Monitoring of glacial mass balance in the Baspa basin using accumulation area ratio method

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In the Himalaya, glacier and snow-melt form an important source of water into the North Indian rivers. However, this source of water is not permanent as glacial dimensions change with climate. One of the important parameters to model future changes in glacial extent is the mass balance. In this communication an attempt has been made to calculate the mass balance for 19 glaciers in Himachal Pradesh using accumulation area ratio (AAR) method. A regression relationship between AAR and specific mass balance was developed using field data from 1982 to 1988 for Shaune Garang glacier and 1976 to 1984 for Gor Garang glacier. Regression analysis suggests good correlation between AAR and specific mass balance with r^2 as 0.80. AAR for 2000 and 2001 was estimated for 19 glaciers in the Baspa basin by systematic weekly analysis of WiFS images of Indian Remote Sensing satellite from May to September. Mass balance was estimated during 2001 and 2002 for 19 glaciers in the basin, suggesting overall specific mass balance value of – 90 and – 78 cm, respectively. The investigations suggest a loss of 0.2347 km^3 of glacial ice in the last two years. The investigation has shown that four glaciers have no accumulation area, as these are located in lower-altitude zones. These glaciers are expected to face terminal retreat due to lack of formation of new ice. This is likely to pose serious problem of availability of water to many villages located in the Baspa basin.

AT present there is about 26 million km^3 of ice on our planet, which cover almost 10% of the world's land area[1]. Moreover, during northern hemispherical winter, snow covers almost 66% of land. In the Indian Himalaya, the glaciers cover approximately 23,000 km^2. area and this is one of the largest concentrations of glacier-stored water other than the polar regions[2]. Melt-water from these glaciers forms an important source of water into the North Indian rivers during critical summer months. However, this source of water is not permanent, as glacial dimensions change with climate. During Pleistocene the earth's surface had experienced repeated glaciation over a large land mass. The maximum area during the peak of glaciation was 46 million km^2, i.e. three times more than the present ice cover of the earth. Available data indicate that during the Pleistocene the earth had experienced four or five glaciation periods separated by interglacial periods. During the interglacial period the climate was warmer and deglaciation occurred on a large scale. This suggests that glaciers are constantly changing with time and it can profoundly affect the run-off of Himalayan rivers. Glacial changes can be further accelerated due to greenhouse effect, caused by man-made changes in the earth's environment. In 2001, Intergovernmental Panel of Climate Change (IPCC) of the UN[3] had suggested an increase in global temperature by 0.6 ± 0.2°C from the year 1900. This has caused wide-scale retreat of glaciers in the Himalaya, Alps, Andes and Rocky mountains[4,5].

Future changes in glacial extent are important, because it can influence river run-off pattern. Many parts of the Himalaya, north of Pir Panjal range, receive little precipitation during monsoon. Melting of glaciers provides water for streams and rivers in the region from July to October. Future changes in glacial length due to climatic variations can be estimated using ablation rate at terminus and change in mass balance[6,7]. The mass balance of a glacier is usually referred to as the total loss or gain in glacier mass at the end of a hydrological year[7]. It is estimated by measuring the total accumulation of seasonal snow and ablation of snow and ice. This can be measured by various ways. In direct measurement, net balance is measured at representative points on the glacier. In the photogrammetric method, contour maps are prepared at an interval of a few years. Two maps can be compared to determine the change in glacier volume. In the hydrological method, net balance can be determined for the whole basin by measuring perception, run-off and evaporation. These methods need extensive field investigations, and due to the rugged terrain of the Himalayas, they can provide the mass balance of only a few glaciers. In order to obtain the mass balance of a large number of glaciers, accumulation area ratio (AAR) method can be used. AAR is a ratio between accumulation area and total glacier area[8]. Accumulation area is the area of a glacier above the equilibrium line. In temperate glaciers, the extent of superimposed-ice zone is insignificant and therefore, the equilibrium-line coincides with the snow-line[7]. Snow-line at the end of the ablation season and AAR can be estimated using remote sensing method[9,10]. In this communication systematic analysis of satellite images was carried out to assess mass balance of 19 glaciers in the Baspa basin. The Baspa river is a tributary of the Satluj river located in Kinnaur District, Himachal Pradesh. The location map of Baspa basin and individual glaciers in the basin are given in Figure 1.

A relationship between AAR and mass balance is developed using field mass balance data of the Shaune and the Gor Garang glaciers. Both the glaciers are located in Baspa river basin. Field data were taken from various reports of Geological Survey of India[11]. Glacier area was estimated using LISS-III of Indian Remote Sensing Satellite (IRS). LISS III sensor has spatial resolution of

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23.5 m in visible and near infrared bands and 70 m in SWIR band. Images of July–September season (25 August 2001 and 11 September 2000) were selected, because during this period snow cover is at its minimum and glaciers are generally fully exposed[12]. Accumulation area for each glacier varies from year to year, depending upon snow-line at the end of the ablation season. Snow-line on the glaciers was monitored by systematically analysing weekly data of WiFS sensor of IRS from May to October. It is ideally suited for snow-cover monitoring due to five-day repetitive coverage and 188 m ground resolution. WiFS has two spectral bands, one in the visible (0.62–0.68 μm) and another in the near infrared spectrum (0.77–0.86 μm). WiFS of IRS-P3 has additional SWIR (1.55 to 1.75 μm) band, which can be used for snow-cloud discrimination.

A remote sensing-based method on AAR and equilibrium-line altitude is useful for glaciers for which no field data are available[9]. A regression relationship between AAR and specific mass balance is shown in Figure 2. Field data are available for different years starting from 1982 to 1988 for the Shaune Garang glacier and 1976 to 84 for the Gor Garang glacier. Both data are used together to estimate a general relationship for the Baspa basin. Regression analysis suggests good correlation between AAR and mass balance, with r^2 as 0.80 (Figure 2). The following regression equation is obtained:

$$Y = 243.01 * X - 120.187, \quad (1)$$

where Y is the specific mass balance in water equivalent (cm) and X is the accumulation area ratio.

The model has shown AAR representing zero mass balance as 0.5 compared to 0.7 in the Alps and Rocky mountains.

Estimation of AAR needs mapping of glacier and accumulation area. Accumulation area for each glacier

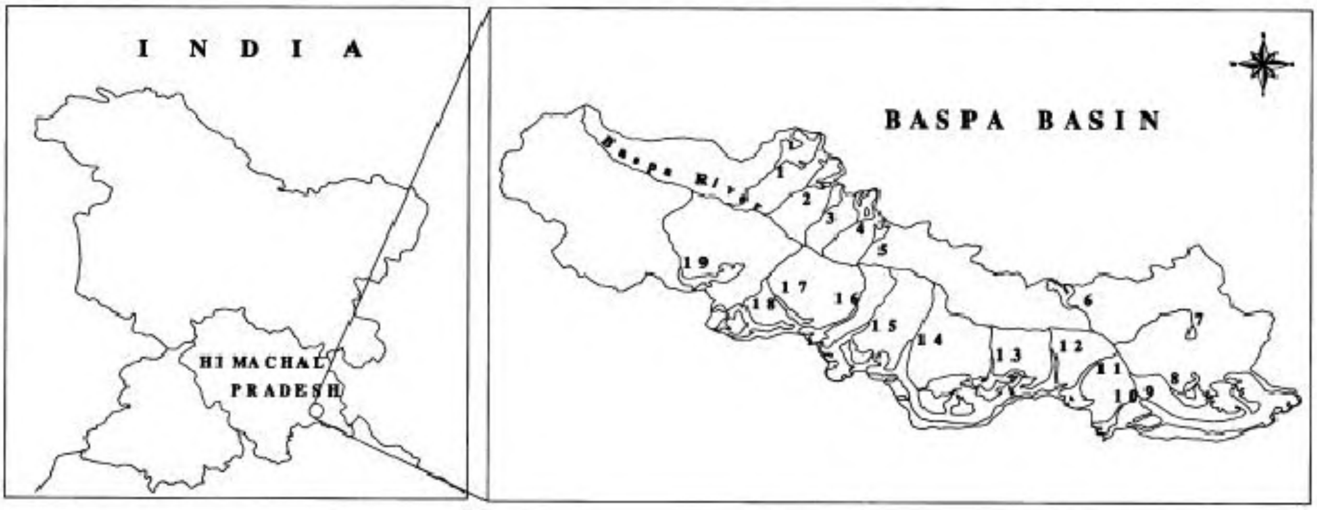

Figure 1. Location map of Baspa basin and individual glaciers in the basin.

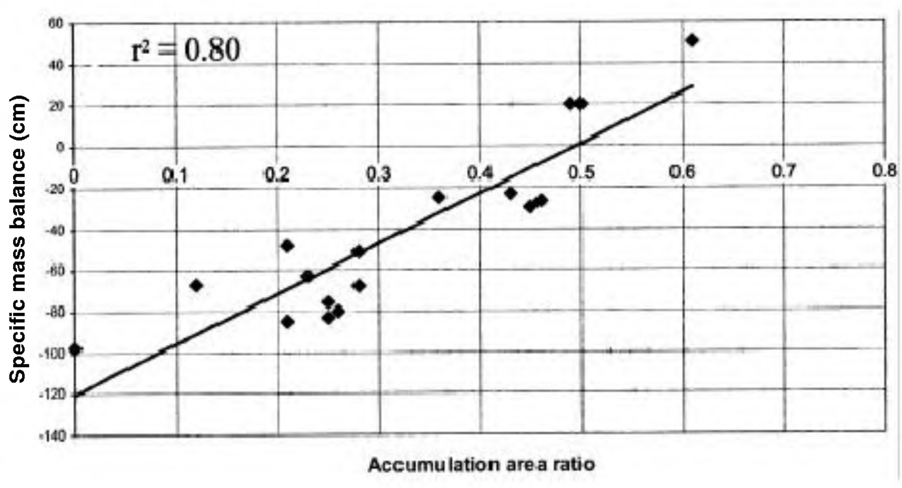

Figure 2. Regression relationship between accumulation area ratio and mass balance for Shaune Garang and Gor Garang glaciers.

will vary from year to year depending upon the snow-line at the end of the ablation season. Snow-line on glacier was monitored by systematically analysing weekly data of WiFS sensor of IRS from May to October. In this investigation WiFS sensor of IRS-1C, 1D and P3 was used. Maximum retreat of snow-line was observed on 27 August 2001 and 24 July 2002 (Figures 3 and 4). Position of snow-line was delineated for 19 glaciers in the basin and their AAR and mass balance was estimated (Table 1).

Mass balance was estimated during 2001 and 2002 for 19 glaciers in the basin using eq. (1). AAR and specific mass balance were estimated for individual glaciers (Table 1). For each glacier, specific mass balance values were multiplied by area to obtain total loss on gain in glacial mass. The mass balance of each glacier was added to assess total loss of glacial ice in the last two years. The investigations suggest a loss of 0.2347 km^3 of glacial ice between 2000 and 2002. In addition, overall specific mass balance in the hydrological year 2000–01 and 2001–02 was estimated as – 90 and – 78 cm, respectively. Orientation of the glacier seems to have profound influence on snow-line altitude. Average altitude of snow-line at the end of the ablation season is 5400 m for southern-facing and 5297 m for northern-facing glaciers. Area–altitude distribution of glaciers also influences mass balance (Table 2). In Table 2, the influence of mid-altitude on glacier mass balance is

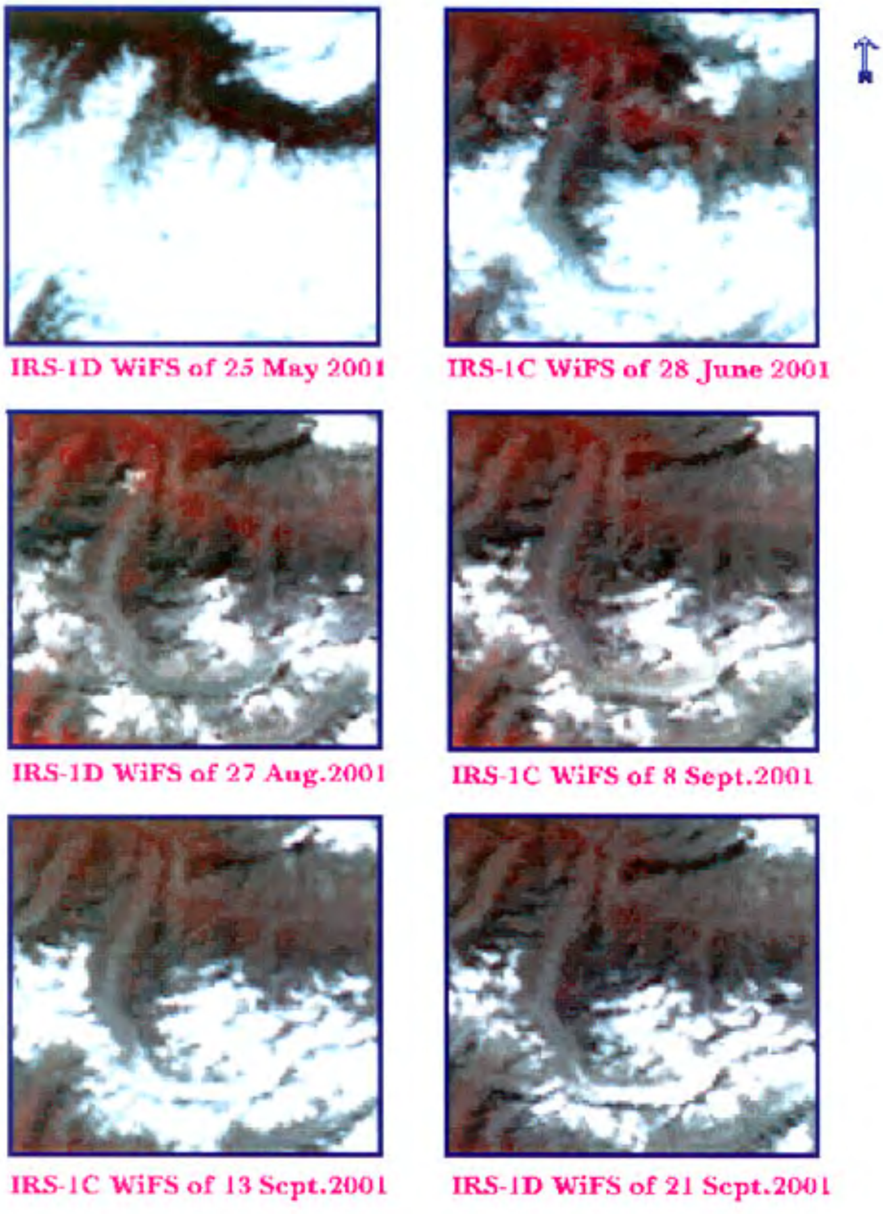

Figure 3. WiFS images of Indian Remote Sensing Satellite showing position of snow-line on Janapa Garang Glacier in 2001.

given. Mid-altitude divides the glacier into half. As mid-altitude changes from 5000 to 5400, specific mass balance also change from – 111 to – 49 cm.

Four glaciers have no accumulation area and average snow-line altitude is well above maximum altitude (Table 1 and Figure 5). In addition, two glaciers have marginal accumulation area and their AAR is less than 0.01. These six glaciers are located in the low-altitude zone with average maximum altitude of 5266 m, which is almost 200 m less than the mean snow-line of the basin. Rock and soil reflectance in the SWIR region is higher than that in snow[13]. Therefore, red tone on satellite images for glacier numbers 1 to 4 (Figure 5) suggests debris cover. Due to excessive debris cover, glaciers are likely to ex-

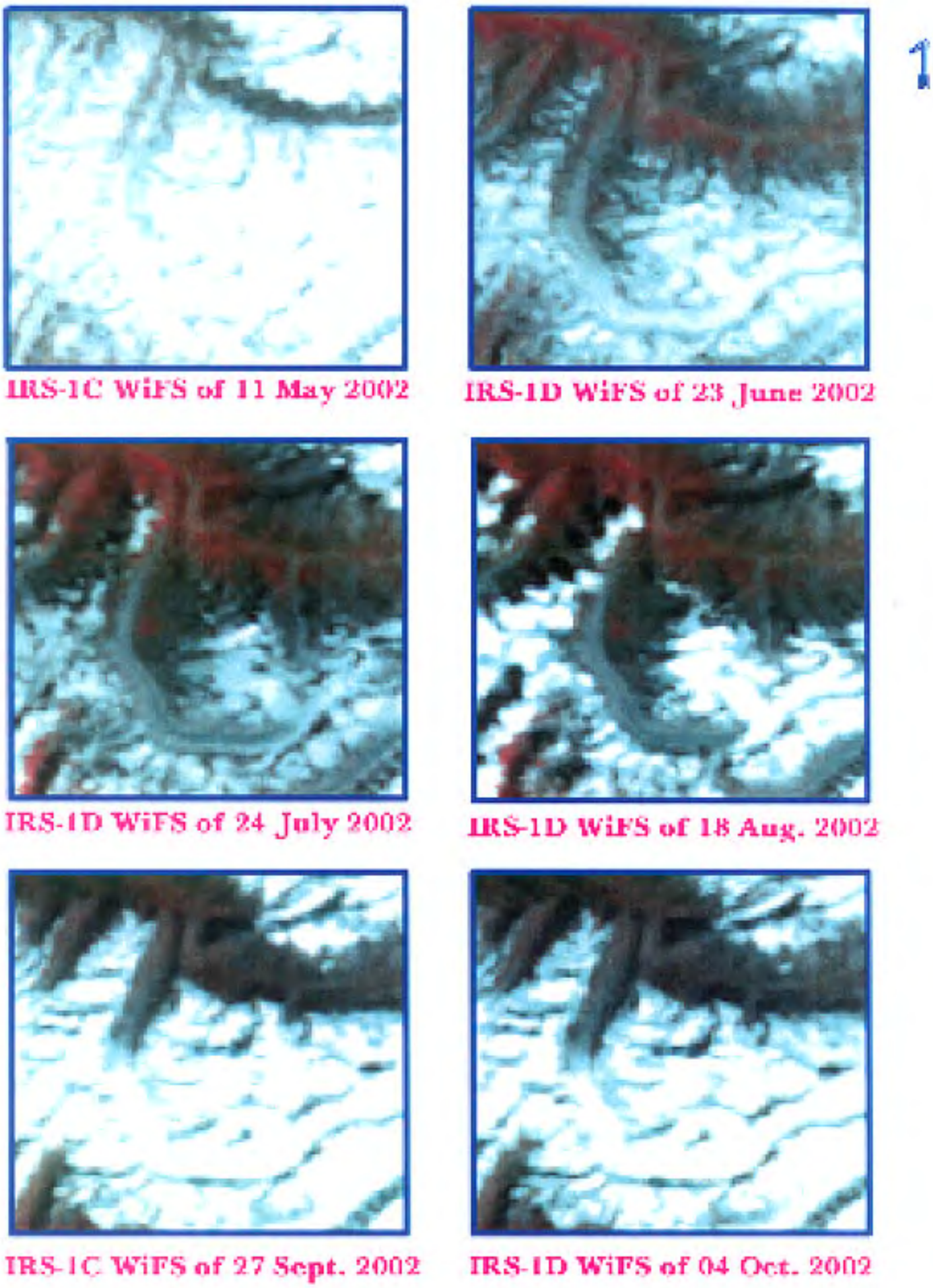

Figure 4. WiFS images of Indian Remote Sensing Satellite showing position of snow-line on Janapa Garang Glacier in 2002.

Table 1. Mass balance for 19 glaciers in the Baspa basin, Himachal Pradesh. Mass balance values are in water equivalent

						2001				2002				
Sl. no	Database number	Glacier area (km^2)	Orientation of ablation	Mid-altitude (m)	Maximum altitude (m)	Snow-line altitude (m)	Accumulation area (km^2)	AAR	Specific Mass balance (cm)	Snow-line altitude (m)	Accumulation area (km^2)	AAR	Specific Mass balance (cm)	Mean mass balance (2001 and 2002)
1	53I07001	8.7	SW	4920	5480	5180	0.96	0.11	– 90	5120	1.13	0.13	– 87	– 88.5
2	53I07002	4.3	SW	4960	5320	–	0	0	– 120	–	0	0	– 120	– 120
3	53I07003	2.0	SW	5040	5200	–	0	0	– 120	–	0	0	– 120	– 120
4	53I07004	4.1	SW	5160	5640	5510	0.12	0.03	– 111	5360	.70	0.17	– 79	– 95
5	53I07005	1.2	SW	4840	5040	–	0	0	– 120	–	0	0	– 120	– 120
6	53I11013	3.2	SE	5520	5880	5550	1.25	0.39	– 25	5560	1.18	0.37	– 30	– 27.5
7	53I11014	0.8	N	5320	5480	5360	0.03	0.04	– 108	–	0	0	– 120	– 114
8	53I12001	5.6	NW	5440	5840	5420	1.29	0.23	– 65	5320	1.01	0.18	– 77	– 71
9	53I12002	33.5	NW	5240	5780	5365	5.03	0.15	– 85	5192	8.71	0.26	– 57	– 71
10	53I12003	2.2	NE	5080	5280	5160	0.22	0.10	– 97	4960	.33	0.15	– 83	– 90
11	53I11009	5.0	NE	5120	5600	5160	1.3	0.26	– 56	5100	2.05	0.41	– 19	– 37.5
12	53I11010	5.8	N	5320	5516	5520	1.16	0.20	– 71	5270	2.26	0.39	– 24	– 47.5
13	53I11011	4.5	N	5360	5536	5533	0.36	0.08	– 101	5433	0.86	0.19	– 74	– 87.5
14	53I07006	30.4	NE	5240	5800	5408	6.69	0.22	– 67	5208	7.90	0.26	– 55	– 61
15	53I07007	9.9	NE	5120	5600	5160	2.57	0.26	– 55	5080	3.37	0.34	– 37	– 46
16	53I07008	4.1	NE	5000	5400	5160	0.53	0.13	– 88	5180	0.57	0.14	– 87	– 87.5
17	53I07009	1.9	NW	4680	5000	–	0	0	– 120	–	0	0	– 120	– 120
18	53I07010	7.0	N	4720	5280	5000	0.49	0.07	– 104	5110	.28	0.04	– 110	– 107
19	53I07011	6.1	NW	5120	5480	5320	0.31	0.05	– 108	5240	1.34	0.22	– 66	– 87

Table 2. Influence of altitude distribution on glacier mass balance. Mass balance values are in water equivalent

Mid-altitude range (m)	No. of glaciers	Specific mass balance (cm)
< 5000	5	– 111
5000–5200	7	– 80
5200–5400	5	– 76
> 5400	2	– 49

perience relatively less melting. However, due to lack of formation of new ice, glaciers might experience terminal retreat. The remaining glaciers are northern-facing and therefore have relatively lower snow-line at the end of the ablation season. In addition, average maximum altitude is also relatively higher, as these glaciers are located on the northern slopes of the Pir Panjal mountain range. A combination of higher area–altitude distribution and lower snow-line gives higher AAR. The difference between average snow-line of northern-facing and southern-facing glaciers was observed to be 160 m. Glaciers located on the northern slope in the altitude region below 5170, and those on the southern slopes below 5330 m will have little or no accumulation area. Six glaciers are located in this altitude zone and have little or no accumulation area. Therefore, these can experience terminal retreat. Mass balance was estimated during 2001 and 2002 for 19 glaciers in the basin, suggesting overall specific mass balance value of – 90 and – 78 cm, respectively. The investigations suggest a loss of 0.2347 km^3 of glacial ice in the last two years.

The investigation has shown that all glaciers have negative mass balance and loose more snow and ice due to melting than accumulation of seasonal snow. This loss in

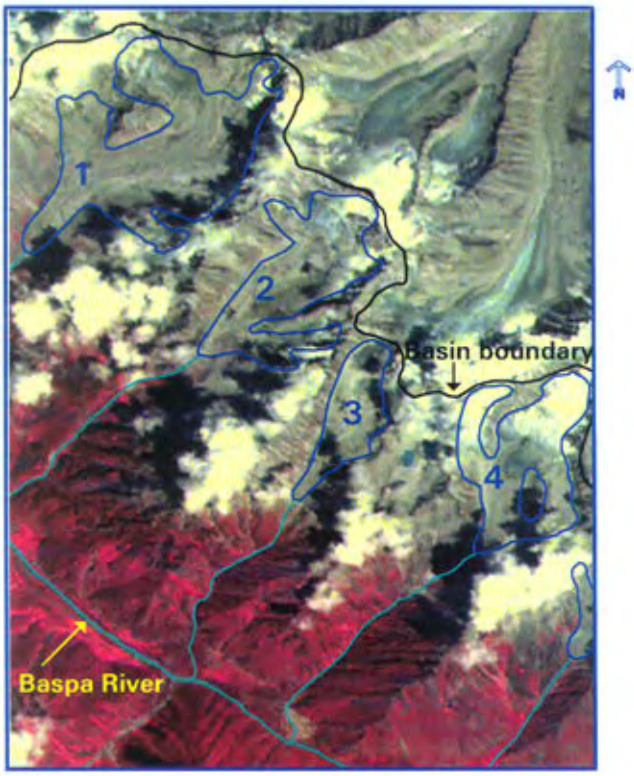

Figure 5. LISS-III images of Indian Remote Sensing Satellite dated August 2000 showing no accumulation area for glacier numbers 1–3.

glacial ice will have profound influence on glacial extent. Significant reduction in glacial extent is also reported for these glaciers during the last century[14]. This is likely to accelerate during the 21st Century. Initially, excessive melting of glaciers will increase stream run-off, and previous investigations have shown increase in run-off of the Baspa basin[13]. However, in the long term, decrease in glacier extent will decrease in stream run-off during summer and autumn seasons, affecting local as well as national economy, since many villages are located on the banks of streams originating from glacier numbers 1–4. In addition, run-off of the Baspa river is also used for generation of hydropower. All these observations suggest that global warming has started to affect glacier melt in the Himalaya and poses questions to the conservation of precious water resources.

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Sediment contamination by arsenic in parts of central-east India and analytical studies on its mobilization

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This communication reports arsenic contamination of sediments in parts of Chhattisgarh. It also investigates the nature of arsenic contamination and the conditions which may favour its release from this matrix. The contaminated sediment serves as a long-time source of arsenic because As mobility and transport in the environment are strongly influenced by its association with the solid phase in soil and sediment. The results establish the sediment contamination of certain water bodies, including a major river in the region. As levels in the contaminated sediments lie between 200 and 10.75 ppm, with a mean level of contamination at 68.00 ppm and standard deviation of 41.81 ppm. A direct result of this contamination has been noted in the form of lower productivity of the Shivnath river in fish population.

Sequential arsenic extraction procedures were adopted to differentiate the nature of arsenic species in the sediment and its mineral assemblages. Two analytical schemes were followed to identify the arsenic phases in the sediment. Sequential extraction analyses indicate that a large portion of the arsenic in Chowki–Rajnandgaon–Durg sediments is in complex silicate matrices or is calcium-bounded. This will limit the mobility of arsenic. Yet about 15% of As which is in the form of exchangeable fraction may get mobilized by changes in the ionic strength of the overlaying matter. This indicates the need for a scientific management of the contaminated sediments in the region.

ARSENIC contamination of groundwater has become a worldwide menace. It is harming the developing countries more vehemently owing to obvious reasons. The Bengal Delta Plain (BDP) has become one of the most severely contaminated parts in the world. Yet, there could be many more BDPs in India, which are yet to be explored. Pandey *et al.*[1] first reported arsenic contamination of the groundwater and the consequent human affliction at a village named Kaurikasa in erstwhile Madhya Pradesh (now Chhattisgarh), which does not share boundary or geology with BDP. A further paper by Pandey *et al.*[2] established the contamination of surface water due to the probable mobilization of contaminated groundwater. Now it is logical to see if the sediments are also contaminated in the affected locations of central-east India.

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