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Assessment of Glacier Health in Alknanada, Sub Basin of Ganga Using Remote Sensing and GIS Techniques

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Abstract Glacier is a key component and plays an important role in the hydrological system. The melt water from glacier is an important source in the Himalayan regions as millions of people rely on it. The source of melt water depends on the distribution of glaciers and its mass balance. Monitoring of glaciers and assessment of its health is thus important to assess the availability of water in Indian Himalaya. In Himalaya and Trans Himalaya regions, the distribution of glaciers varies widely and depends mainly on the topography and monsoon characteristics. Around 32,392 glaciers are spread over in the Indus, Ganga and Brahmaputra Basins covering the Himalaya and Trans Himalaya regions, and it is difficult to monitor these via field due to rugged terrain. Therefore, in this study remote sensing and GIS techniques have been used to study the glaciers and its health in Alaknanda, sub-basin of Ganga, India.
Keywords *Glacier Health; Composite Health Index; Alaknanda; Ganga Basin*

1. Introduction

The glacier regions of Indus, Ganga and Brahmaputra basins encompass about 0.94 million km^2 areas respectively. Almost 71,182 km^2 are covered by glaciers and spread over the karakoram to North eastern Himalayan region (Sharma et al., 2011; Kulkarni and Buch, 1991; Kulkarni et al., 1999; 2005; WIHG & HPRS, 1992-93). Besides the annual mass balance, other technique for classification of glacier into healthy or fragile glaciers is the assessment of the health status which is very much needed to estimate the effect of climate on the glacial environment (Benn, 1998; Flint, 1971; Paterson, 1994; Sugden, 1976). Therefore, in this study, the glacier health is assessed based on Remote Sensing and GIS technique along with ancillary data. Further, Composite Health Index (CHI) method is used for the classification and to understand the present health condition of glaciers in Alaknanda, Sub-basin of Ganga.

2. Study Area

The Alaknanda River Basin is one of the major basins of Ganga. The Alaknanda basin lies between 30°0' N to 31°0' N and 78°45' E to 80°0' E and represents the eastern part of the Garhwal Himalaya (Figure 1). Alaknanda covers an area of 10882 km^2. Out of the total area, 433 km^2 is covered by glaciers (Figure 2). The altitude of the glaciers varies between 3500 to 6000 meters (Figure 5).

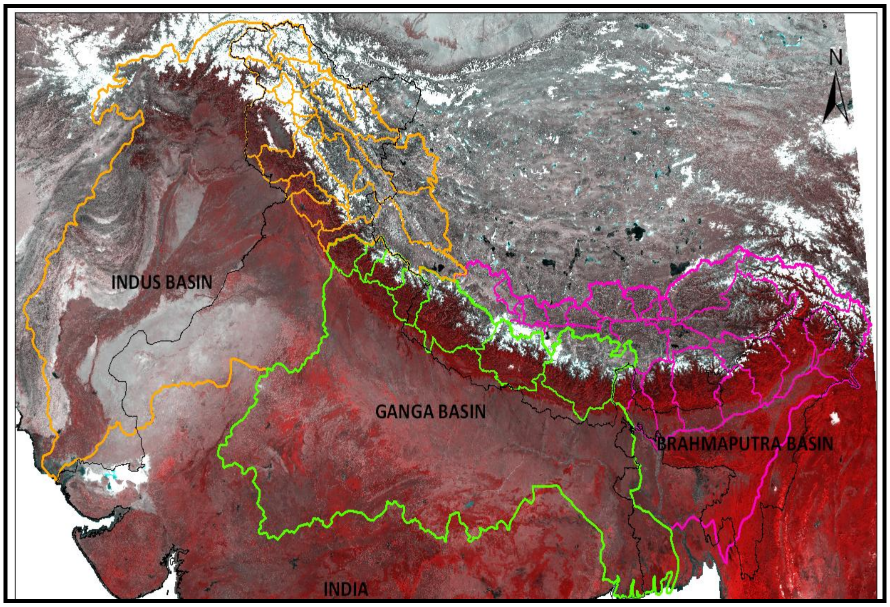

Figure 1: *Index of Alaknanda, Sub Basin of Ganga River Basin*

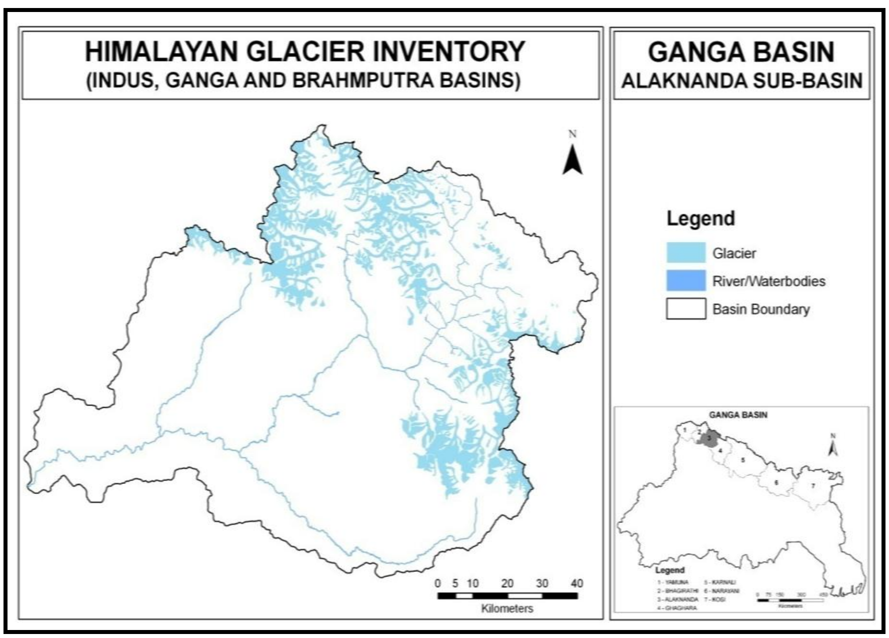

Figure 2: *Glaciers and Watershed of Alaknanda Basin*

3. Data used and Methodology

The data used are IRS AWiFS and SRTM DEM (Table 1). Advanced Wide Field Sensor (AWiFS) includes four spectral bands with 56m spatial resolution covering a swath of 740 km. The band combinations are green (0.52-0.59 µm), red (0.62-0.68 µm), NIR (0.77-0.86 µm) and SWIR (1.55-1.70 µm). AWiFS data is obtained from National Data Centre of National Remote Sensing Center (NRSC) Hyderabad and DEM from Shuttle Radar Topography Mission (SRTM). The glacier morphology map and data sheet for glacier inventory are prepared using IRS-P6 AWiFS data from 2005 to 2007. The morphological parameters like Area of glacier, Length, Elevation, Orientation and Ice exposed area are taken from the inventory datasheet and with these parameters, the secondary parameters such as Accumulation area ratio, Percent debris cover, Percent slope are obtained. Further, they are grouped into 5 classes and rank is assigned as per the significance.

Table 1: *Primary Data Set Used for Analysis*

Theme	Feature Type	Main Source	Remarks
1. Base Map			
Topographic map	Polygon	SOI open series maps	15’ 15’ latitude-longitude grid and SOI reference no.
Country Boundary	Polygon	SOI and admin. Maps	Country
Digital Elevation Model	Grid	SRTM data	Image grid
2. Hydrology			
Drainage lines	Line	Irrigation Atlas & Satellite Data	Streams – nomenclature
Drainage poly	Polygon	- DO -	Water body, river boundary
Watershed Boundary	Polygon	Watershed Atlas, Satellite data	Watershed boundary and alpha numeric codes
3. Glacier			
Glacier boundary	Polygon	Satellite data	Ablation, accumulation, snow cover areas, etc
Glacier lines - Snow Line / Ice divide	Line	Satellite data	Line divide between accumulation and ablation area
Glacier point - Snout location	Point	Satellite data	Glacier terminus point and glacier coordinate point
Glacier elevation locations	Point	Satellite data & DEM	Glacier elevation location points like highest or lowest elevation of glacier, etc.

Based on Saaty's (Saaty, 2008) method, the parameters are assigned and the comparison matrix is prepared. The matrix is solved by Eigen vector method and the consistency index including Eigen weights and consistency ratio are derived. The consistency ratio less than or equal to 0.1 is acceptable (Saaty, 2008). Larger values require the decision maker to reduce the inconsistencies by revising judgments. Weighted ranks are obtained by multiplying the Eigen weights and rank assigned. For a given glacier, the composite weights are obtained by summation of all weighted ranks, known as Composite Health Index (CHI) values. They are categorized into five health status classes to identify the relative fragile or healthy glaciers in the Alaknanda basin (Figure 3).

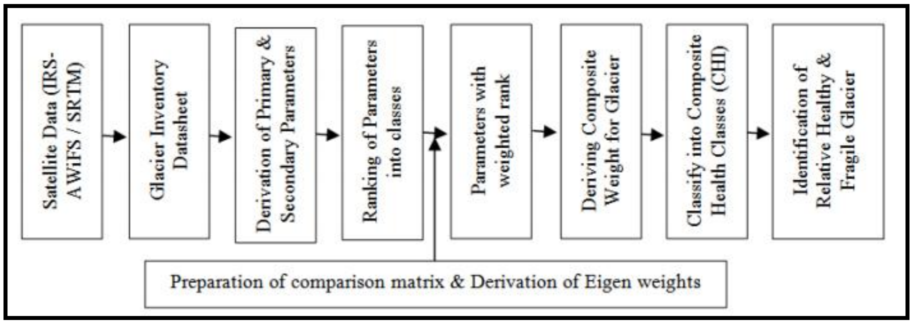

Figure 3: *Development of Comparison Matrix & Derivation of Eigen Weights*

4. Results

The Alaknanda sub-basin spread over in 10882 km^2 area and it has 253 glaciers, covering 39 percent as the glaciated area. The aerial distribution varies from 3500 to 6000 m.a.s.l. The accumulation area is 787.07 km^2, debris covered ablation area debris is 349.79 km^2, ice exposed ablation area is 193.07 km^2. The total volume of glacier ice as estimated in Alaknanda sub-basin is 183.85 km^3. For all the 253 glaciers in Alaknanda, the weighted analysis has been carried based on the eight parameters in GIS and CHI values lies between 241 and 544. Each of the eight parameters is ranked as per its significance for the glacier health. Thereafter, they are categorized in to five relative glacier health categories (Figure 4, Table 9). Based on the CHI values, it is estimated that out of 253 glaciers in Alaknanda basin, there are 35 fragile glaciers having CHI values less than 290, which cover area of 73.9 km^2 and 11 healthy glaciers having CHI values greater than 440, which cover area of 26 km^2. The mean size of fragile glaciers (CHI category I and II) is 3.4 km^2 healthy glacier (CHI category IV and V) is 5.8 km^2. The glaciers in this basin are with less albedo, because of higher percentage of debris covered ablation area. The Glaciers having AAR greater than 0.6 are 122, which covers 10.75%, area and less than 0.6 are 131, which cover 85.29% area.

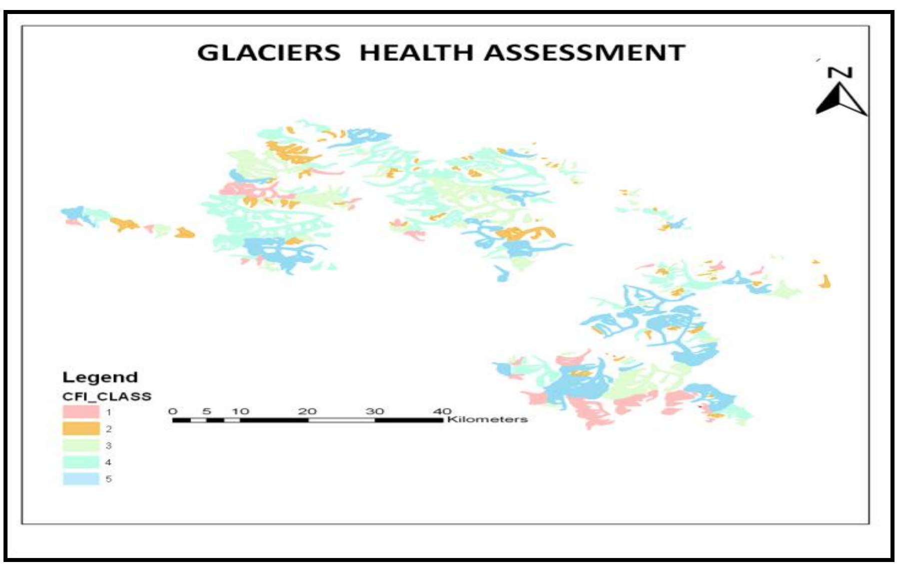

Figure 4: *Assessment of Glaciers Health in Alaknanda Sub-basin*

There glaciers with around 21% are oriented in northeast direction but cover only 9% area. The 19% southeast direction glaciers cover almost 31% area. The southwest direction has 20% glaciers covering 21% area. The south facing glaciers are very few in number about 9% glaciers, which cover 16% area. The west facing glaciers are the least in number and area i.e. 5% with an area of 1%. The ranks of the eight parameters are given in Tables 2 to 8. Higher rank has been assigned to the higher values of AAR, Area, Length, elevation, percentage debris cover and vice versa in the case of ice exposed area and percentage slope. The lower CHI values represent the relatively fragile glacier and the higher values represent the relatively healthy glaciers.

Table 2: *Glaciers Length*

Class	Class-Interval (Km)	No_of_Counts	Rank
1	<1.0	25	I
2	=>1.0 TO <2.0	71	II
3	=>2.0 TO <5.0	114	III
4	=>5.0 TO<10.0	26	IV
5	>10.0	17	V

Table 3: *Glaciers Area*

Class	Class-Interval (Km)	No_of_Counts	Rank
1	<1.0	199	I
2	=>1.0 TO <2.0	103	II
3	=>2.0 TO <5.0	98	III
4	=>5.0 TO<10.0	35	IV
5	>10.0	49	V

Table 4: *Percent Debris Cover*

Class	Class-Interval (Km)	No_of_Counts	Rank
1	<1.0	26	I
2	=>1.0 TO <2.0	44	II
3	=>2.0 TO <5.0	52	III
4	=>5.0 TO<10.0	22	IV
5	>10.0	17	V

Table 5: *Percent Slope*

Class	Class-Interval	No_of_Counts	Rank
1	<1.0	77	I
2	=>1.0 TO <2.0	78	II
3	=>2.0 TO <5.0	81	III
4	=>5.0 TO<10.0	14	IV
5	>10.0	3	V

Table 6: *Area Accumulation Ratio (AAR)*

Class	Class-Interval	No_of_Counts	Rank
1	<1.0	215	I
2	=>1.0 TO <2.0	8	II
3	=>2.0 TO <5.0	3	III
4	=>5.0 TO<10.0	1	IV
5	>10.0	1	V

Table 7: *Ice Exposed Area*

Class	Class-Interval	No_of_Counts	Rank
1	<1.0	38	I
2	=>1.0 TO <2.0	42	II
3	=>2.0 TO <5.0	107	III
4	=>5.0 TO<10.0	67	IV
5	>10.0	53	V

Table 8: *Orientation of Ablation & Accumulation Areas*

Direction	No. of Glaciers
E	18
N	20
NE	52
NW	27
S	23
SE	48
SW	50
W	15
Total	253

Table 9: *Weightage Classes of Glaciers in Alaknanda Sub-Basin*

Health Class	Class Weight	No Of Glaciers
I	<205	35
II	205 - 235	82
III	235 - 265	66
IV	265 - 295	46
V	>295	24

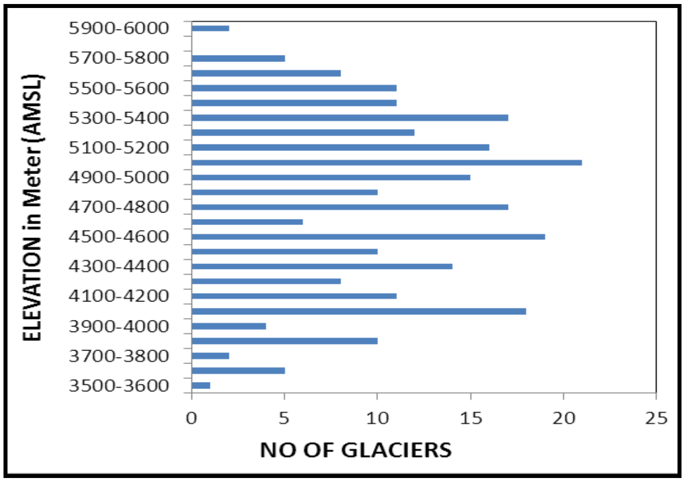

Figure 5: *Area Altitude distribution of Glaciers in Alaknanda Basin*

5. Discussion

The glaciers oriented in northeast direction may retreat partly than the glaciers located in the southwest direction. This depends upon the availability of solar energy on the glacier surface. Among the eight parameters considered for the study, the AAR and altitude plays a major role, as these indicate the health of the glaciers and the status of mass balance. The CHI values represent the health condition of the glaciers, i.e., the lower value represents the fragile glaciers and vice versa in case of healthy glaciers.

6. Conclusion

The weighted analysis method based on multi parameter is very useful for deriving the Composite Health Index (CHI). Thus, the different health classes can be derived using remote sensing and GIS techniques at Sub-basin or Basin level. Thereafter, the derived parameters can be validated upon the availability of retreat values.

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