APPLICATION OF REMOTE SENSING TECHNIQUES TO STUDY HYDRO-METEOROLOGICAL CHANGES ON THE DYNAMICS OF GLACIERS, BHAGIRATHI BASIN, GARHWAL HIMALAYA

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ABSTRACT

Hydro-meteorology is an interdisciplinary science involving the study and analysis of the interrelationships between the atmospheric and land phases of water as it moves through the hydrologic cycle. The recent development in remote sensing gives an opportunity to map natural features on earth surface with more accurately as 20 years before. In this paper, the de-glaciation pattern of the Bhagirathi basin has been studied from year 1980-2006 and various climatic parameters are also analyzed during this period and compared with the changes on the glacier dynamics. Bhagirathi River and its tributaries are dependent predominantly on glacier and snow melt and precipitation. The average rainfall data for the Garhwal Himalaya varies between 1000 to 2500mm of which 50-80% falls during the monsoon period between June and September. Over the study period, average daily maximum and minimum temperatures were computed to be 14.7 and 4.1°C, respectively, whereas average mean temperature was 9.4°C. The investigation was carried out with the satellite images from the Landsat images of Multispectral Scanner (MSS) and Thematic Mapper (TM and ETM+). Alongwith the Landsat images, Indian Remote Sensing Satellite (IRS) LISS-III images have been used for preparing a repetitive glacier inventory. The retreat rate was faster in year 1980-2000 compare to the year 2000-2006. With the gradual retreat, the tributaries of the glaciers are susceptible to a detachment from the main body, thus showing fragmentation.

Keywords: remote sensing, hydro-meteorology, glaciers, Bhagirathi basin, Himalaya.

1. INTRODUCTION

Glacial environment exhibits rapid, dynamic spatially variable changes of processes. The complex relationship between glacier dynamics and mass balance fluctuations is poorly understood. At present, the World Glacier Monitoring Services (WGMS) of International Commission on snow and Ice (ICSI/IAHS) collects data for glaciers under Global Environmental Monitoring System (GEMS). The database includes changes in length of glacier, mass balance, specific balance, cumulative specific balance, accumulation area ratio (AAR) and equilibrium line altitude (ELA) given for Alps and Scandinavia since 1945. In addition, extensive information such as balance maps, balance/altitude diagrams, relationship between AAR and ELA and balance have been worked out. As global warming continues to increase the atmosphere temperature, it will lead to a continuous shift of zero temperature line (snow line) toward higher altitude. Thus, glaciers will receive more liquid precipitation and less monsoonal solid precipitation. Shift in snowline will result in lesser input to glacier mass balance during summer periods. Therefore, higher atmosphere temperature and more liquid precipitation at higher altitude in the Himalayas will lead to rapid retreat of glaciers and downstream flooding in the coming future [1, 2].

The average rainfall data for the Garhwal Himalayas varies between 1000 to 2500mm of which 50-80% falls during the monsoon period between June and September. The Bhagirathi river basin experiences strong climatic seasonal variations, which is also clearly reflected in the monthly variation in stream flows. Maximum flow takes place during June-September, when both rainfall and rate of snow melt are at maximum. Most of the Garhwal Himalayan streams carry 69-83% of their annual flow during the summer monsoonal months.

Bhagirathi river basin is situated in the Uttarkashi district of Uttarkhand State. Bhagirathi river basin is not a single valley glacier, this is a combination of several other glaciers that are fed to it and form a huge mass of ice. Bhagirathi peaks are a group of peaks each with a height above 6400m. The three peaks Bhagirathi I, II, and III stand at and dominate the end of the valley leading up to Gaumukh. These peaks form a part of the Himalayan ranges in the Gharwal region. The glacier flows at a gentle slope except for a few ice walls and crevices developed in the upper regions of the glacier whereas in the lower part (above the snout), the glacier is covered by debris which imparts a muddy appearance to its surface. It is the combination of large number of glaciers that forms the huge mass of ice. The base map of the Bhagirathi basin is shown in Figure-1. Bhagirathi river basin is divided into six V order basins as follows.

	V Order basins	Status
1	Bhilangna Ganga	Glacierised
2	Pilang	Glacierised
3	Kaldi	Non-glacierised
4	Jalandhri Gad	Glacierised
5	Jahnvi Ganga	Glacierised
6	Bhagirathi Ganga	Glacierised

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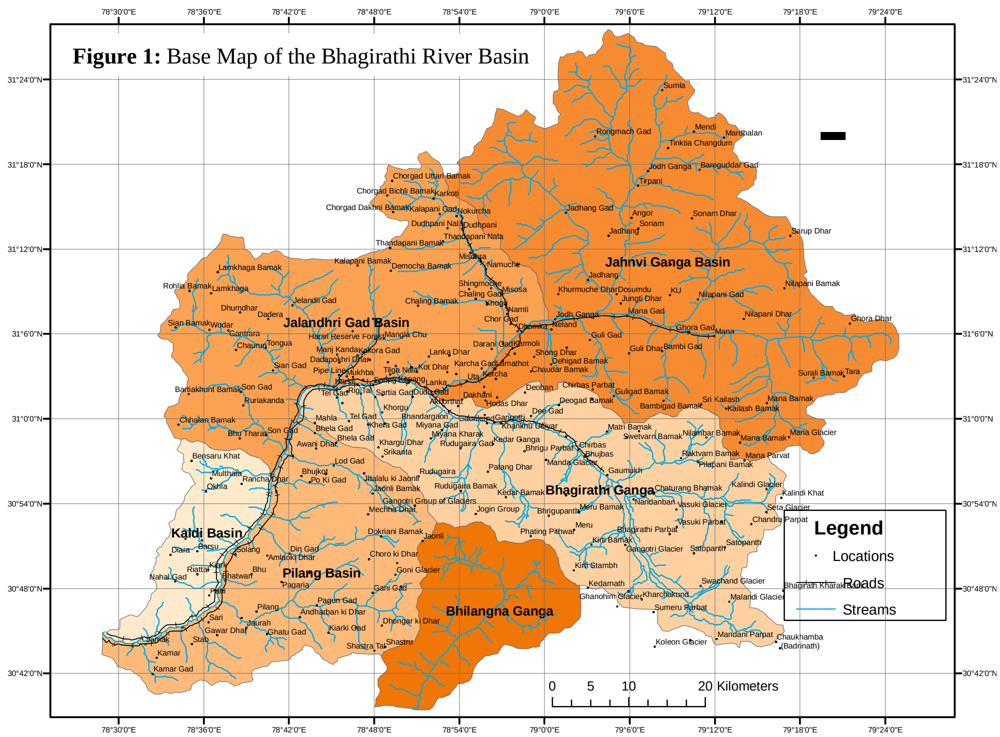

Figure 1: Base Map of the Bhagirathi River Basin

2. MATERIALS AND METHODS

The Bhagirathi Basin boundary has been defined based on the inventory published by Geological Survey of India (GSI), 1990. For identifying the various features of glacier, satellite images of Landsat and IRS were acquired for the months of September-October for the years 1980, 1990, 2000 and 2006. For generating the right kind of FCC image for glaciers identification, the multispectral image formed by standard band combination such as 4, 3, 2 of the Landsat and 3, 2, 1 of the IRS is used. Other collateral information such as the altitude information of the glaciers features (terminus point, highest point etc.,) is derived from toposheets. A few of the glaciated areas are visited to validate the procured result from image for ground truth in the study area in accessible part of basin. After validation, the correction is made in the entire basin. The compiled data is analyzed for its regional distribution and other statistics to relate the distribution pattern in the basin.

For a better analysis, that period of the year is selected when the seasonal snow cover is at its minimum and the permanent snow cover and the glaciers are fully exposed. Because of this criterion, the images acquired in the months of September-October are selected because; they facilitate a better interpretation and analysis. The investigation was carried out with the satellite images from the Landsat images of Multispectral Scanner (MSS) and Thematic Mapper (TM). Alongwith the Landsat images, Indian Remote Sensing Satellite (IRS-P6) LISS III images have been used for preparing a repetitive glacier inventory. The landsat images have been used for an accurate delineation of the glacial boundary in many basins.

After the image to image co-registration, the projections of all the images were defined. To bring all the images under one platform to work, it is compulsory that all of them should be assigned the same projection system and datum, as for this study we used UTM WGS 84. Inventory data for the basin is generated using LANDSAT and IRS satellite imageries using different interpretations methods. Climate data are collected from automatic weather station in Bhojwasa and other data from IMD was used and done simple statistical analysis.

3. RESULTS

3.1 Satellite imagery analysis

In the western and central parts of the Himalayas, cloud cover is quite common especially during the summer months. In the visible part of the spectrum, snow and cloud, both appear bright white and are liable to be confused with each other and this leads to problems in snow cover area estimation [3]. Another important consideration is the mountain shadow. The IRS LISS-III sensor acquires data in the forenoon and the prevailing low angle of solar illumination leads to shadows. In such a case, on simple images, it is difficult to discriminate snow covered areas under mountain shadows from snow-free areas. Snow is characterized by a high reflectance in the visible (0.5-0.7A) region and a rather strong absorption in the short-wave infrared (SWIR) (1.0-3.5A) region [4, 5]. In contrast, clouds exhibit a near-uniform high reflectance due to non-selective scattering. A spectral band ratio can enhance features, if there are differences in spectral slopes [6]. Therefore, a ratio of visible/SWIR helps differentiate snow from clouds/other non-snow covered surfaces.

On satellite images, the glacial boundary was digitized by means of ERDAS Imagine, in which the raster image was used in the standard combinations of bands 4, 3 and 2. The 4, 3, 2 bands combination is, in particular, applicable for delineating the glacial features. Image enhancement technique was used to enhance the difference between glacial and non-glacial areas. The delineation of the glacier boundary and the terminus is one of the important aspects of estimation of glacier change. If glaciers are not covered by debris, identification of snow, ice and rock on satellite imagery is possible due to substantial difference in spectral reflectance. Numerous glacio-morphological features are interpreted and used as a tool to identify the snout or the terminal point of the glacier. The semiarid to arid climate of the region makes it extremely amenable to glacial geomorphological studies and snout determination because of the well preserved moraines and other geomorphological features. Many times, moraine dammed lakes are formed downstream of the glacial terminus. Depending upon relative positions of the sun and the wall, it can form shadow in downstream, which can be used as a marker for terminus delineation, marking the maximum extent of the past glaciation records [7]. However, even because of certain limitations of remote sensing studies like presence of cloud cover or debris cover (in some cases), all precautions were taken to interpret and focus on the images carefully and extract all the information.

Another aspect of this study was to make an attempt in analyzing the maximum extent of the past glaciation in the basin. A study was undertaken to approach for a rough estimate in marking the maximum extent till which the glacial would have had its activity. Though the methodology is not free from errors, but still, it can be treated as a primitive approach. The method incorporated can be further improved and modified. The glacial/fluvial transition points were identified on the longitudinal profile of river basin. Glaciated valleys are easily identified by U-shaped cross sections and characteristics of their longitudinal profiles that contrast strongly with fluvial valley form. The altitude at which the glaciated valleys change from U to V shape was observed and located. Longitudinal valleys have wide, low-gradient floors punctuated by multiple steps and over deepening tens to hundreds of meters deep due to glacial activity [8].

Features are divided into four major categories as Vegetation, Open Rocks, Debris Covered Ice and Snow. Figures 2-5 shows the classified images of the years 1980, 1990, 2000 and 2006. The Table-1 and Figure-6 show the result of imagery analysis of the entire basin in different time periods. It shows that rate of retreat of the debris covered ice and the snow are high from 1980 to 2000 as shown in Table-1 and Figure-6. But it shows less retreat from 2000-2006. It indicates that the rate of retreat is not stable and it is totally influenced by other factors like seasonal rainfall, snow, temperature etc.

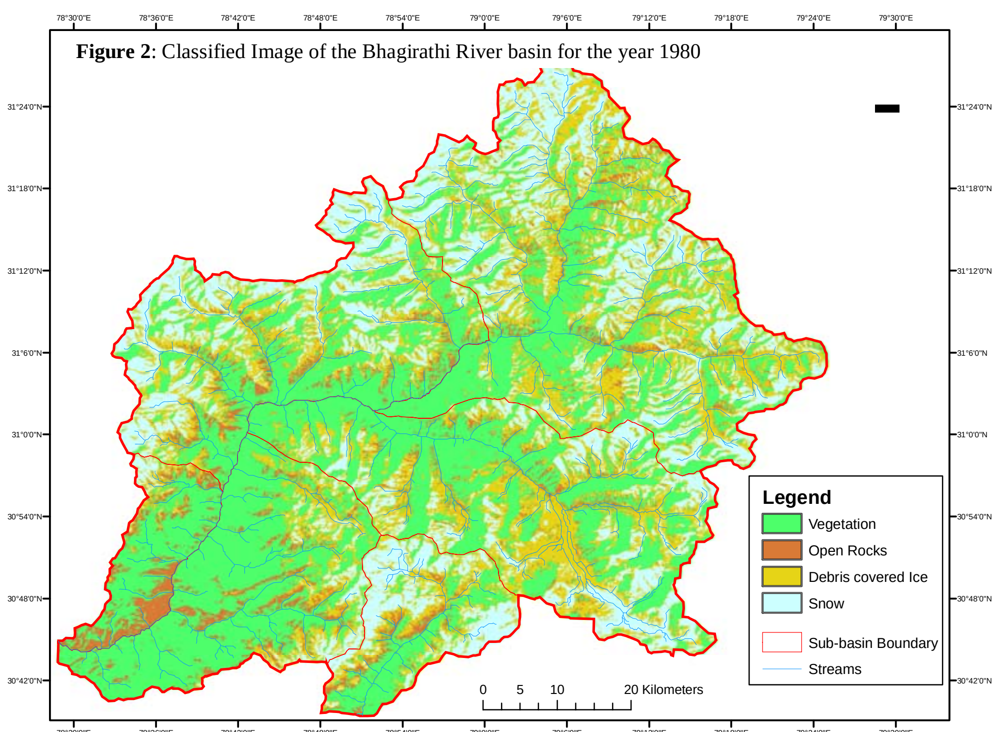

Figure 2: Classified Image of the Bhagirathi River basin for the year 1980

Source: MSS Imagery of December 1980

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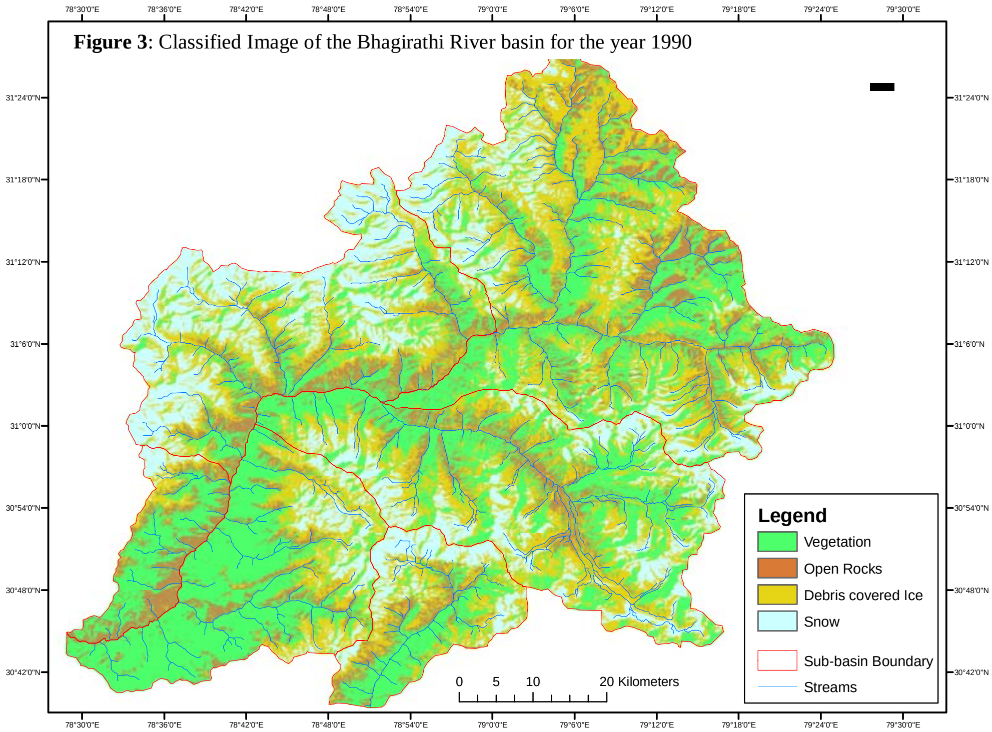
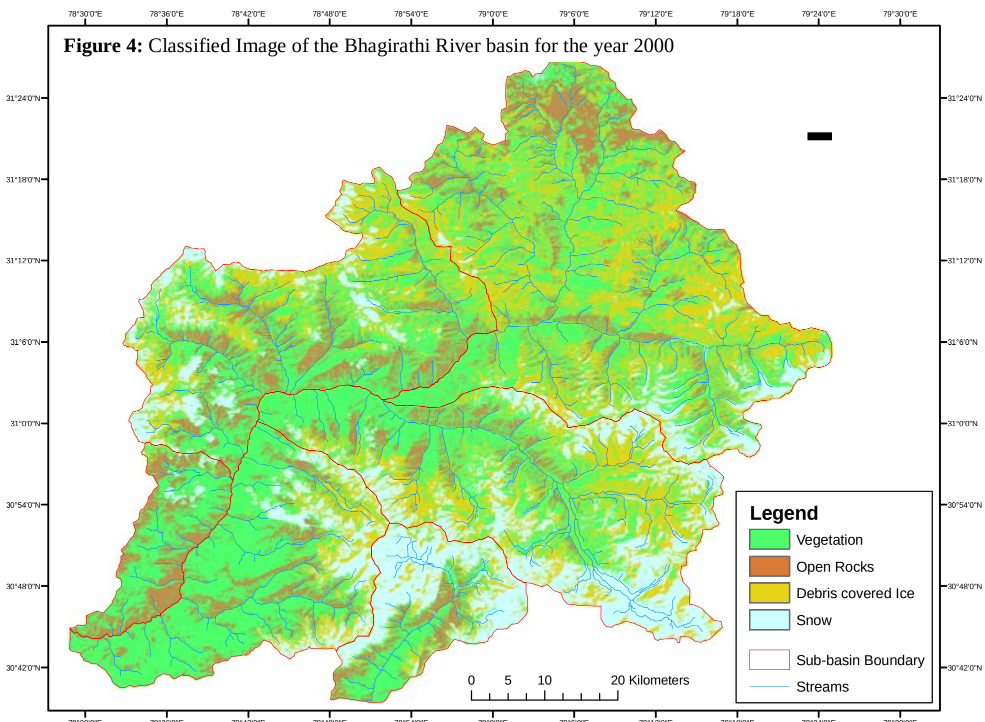
Figure 3: Classified Image of the Bhagirathi River basin for the year 1990



Source: TM Imagery of October 1990

Figure 4: Classified Image of the Bhagirathi River basin for the year 2000



Source: ETM+ Imagery of October 2000

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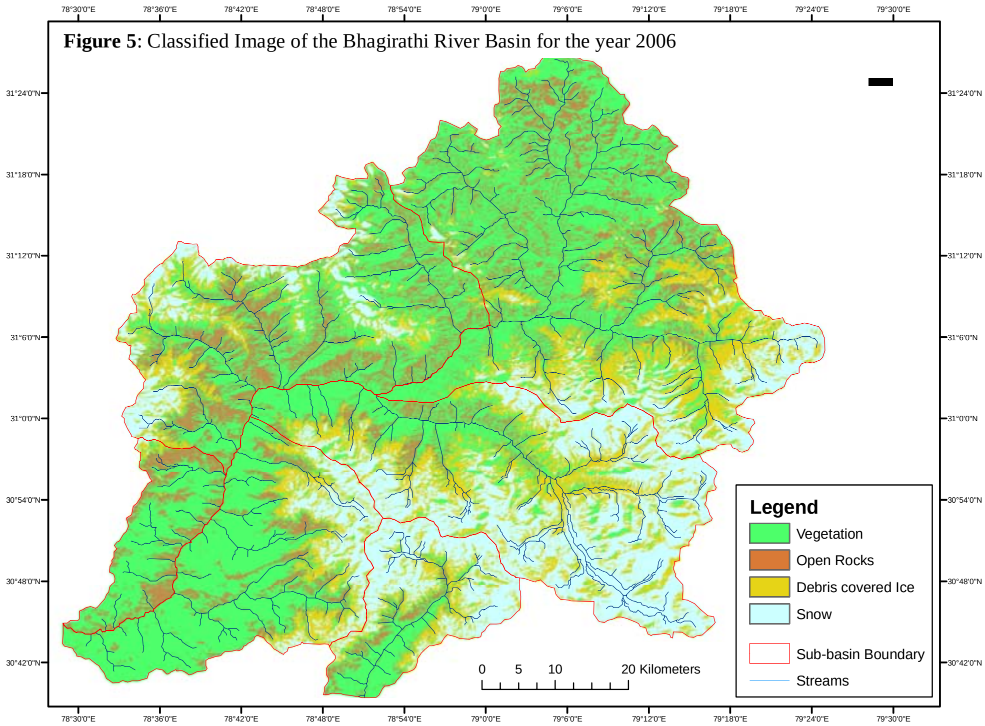
Figure 5: Classified Image of the Bhagirathi River Basin for the year 2006



Source: IRSP6-LISS-III of October 2006

Table-1. Area of the each feature in different time periods of Bhagirathi river basin (sq.km.)

Features	**1980**	**1990**	**2000**	**2006**
Vegetation	1603	1745	1936	2088
Open Rocks	490	617	738	910
Debris Covered Ice	1354	1292	1139	902
Snow	1137	919	760	675

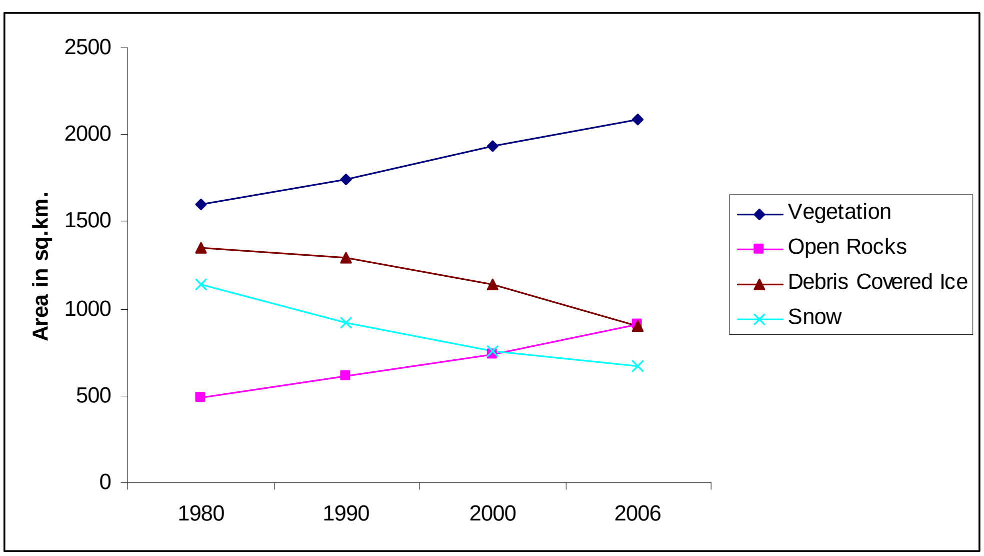


Figure-6. Showing the distribution of different features in the entire Bhagirathi basin.

The retreat rate was faster in year 1980-1990 compare to the year 1990-2006. At the same time Vegetation and Open Rocks area are increasing considerably while the Debris Covered Ice and Snow cover area is decreasing linearly. So, it indicates that rate of retreat is reduced during the recent time. This also may be due to high precipitation in these years. A GPS survey [9] reported that the lower recession rate during 2004-05 possibly indicates the high and frequent snowfall recorded in that area during the 2004 winter months. So, the accumulation has increased dramatically during these periods.

3.2 Climate data analysis

Climatic data from automatic weather station installed at Bhojwasa, just about three kilometers from the snout of the Gangotri Glacier (Gaumukh). Other data are collected from IMD, Pune for different periods. Table-2 shows the summery of the average and means values of the different parameters [10, 11]. Simple statistical analysis has been done to compare the relation between the various parameters.

Table-2. Weather data for summer season, recorded at Bhojwasa station.

Years	May	June	July	August	Sept.	Oct.
	Average rainfall (mm)					
1999*	-	33.0	70.1	75.6	55.9	9.2
2000*	-	148.0	86.3	51.1	19.7	0.0
2000-2003	12.0	56.1	45.2	68.5	76.9	0.3
	Mean monthly temp. C°					
1999^	-	10.5	12.0	11.0	8.9	4.6
2000^	10.8	10.1	11.8	10.9	8.8	6.6
2000-2003	8.8	10.3	11.7	10.8	8.0	5.4
	Mean monthly max temp. C°					
2000-2003	15.4	15.6	16.2	15.0	13.2	12.4
	Mean monthly min temp. C°					
2000-2003	2.3	5.0	7.0	6.5	2.9	-1.5
	Difference (in temp. C°) mean monthly max. min.					
2000-2003	13.2	10.6	9.2	8.5	10.2	13.4
	Mean monthly relative humidity (%)					
2000-2003	69	83	88	89	78	67
	Mean sunshine duration in hours					
2000-2003	7.2	5.4	4.7	4.0	5.2	6.8

3.3 Discharge data analysis

Figure-7 gives the average daily discharge data for the year 2000-2002 [10, 11]. A time series analysis of the runoff component of the downstream Bhagirathi river (Ganges river) has been done to see the changes in the runoff for the last eleven years from 1995-2005 as shown in Figure-8. For this purpose, average runoff data at Uttarkashi and Rishikesh station have been used.

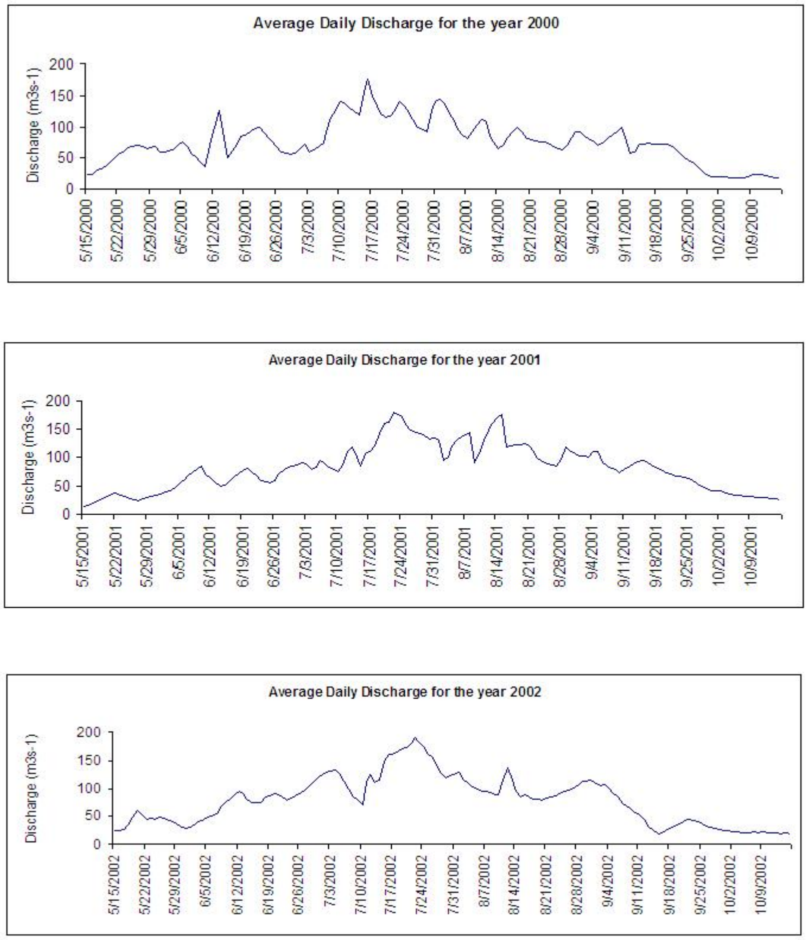


Figure-7. Daily discharge data at the Bhojbasa observation station [after 10, 11].

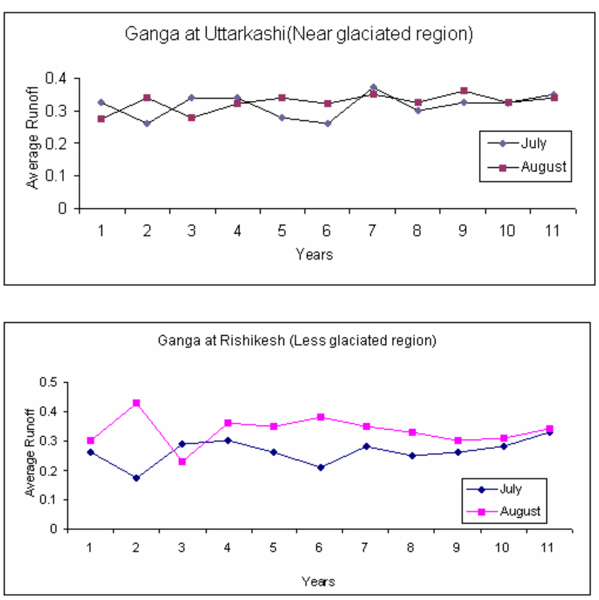


Figure-8. A time series analysis of the average runoff during July - August months of 1995-2005 for the Ganges River (Source: IMD, Pune).

4. DISCUSSION AND CONCLUSIONS

The Bhagirathi river basin experiences strong climatic seasonal variations, which is also clearly reflected in the monthly variation in stream flows. Maximum flow takes place during June-September, when both rainfall and rate of snow melt are at maximum. Most of the Garhwal Himalayan streams carry 69-83% of their annual flow during the summer monsoonal months. Rainfall and air temperature represent the most important parameters of meteorology for any particular region. Rainfall observations clearly indicate that although the intensity was higher in May, the number of rainy events was much lower during this month. Whereas in July, when the monsoon approaches, the total number of rain events increased due to drizzle-type of rainfall throughout the day. It also shows that the timings of rainfall occurrence varied over the summer season. It is observed that changes in minimum temperature are more significant than those in maximum temperature. Diurnal variations in temperature indicate that, generally, maximum temperature is observed around 1400h, while the minimum is observed in the early morning hours.

Imagery analysis shows that a linear decrease in the snow cover and debris cover. And also shows that there was little faster retreat in the year 1980-2000 compare to the 2000-2006. Temporal variation in area of the thin debris covered ice suggests decreasing trend. Decrease in thin debris covered ice and glaciations show logarithm relationship, it indicates that the basins covered by higher percentage of glacier show less degree of shrinkage for thin debris covered ice area and vise verse. The increase in vegetation areas may probably result due anthropogenic disturbances or natural. But, this area is far away from human activity and hence change in vegetation cover is related to natural processes. The increase in vegetation cover in these areas is due to moderation of the limiting factor of the atmospheric temperature.

Moreover, the larger glaciers have shown a reduction in the areal extent, whereas the smaller glaciers have increased in number. With the gradual retreat, the tributaries of the glaciers are susceptible to a detachment from the main body, thus showing fragmentation. This fragmentation has been observed in the images during the interpretation and analysis process. Therefore, it can be said that smaller glaciers are more prone to the changes in climatic conditions and larger glaciers more susceptible to fragmentation. The hydrograph analysis of the Bhagirathi River shows that the July and August runoff component is increased in last eleven years. So, this result clearly shows that there is a linear increase in the runoff. This analysis supports the result of the satellite imagery analysis results.

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