Copland, L., Sylvestre, T., Bishop, M.P., Shroder, J.F., Seong, Y.B., Owen, L.A., Bush, A. and Kamp, U. (2011) Expanded and Recently Increased Glacier Surging the Karakorum. *Arctic, Antarctic, and Alpine Research*, **43**, 503-516.

[3] Hewitt, K. (2005) The Karakorum Anomaly? Glacier Expansion and the "Elevation Effect", Karakorum Himalaya. *Mountain Research and Development*, **25**, 332-340. http://dx.doi.org/10.1659/0276-4741(2005)025[0332:TKAGEA]2.0.CO;2

[4] Mayer, C., Lambrecht, A., Beló, M., Smiraglia, C. and Diolaiuti, G. (2006) Glaciological Characteristics of the Ablation Zone of Baltoro Glacier, Karakoram, Pakistan. *Annals of Glaciology*, **43**, 123-131. http://dx.doi.org/10.3189/172756406781812087

[5] Barrand, N.E. and Murray, T. (2006) Multivariate Controls on the Incidence of Glacier Surging in the Karakorum Himalaya. *Arctic, Antarctic, and Alpine Research*, **38**, 489-498.

[6] Bahuguna, I.M., Rathore, B.P., Brahmbhatt, R., Sharma, M., Dhar, S., Randhawa, S.S., Kumar, K., Romshoo, S., Shah, R.D., Ganjoo, R.K. and Ajai (2014) Are the Himalayan Glaciers Retreating? *Current Science*, **106**, 1008-1015.

[7] Koul, M.N. and Ganjoo, R.K. (2010) Impact of Inter- and Intra-Annual Variation in Weather Parameters on Mass Balance and Equilibrium Line Altitude of Naradu Glacier (Himachal Pradesh), NW Himalaya, India. *Climatic Change*, **99**, 119-139. http://dx.doi.org/10.1007/s10584-009-9660-9

[8] Owen, L.A. and Dortch, J.M. (2014) Nature and Timing of Quaternary Glaciation in the Himalayan-Tibetan Orogen. *Quaternary Science Reviews*, **88**, 14-54. http://dx.doi.org/10.1016/j.quascirev.2013.11.016