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Control of Terrain Parameters on Glacier Shrinkage Pattern in Pin Parbati Valley, Himachal Himalaya, India

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Abstract: The PCA (Principal Component Analysis) technique is used in evaluating the relationship between terrain parameters and old and new glacier surface area. The results indicate that the profile curvature shows a clear relationship with new glacier surface area development, whereas it does not show any relationship with the old glaciers surface area. It indicates that the new glaciers are being controlled by the terrain characteristics whereas the terrain characteristics have less control on the older glaciers surface. The correlation matrix between terrain characteristics of old and new glacier surface area also conforms to the results of principal component analysis.

The present study also shows a clear trend in glacier shrinkage between 1963 and 2001 in the Pin Parbati valley in Himachal Himalayas, India. Temporal change in glacier area indicates overall loss of 27% for the period 1963-2001. The shrinkage of glacier varies with glacier size. The smaller glaciers show maximum shrinkage in comparison to the larger glaciers.

Key words: Terrain parameters, profile curvature, PCA, glacier shrinkage, Pin Parbati valley, Himachal Himalayas.

Introduction

Monitoring the change in glacier area and mass provides useful information for researchers examining climatic change and variability. The change in glacier area depends on the snow and ice accumulation-ablation, which is related to regional precipitation and temperature characteristics. However, in mountain regions the terrain characteristics also influence on glacier evolution (Bishop et al., 2001; Evans, 2006a). Therefore, in certain locations in mountains the glacier evolution is different than other locations according to the characteristics of the local terrain (Allen, 1998; Benn and Lehmukhul, 2000). The study of terrain characteristics and their relationship with glacier cover in mountain region is very important for predicting the future glacier cover under climate change scenarios. The studies conducted by the Lopez and Moreno et al. (2006) in Spanish Pyrenees suggest that altitude, profile curvature, slope and aspect are major factors, and control the development of glaciers. The influence of these factors may be different from place to place in different conditions. Hence, influence of terrain characteristics on glacier evolution may be crucial in Himalayas due to the complex terrain and its relation to glaciation and glacier recession processes. Moreover, these mountain glaciers exhibit intense glacier recession than in other parts of the world. The studies conducted by Kulkarni et al. (2005) indicate an alarming rate of glacier retreat in Himachal Himalayas. Because of rapid rate of shrinkage of glacier, the glacier cover has been reduced by 19% since 1962 in the Baspa valley (Kulkarni et al., 2005). The melt water from these glaciers is a major source of the freshwater for the population living in South and Central Asia. Therefore, it is important to assess the depletion of glacier as water resource for developing suitable strategy for sustaining the population depending on these resources. In the present study the glacier cover and its relationship with the terrain characteristics has

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been evaluated and the pattern of glacier shrinkage with respect to the terrain parameters are discussed in detail.

For assessing the impact of climate change on glaciers area, the glacier inventory provides a basic tool against which the change can be detected. The present study examines the glacier cover change in the Pin Parbati valley located in Eastern Himachal Pradesh covering 400 km^2 glacier area. This study will contribute for the better understanding of possible impacts of climate change in the region where only few studies are available on this aspect. However, the field based mass balanced studies would deliver more accurate results concerning glacier recession.

Methodology

The glacier surface area in the region has been mapped using Survey of India toposheets on 1:50,000 published by Survey of India in 1962 (53E/5, 53E/9, 53E/10. 53E/13). Information given on toposheets was used in geo-referencing the toposheets. After geo-referencing the glaciers boundaries were mapped using Geomatica 9.1. These glaciers were mapped as individual polygons and each polygon was treated as separate glacier as existed in the 1970's toposheets. The new glacier inventory has also been prepared using LANDSAT ETM$^+$ acquired in October 2001 for the granule Path 147 and Row 38. An FCC was prepared based on 432 (RGB) bands of LANDSAT ETM$^+$ data and the new glacier inventory was prepared from this FCC. Some enhancement techniques were also done for accurate mapping of the glacier boundaries. A change detection layer has been prepared using old and new glacier inventory.

The terrain parameters of the individual glaciers (mean, maximum, minimum altitude, slope, plane curvature, profile curvature, surface curvature and tangential curvature) were extracted. The slope and aspects were extracted from the SRTM DEM using Geomatica 9.1 using DEM models. However, the plane curvature, profile curvature, surface curvature and tangential curvature layers were extracted from SRTM DEM using TAS (Terrain Analysis System 3.0).

The PCA (Principal Component Analysis) of glacier cover and its relationship between terrain characteristics has been extracted using SPSS 10.01. In the processes of extracting PCA the glacier cover has been taken as independent variable and other terrain parameters (mean, maximum, minimum altitude, slope and aspect, plane curvature, profile curvature, surface curvature and tangential curvature) taken as dependent variables.

Result and Discussion

A glacier inventory was prepared for glaciers in Pin Parbati valley, HP, Himalayas (Figure 1) using topographic sheet based on aerial survey in 1962. This glacier inventory was used in establishing the relationship between glacier cover area and their terrain parameters such as mean, maximum, minimum altitude, slope and aspect, plane curvature, profile curvature, surface curvature and tangential curvature. The relationship between terrain parameters and glacier cover area was evaluated using Principal Component Analysis under SPSS environment, in which the glacier cover area was taken as independent variable and terrain parameters as dependent variables. The result indicates that 76% of the variance of glacier surface area can be explained by four factors, which have eigen value more than 1 (Table 1).

The results indicate that the first factor i.e. the altitude contributes about 32% of the total variance; the altitude also controls the important glaciological activities such as the ablation and accumulation. Plane curvature and tangential curvature contribute to the total variance of 20% for explaining the total variance. The curvature factor is important for the accumulation of snow in cirque.

Table 1: PCA (Principal Component Analysis) of the old glaciers surface area and its terrain characteristics

Components	*Eigen values*	*% of variance*	*Cumulative % of variance*
1	3.298	32.982	32.982
2	2.023	20.233	53.216
3	1.314	13.141	66.357
4	1.058	10.575	76.932
5	0.829	8.286	85.219
6	0.715	7.154	92.373
7	0.429	4.288	96.661
8	0.213	2.131	98.792
9	0.112	1.122	99.913

Rotated component matrix and factors

Variables	*Factor 1*	*Factor 2*	*Factor 3*	*Factor 4*
Minimum altitude	0.815			
Maximum altitude	0.877			
Aspect			0.709	
Slope				0.878
Tangential curvature		0.946		
Surface curvature			0.696	
Profile curvature				-0.072
Plane curvature		0.931		

Snow accumulation in the cirque is directly related to the cirque concaveness. The third factor surface curvature and aspect contribute 13% of the total variance. The slope is an independent factor and contributes about 6% of the total variance. The present study shows that 76-72% of the glaciers have slope less than 30 degree, and 90% of the glaciers have slope less than 40 degree. However, only few glaciers are having slope more than 40 degree. It indicates that a moderate slope is favourable for glacier development and very high slope of the terrain is not favourable for glacier development in the region.

A relationship between terrain parameters for new glacier cover is also studied using Principal Component Analysis under SPSS environment, in which the new glacier cover area is taken as independent variable and terrain parameters as dependent variables. The result indicates that 80% of the variance of glacier surface area can be explained by five factors, which have eigen value more than 1 (Table 2). The first factor, minimum altitude, contributes about 22% of the total variance; plane curvature and tangential curvature contribute about 21% for explaining the total variance. The third factor contributes 12% of the total variance as total effect of maximum altitude. Fourth factor contributes by negative relationship with slope and positive relation with surface curvature; these two in combination explain about 12% of the total variance. Fifth factor explains about 12% of variance by the profile curvature with a negative relation with new glacier surface area. The more negative profile curvature represents concaveness and help in development of glaciers. The profile curvature shows a clear relationship with new glacier, but the relationship is absent for the old glaciers. This also conforms to the conclusion of the control of terrain characteristics on the new glaciers rather than the old glaciers.

Table 2: PCA (Principal Component Analysis) of the new glaciers surface area and its terrain characteristics

Components	*Eigen values*	*% of variance*	*Cumulative % of variance*
1	2.098	23.314	23.314
2	1.923	21.365	44.679
3	1.173	13.038	57.716
4	1.04	11.556	69.273
5	1.017	11.302	80.575
6	0.886	9.842	90.417
7	0.78	8.661	99.078
8	8.29E+00	0.922	100
9	-3.864E-	-4.29E-15	100

Variables	*Factor 1*	*Factor 2*	*Factor 3*	*Factor 4*	*Factor 5*
Maximum altitude			0.868		
Minimum altitude	0.98				
Aspect					
Slope				-0.616	
Plane curvature		0.976			
Profile curvature					-0.855
Surface curvature				0.734	
Tangential curvature		0.976			

A relationship of terrain characteristic for old glaciers and new glacier cover has been evaluated using the correlation matrix analysis as given Table.3. The correlation matrix of new glacier cover area suggests that the new glacier cover is much more influenced by the Maximum altitude than mean and minimum altitude. It suggests that a maximum altitude that is the accumulation zone of the glaciers determine the mass balance of the glacier and also the glacier shrinkage processes. From Table 3 it can be seen that the old glaciers show a slight negative relationship with aspect, while as new glacier cover show a slightly positive relationship with aspect. So, under glacier shrinking processes the aspect is expected to play important role for the glacier shrinkage pattern. The slope shows a positive relationship with the old glacier area, but with the new glacier cover it has a negative relationship. It suggests that under glacier shrinking processes the glacier cover area will remain only in low slope region of Himalayas.

The average curvature index values for the old and new glaciers cover area have been studied. It suggests that the average tangential curvature and plane curvature of the new glaciers area is more than the old glaciers cover area, which means that the new glaciers mass is diverging in different directions from the old glacier mass in the region. The decrease in surface curvature index

Table 3: Correlation matrix of the old and new glacier surface area and their terrain parameters

Variable	*Old glacier cover*	*New glacier cover*
Mean Alt	0.10336438	0.121904437
Min Alt	0.08823115	0.048661114
Max Alt	0.07576912	0.285780894
Aspect	-0.0903927	0.019838788
Slope	0.31363572	-0.22203231

values for the new glacier area suggests that the new glacier area occupy more concave cirques than the old glaciers. However, slight increase in PCl (Profile Curvature Index) is related to change in glaciers surface curvature under depleting the thickness of glaciers. In this situation the central part of the glacier is least affected by glacier shrinking processes than the outer part of the glacier and relatively the central part of the glacier become more convex and results in more PCl for the new glacier than the old glaciers.

The glacier shrinkage pattern has been studied using Remote sensing and GIS techniques. A Glacier inventory is prepared for the glaciers represented on the Toposheets (53 E/5, 53 E/9, 53 E/10 and 53 E/9) surveyed in 1962. In this inventory, the total glacier cover area is 528716558 meter square with total perimeter of 1672211 metre. The new glacier inventory based on the Landsat ETM + FCC acquired in 2001 show a total surface cover area of 385796225 meter square with total perimeter of 1612335 metre. The glaciers cover area between the period of 1962-2001, as given in Figure 1. The results show an average of 27% of decrease in glacier area since 1962.

A scatter diagram for all the glaciers present in the valley for different shrinkage percentage classes and glaciers area classes indicates that the small sized glaciers are more prone to glacier shrinkage (Figure 2). Reduction in glacier size is not uniform for all glaciers; reduction in size is most prominent for smaller glacier and big glacier area is least affected. The glaciers situated on outer boundary of the basin indicate higher degree of shrinkage in glacier area, while glaciers situated in the main valley show least shrinkage (Figure 3). This is probably related to glacier thickness and mass balance of the glacier. The glacier area is directly related with thickness. Hence, smaller glaciers respond to climate change earlier than the large glaciers. The intensity of glacier shrinkage process on small glaciers is much higher. Because, these glaciers are situated on small mountain plateaus or on gentle mountain slopes and exposed to more solar radiation. However, valley glaciers are usually located in mountain valleys, surrounded by steep mountain cliffs covered with debris and less solar radiation received on the glacial surface and affect glacial shrinkage much lesser than small glacier (Kulkarni et al., 2007).

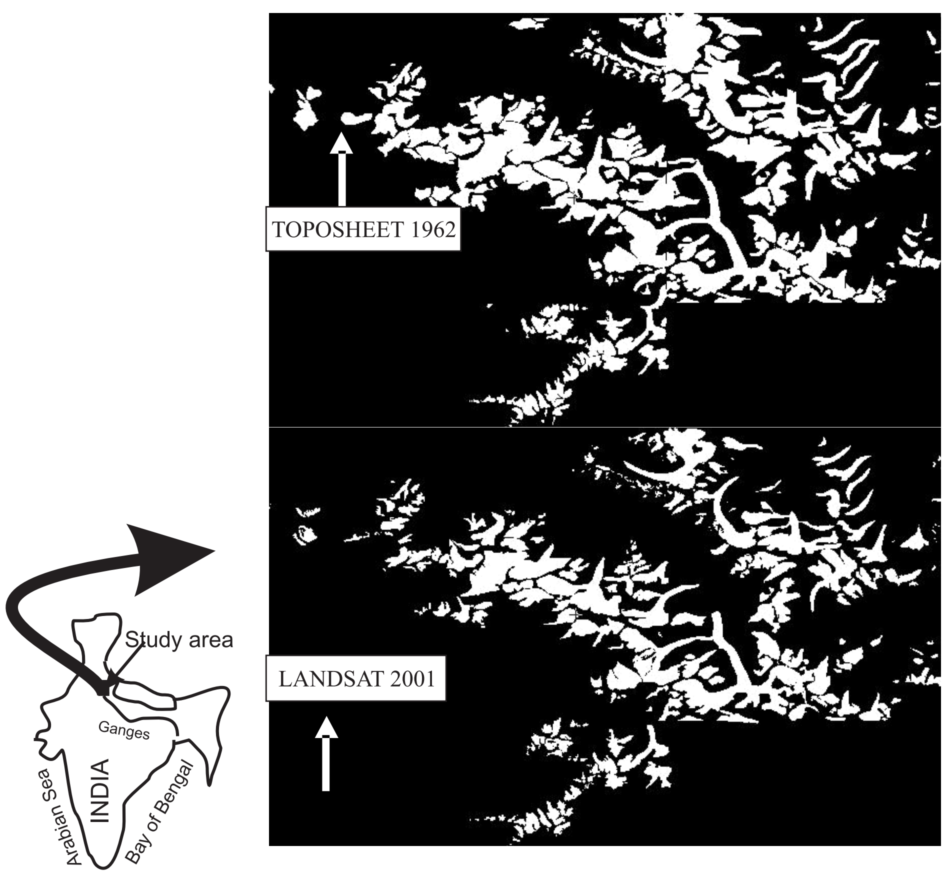

Figure 1: Location map of study area and glacier covered area in 1962 and 2001.

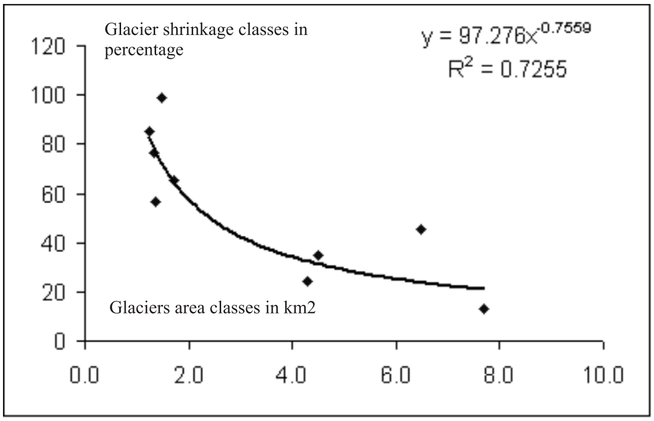

Figure 2: Relationship between percentage of shrinkage and surface area of the glacier.

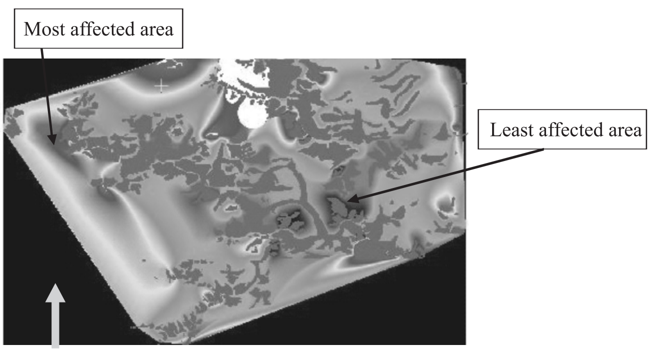

Figure 3: Glacier shrinkage pattern in Pin Parbati valley.

Conclusions

The glacier shrinkage pattern suggests that the glacier cover area in the Pin Parbati valley has been reduced by about 27% in size from 1962 to 2001. Reduction in glacier size is not uniform for all types of glaciers. The reduction in size is most prominent for smaller glaciers, while large glaciers have not been much affected. The new glacier cover area is largely governed by terrain characteristics than the old glacier cover. It suggests that the glacier cover in Himalayas will be controlled by topographic characteristics rather than by climatic factors. In future the glaciers will exist only in higher altitudes, on lesser slopes and more concave basins than the present glaciers.

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