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Analysis of the Snow Cover Area of the Gangotri and Surrounding Glaciers using Remote Sensing and GIS

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Abstract: ***Himalayas has one in every of the biggest resources of snow and ice, which act as a freshwater reservoir for all of the rivers originating from it. Monitoring of these sources is vital for the assessment of availability of water within the Himalayan Rivers. The mapping of Glaciers could be very tough undertaking due to the inaccessibility and remoteness of the terrain. Faraway sensing techniques are regularly the simplest way to research glaciers in remote mountains and to monitor a large range of glaciers in multitemporal manner. This paper presents the results obtained from the analysis of 5 set of Landsat 8 Band 3 - Green and Band 6 - SWIR 1 images from year 2017 to 2021 for the monitoring and analysis of approx 76% of Gangotri and Surrounding Glaciers (GSG) main snow covered area. It is seen in the analysis that there has been a down fall around 85 sq km of the Snow Cover of the Gangotri and Surrounding Glacier and Surrounding Glaciers (GSG) Area in the years of 2018 and 2019 respectively from the year 2017. In 2020 huge recovery has occurred with a drastic increase in snow cover area by approximately the same amount which has been previously depleted. After 2020, it seems that a gradual drop of 27 sq km occurred in 2021. Calculation shows a dip of 14.91% of snow cover area from 2017 to 2018 of the Gangotri and Surrounding Glaciers (GSG) which was recovered to original level in 2020. Slight dip of around 4.88% occurred in the current year 2021.***

I. INTRODUCTION

A glacier is a continual body of dense ice that is continuously moving underneath its own weight. A glacier bureaucracy where the accumulation of snow exceeds its ablation over many years, frequently centuries. Glaciers slowly deform and drift under stresses brought on by way of their weight, developing crevasses, seracs, and different distinguishing functions. They also abrade rock and debris from their substrate to create landforms such as cirques, moraines, or fjords. Glaciers shape simplest on land and are distinct from the a good deal thinner sea ice and lake ice that bureaucracy on the floor of our bodies of water. They are the Earth's largest freshwater reservoir, together covering an area the dimensions of South the us. Snowfields are underneath growing strain due to developing demand for sparkling water, industrialization and urbanization. Except, because of their excessive sensitivity to changes inside the climatic surroundings, they're additionally taken into consideration as key signs of some outcomes of world warming. Therefore, it has emerge as very critical to display.

About 15,000 Himalayan glaciers form a completely unique reservoir which supports perennial rivers including the Indus, Ganga and Brahmaputra. The Gangetic basin alone is domestic to 500 million human beings, approximately 10% of the total human populace. Mapped glacier landforms of Gangotri and Surrounding Glaciers (GSG) the usage of Landsat TM information; they tested that selected digitally processed TM band combination may want to assist to map decided on glacial functions. The Survey of India has prepared topographic maps of the glaciated terrain of the Himalaya with restricted use of aerial pix on 1:50,000 scale. After this survey, no revised maps have been posted even after the terrain changed into resurveyed the use of air pictures offer an inventory of glaciers inside the Satluj river basin that includes the Beas and Spiti sub-basins the usage of Georeferenced IRS-1A and IRS-1B-LISS-II facts and Landsat satellites on 1:50,000 scale.

Various features which include accumulation region, ablation location, brief snow line/ equilibrium line, moraine-dammed lakes, deglaciated valleys and everlasting snowfields had been mapped counting on precise repentance characteristics. Datasets are essential to track glacier changes over a long term length. Few monitoring programs exist because of restricted financial sources. Of the 160,000 predicted glaciers within the international, much less than 1% are monitored. Loss of informative records makes it especially critical to use all historic facts from maps, aerial pictures and other sources to assess glacier trade. Measurements of snow cowl inside the mountainous basins are very tough. Traditional strategies have obstacles in the monitoring of snow protected region in excessive-altitude glacierized basins because of exceptionally rugged terrain and harsh climate conditions. In this perspective, far flung sensing techniques are frequently the high-quality manner to analyze glaciers in far flung inaccessible places and also to vital to reveal the glaciers for environmental surveillance. Long-term tracking is required to advantage a better expertise of the relationships between glaciers, climate, hydrology and hazards. Considerable screen massive number of glaciers on the identical time.

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II. STUDY AREA

The Gangotri and Surrounding Glaciers (GSG) are one of the largest ice bodies in the Garhwal Himalayas, is located in the Uttarkashi district of the state of Uttarakhand in India. It is one of the most sacred shrines in India, with immense religious significance. Being the main source of the river Ganga, it attracts thousands of pilgrims every year. The Gangotri glacier is a vital source of freshwater storage and water supply, especially during the summer season for a large human population living downstream. There are around 5000 glaciers exist in the Indian part of the Himalayas covering approx. 38,000 sq km of the mountain area.

Himalayan glaciers form the largest body of ice outside the Polar caps and are the source of water for the innumerable rivers that flow across the Indo-Gangetic plains. The north-west facing Gangotri glacier is a valley type glacier originating in the Chaukhamba group of peaks. Numerous smaller glaciers join the main stem of the main glacier to form the Gangotri group of glaciers. The complete Gangotri glacier system along with its tributaries covers an area of 210.60 sq km (ETM+2000). The area and length of the main trunk of the glacier is 62.112sq km and 29.85 km respectively. It has varying elevation of 4,015–6,145 meters above sea level (SRTM Data Analysis).The snout of the glacier occurs at an altitude of about 3,949 m above sea level, and this is the place from where the Bhagirathi originates). The total area of Gangotri and Surrounding Glacier lies between snout position at 78º50’50” E to 79º30’50” E and 30º39’0” N to 31º2’ 00” N [Fig 1]. The Area considered under analysis is between 79º0’00” E to 79º30’50” E and 30º39’00” N to 31º0’00” N which considers about 76% approximately of the total area of Gangotri and Surrounding Glaciers.

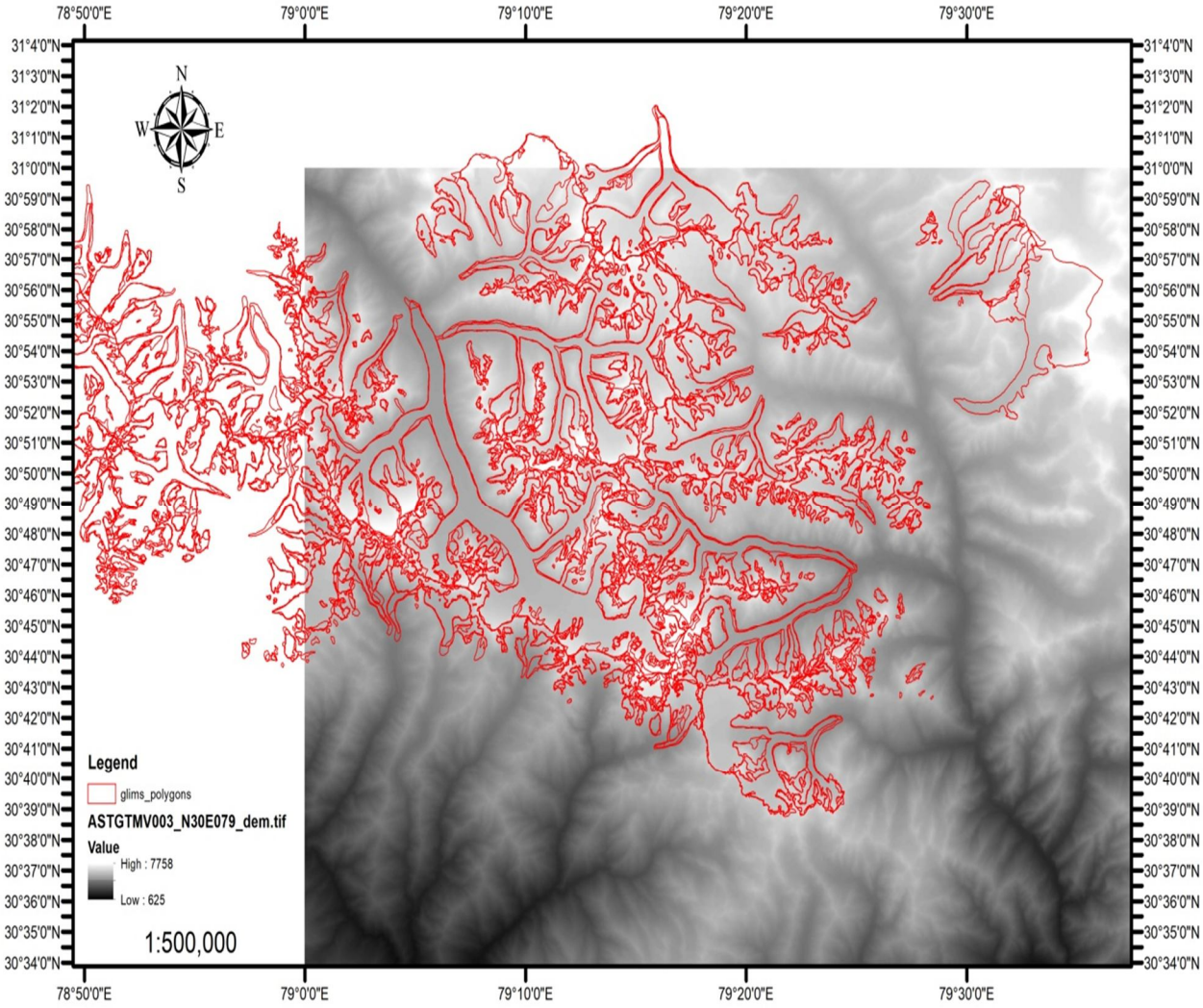


Fig 1. Gangotri and Surrounding Glaciers (GSG) Glims Outline

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A. Contour (100 & 250 m)

Contour maps are used to show the below ground surface of geologic strata, fault surfaces (especially low angle thrust faults) and unconformities. Isopach maps use isopachs (lines of equal thickness) to illustrate variations in thickness of geologic units.

The following maps [Fig 2. & 3.] shows contour interval of 100 m and 250 m respectively with at a height of 13,200 ft (4,023 m) to 22,965 ft (7,000 m).

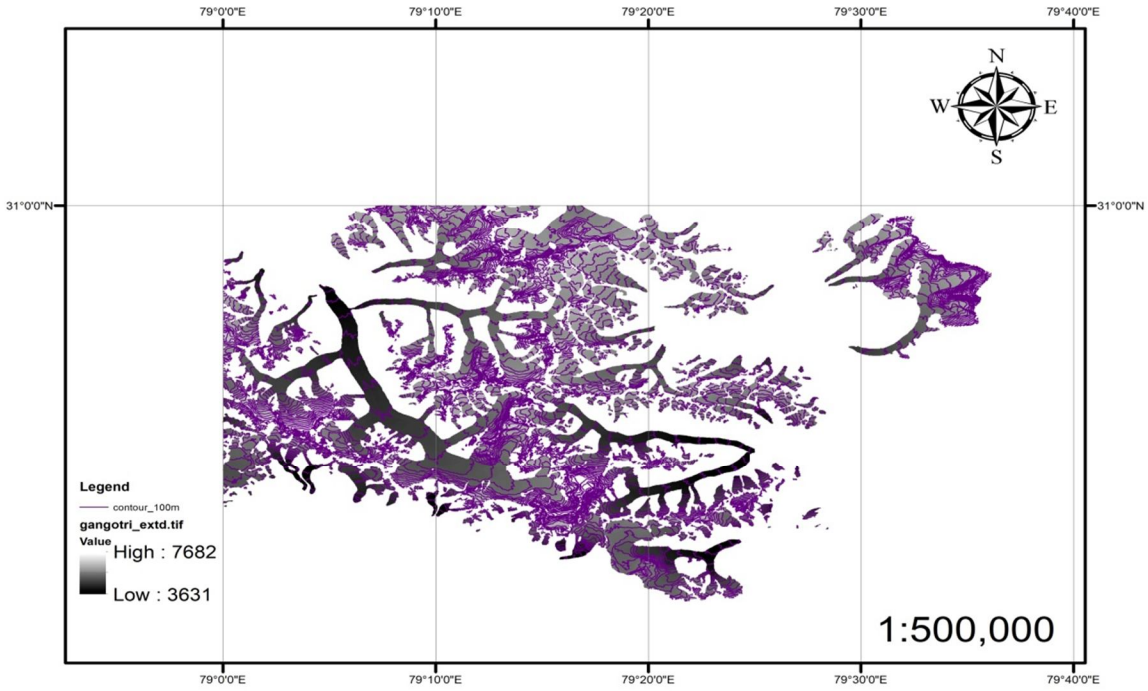


Fig 2. Gangotri and Surrounding Glaciers (GSG) divided into 100m Contour Lines

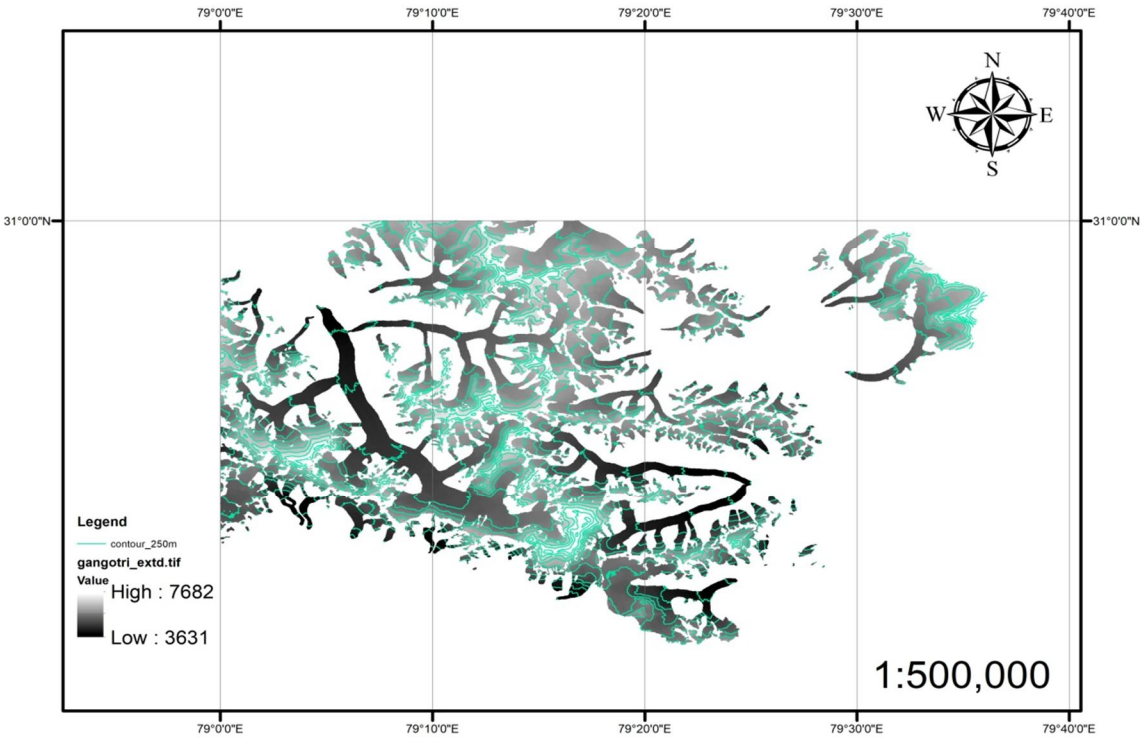


Fig 3. Gangotri and Surrounding Glaciers (GSG) divided into 250m Contour Lines

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B. Hillshade

The hillshade function produces a grayscale 3D representation of the terrain surface, with the sun's relative position taken into account for shading the image. Hillshading is a technique for visualizing terrain determined by a light source and the slope and aspect of the elevation surface. It is a qualitative method for visualizing topography and does not give absolute elevation values. This function provides two options for generating hillshades: traditional and multidirectional. The traditional method calculates the hillshade using an illumination source from one direction using the altitude and azimuth properties to specify the sun's position. The multidirectional method combines light from multiple sources to represent the hillshaded terrain. The advantage of the multidirectional hillshade method is that more detail is displayed in areas typically affected by oversaturation and deep shadows than when using the traditional hillshade method. [1]. The following map [Fig 4.] shown below represents the Hillshade with high of 254 points and low of 0 point of the Gangotri and Surrounding Glaciers (GSG) region.

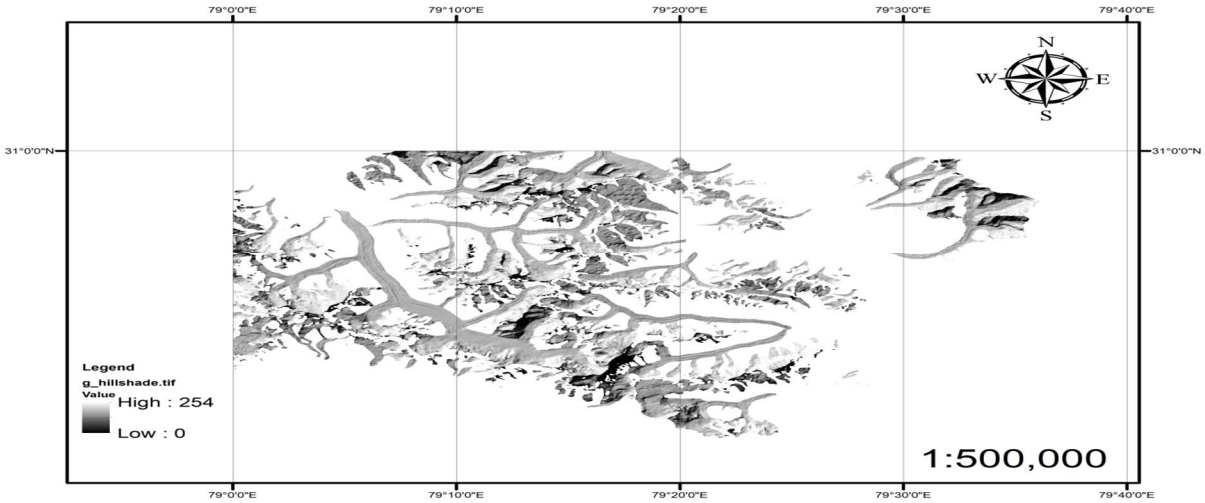


Fig 4. Map Showing Hillshade of the Gangotri and Surrounding Glaciers (GSG)

C. Aspect

Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1. The compass direction that a topographic slope faces, usually measured in degrees from north. Aspect can be generated from continuous elevation surfaces. For example, the aspect recorded for a TIN face is the steepest downslope direction of the face, and the aspect of a cell in a raster is the steepest downslope direction of a plane defined by the cell and its eight surrounding neighbors. The following map [Fig 5.] show the Aspect i.e. that's the directions specifically identified with defined colors with high of 359.886 points and low of -1.[2]

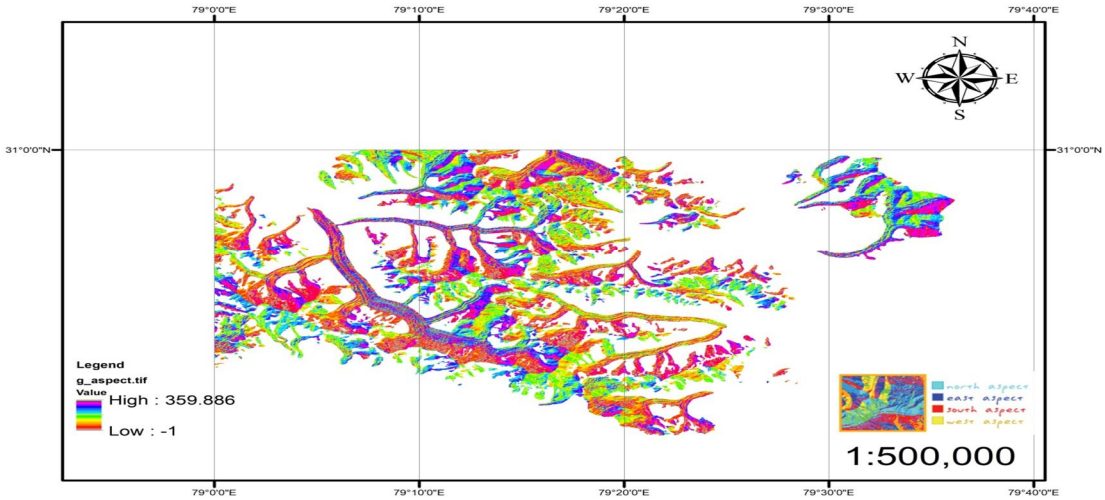


Fig 5. Map Showing Aspect of the Gangotri and Surrounding Glaciers (GSG)

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D. TIN

TINs are a digital means to represent surface morphology. TINs are a form of vector-based digital geographic data constructed by triangulating a set of vertices (points). The vertices are connected with a series of edges to form a network of triangles. The edges of TINs form contiguous, non overlapping triangular facets and can be used to capture the position of linear features that play an important role in a surface, such as a ridge line or stream course. Because nodes can be placed irregularly over a surface, TINs can have a higher resolution in areas where a surface is highly variable and a lower resolution in areas that are less variable.

The input features used to create a TIN remain in the same position as the nodes or edges in the TIN. This allows a TIN to preserve all the precision of the input data while simultaneously modeling the values between known points. You can include precisely located features on a surface—such as mountain peaks, roads, and streams—by using them as input features to the TIN nodes.

There are different methods of interpolation to form these triangles, such as Delaunay triangulation or distance ordering. ArcGIS supports the Delaunay triangulation method. The resulting triangulation satisfies the Delaunay triangle criterion, which ensures that no vertex lies within the interior of any of the circumcircles of the triangles in the network. If the Delaunay criterion is satisfied everywhere on the TIN, the minimum interior angle of all triangles is maximized. The result is that long, thin triangles are avoided as much as possible. A TIN expects units to be in feet or meters, not decimal degrees. Delaunay triangulations are not valid when constructed using angular coordinates from geographic coordinate systems.[3]

The following map [Fig 6.] shows the TIN surface morphology of the Gangotri and Surrounding Glaciers (GSG) region with different variation.

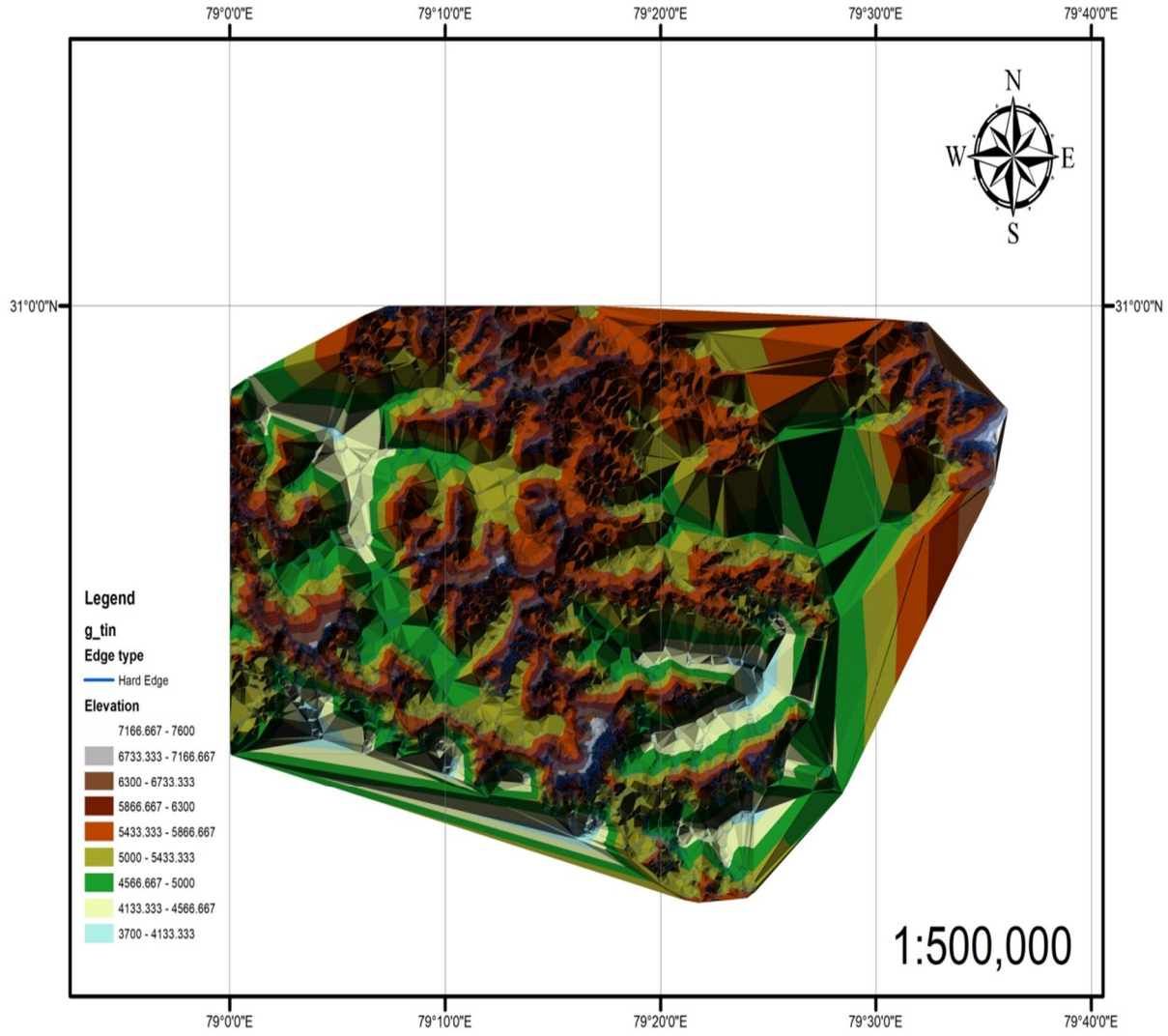


Fig 6. Map Showing TIM of the Gangotri and Surrounding Glaciers (GSG)

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E. Drainage

This glacier has three main tributaries, namely Raktvarn (15.90 km), Chaturangi (22.45 km) and Kirti (11.05 km) and more than 18 smaller tributary glaciers The Raktvarn system contains 7 tributary glaciers; among them Thelu, Swetvarn, Nilambar and Pilapani are important. Similarly the Seeta, Suralaya and Vasuki are the major tributaries which make up the Chaturangi system, while the Kirti system is made up of only three tributary glaciers. Besides these three major tributary systems, some other tributary glaciers of this area drain directly into the Gangotri glacier; among them Swachand, Miandi, Sumeru and Ghanohim are important. Four other glaciers, Maitri, Meru, Bhrigupanth and Manda drain into the river Bhagirathi. The total glacierized area of the catchment is 258.56 km², out of which the Gangotri system comprises 109.03 km², followed by Chaturangi (72.91 km²), Raktvarn (45.34 km²) and Kirti (31.28 km²). The remaining four glaciers contain 29.41 km² of glacierized area; among them maximum contribution is Bhirgupanth glacier (14.95 km²).[4]

The following map [Fig 7.] shows the Drainage Pattern of the Gangotri and Surrounding Glaciers (GSG) Region.

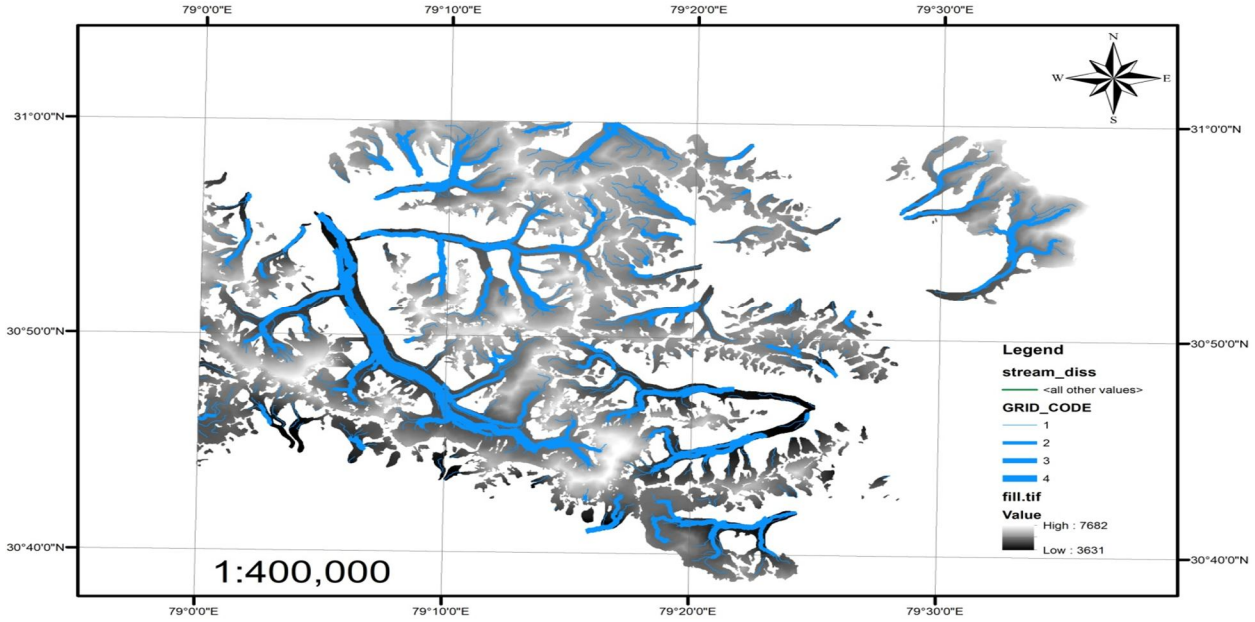


Fig 7. Map Showing Drainage Pattern of the Gangotri and Surrounding Glaciers (GSG)

III. LANDSET 8 DATA SETS

These are the following Landsat 8 Data Sets used while continuing the experiment for finding Glacial Area Changes of the Gangotri and Surrounding Glaciers (GSG) Area using Remote Sensing and GIS. [Table 1.]

Satellite Data	Date of acquisition	Resolution (meters)	Bands	Data Set Information
LANDSAT 8	2021-02-05	30	Band 3 - Green	LC08_L2SP_145039_20210205_20210303_02_T1_SR_B3
LANDSAT 8	2021-02-05	30	Band 6 - SWIR 1	LC08_L2SP_145039_20210205_20210303_02_T1_SR_B6
LANDSAT 8	2020-02-03	30	Band 3 - Green	LC08_L2SP_145039_20200203_20200823_02_T1_SR_B3
LANDSAT 8	2020-02-03	30	Band 6 - SWIR 1	LC08_L2SP_145039_20200203_20200823_02_T1_SR_B6
LANDSAT 8	2019-02-16	30	Band 3 - Green	LC08_L2SP_145039_20190216_20200829_02_T1_SR_B3
LANDSAT 8	2019-02-16	30	Band 6 - SWIR 1	LC08_L2SP_145039_20190216_20200829_02_T1_SR_B6
LANDSAT 8	2018-01-28	30	Band 3 - Green	LC08_L2SP_145039_20180128_20200902_02_T1_SR_B3
LANDSAT 8	2018-01-28	30	Band 6 - SWIR 1	LC08_L2SP_145039_20180128_20200902_02_T1_SR_B6
LANDSAT 8	2017-02-10	30	Band 3 - Green	LC08_L2SP_145039_20170210_20200905_02_T1_SR_B3
LANDSAT 8	2017-02-10	30	Band 6 - SWIR 1	LC08_L2SP_145039_20170210_20200905_02_T1_SR_B6

Table 1. Table showing all the LANDSAT 8 Data Sets used with Date of Acquisition & Information [5]

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A. Methordology

Adding the LANDSET 8 Data (B3 & B6) and inserting the Glims Polygon we need to remove the Cloud Cover and Solar Angle. By following the further steps, we will find the NDSI Data. After extracting the NDSI Data from the Glims Polygon of the Gangotri and Surrounding Glaciers (GSG) Area, Threshold Data is converted through Raster calculator by dividing the data into two parts, one greater than 0.4 and less than that.

Now converting the Threshold Data to Polygon provides us with all sets to polygon data which further is Dissolved. This Dissolved Data contains 2 part: 0 and 1.

The GRIDCONE 1 set covers the Snow Cover Area which needs to be extracted by adding Area option with Sq. km. as division factor. So by this method we could find the Snow Cover Area with NDSI and we have to repeat these steps for the total number of Data Sets of 5 years.

B. Steps

1) STEP 1: Insert the Landsat 8 Data (B3 & B6) with cloud cover 10 - 20%.
2) STEP 2: Insert the Glim Data of the Gangotri and Surrounding Glaciers (GSG).
3) STEP 3: Cloud Cover and Solar Angle Correction.
4) STEP 4: Calculate the NDSI DATA.
5) STEP 5: Convert NDSI DATA to EXTRACTED NDSI.
6) STEP 6: Convert it to THRESHOLD NDSI.
7) STEP 7: Convert the THRESHOLD NDSI to POLYGON.
8) STEP 8: Dissolve the POLYGON.
9) STEP 9: Add Area to the Attribute Table.
10) STEP 10: Calculate the Geometry in Sq. km.
11) STEP 11: Implement the steps for the all the 5 years.
12) STEP 12: Mark the Area given data per year.
13) STEP 13: Compare Geometry Area for 5 year.

C. Important Formulas

1) Cloud Cover Correction

$$\textit{Cloud Cover Correction} = 0.00002 * LS8\,(B3 \text{ or } B6) + -0.1$$

2) Solar Angle Correction

$$\textit{Solar Angle Correction} = \frac{LS8\,(\textit{Cloud Cover Corrected } B3 \text{ or } B6)}{0.999922228680759530066414122669 8}$$

3) NDSI Calculation

$$NDSI = \frac{Green - SWIR\ 1}{Green + SWIR\ 1}$$

Green - LANDSAT 8 Band 3
SWIR 1 - LANDSAT 8 Band 6

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IV. DATA SET 1 : LANDSAT 8 [2021-02-05]

1) Extended NDSI 2021

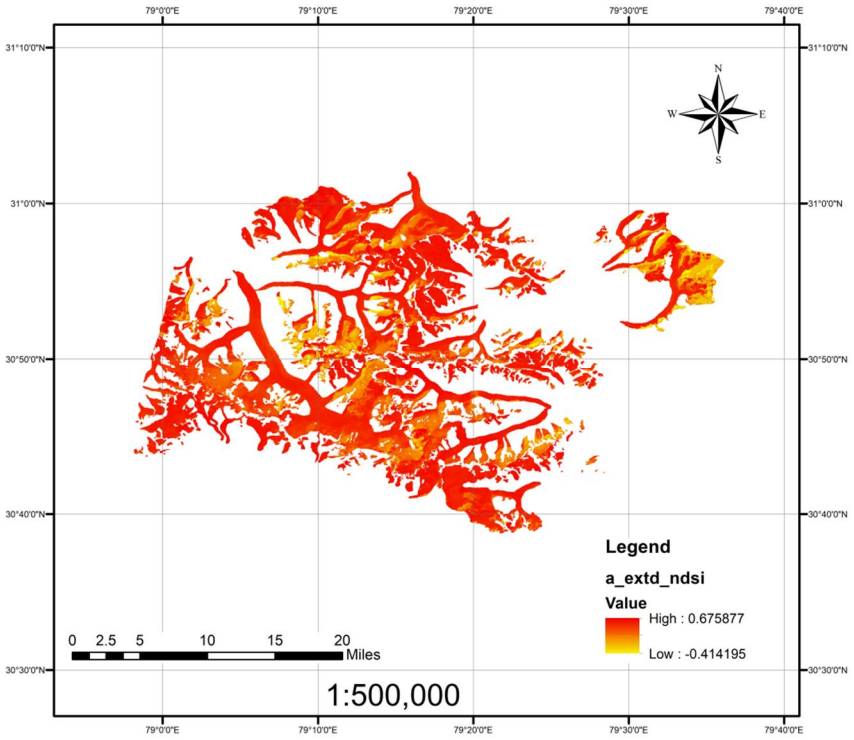


Fig 8. Extended NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2021

2) Threshold NDSI 2021

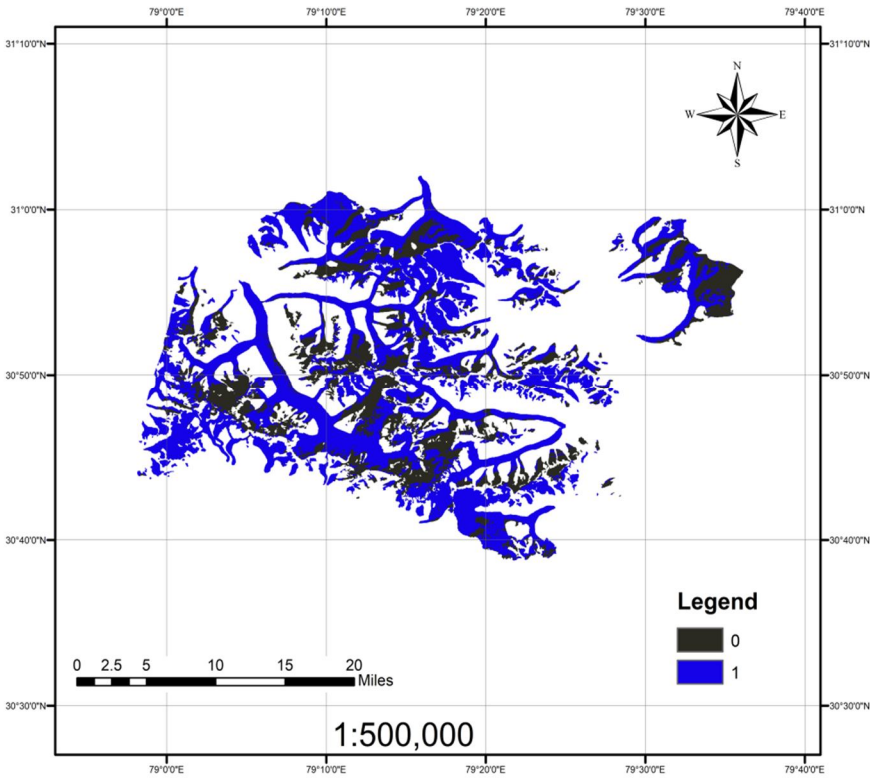


Fig 9. Threshold NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2021

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3) Snow Cover Area 2021

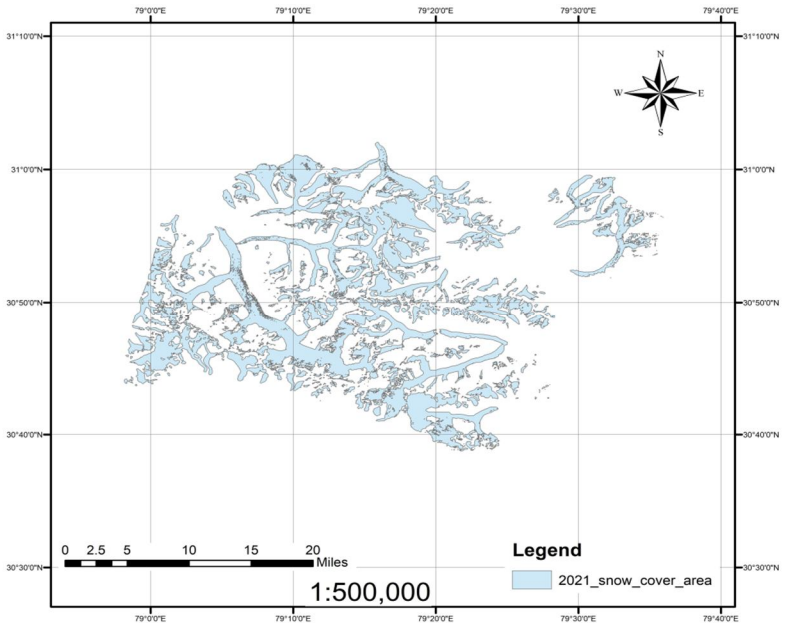


Fig 10. Snow Cover Area of Gangotri and Surrounding Glaciers (GSG) Area for Year 2021

2021_snow_cover_area

FID	Shape *	GRIDCODE	area
0	Polygon	1	534.445

Table 2. Table showing Snow Cover Area of 2021

A. Data Set 2 : LANDSAT 8 [2020-02-03]

1) Extended NDSI 2020

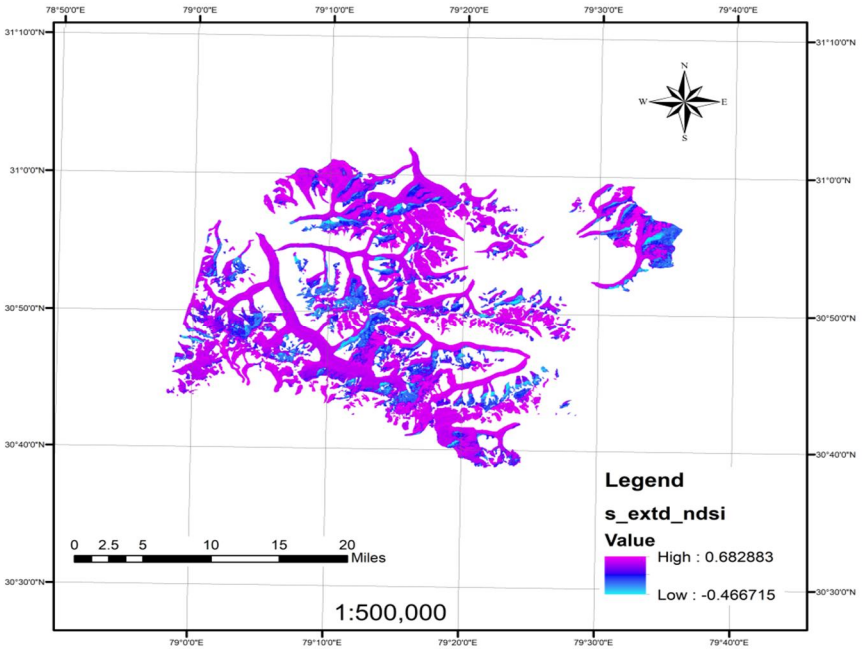


Fig 11. Extended NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2020

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2) Threshold NDSI 2020

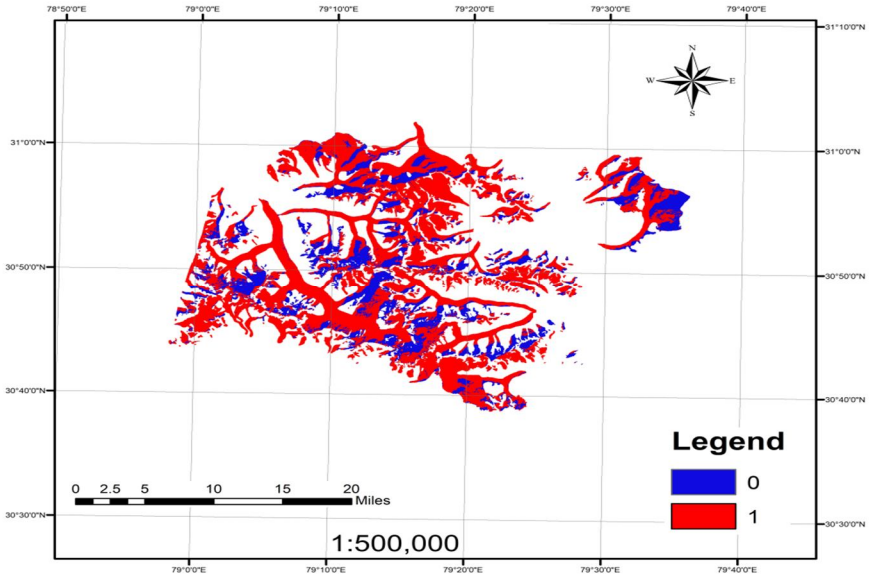


Fig 12. Threshold NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2020

3) Snow Cover Area 2020

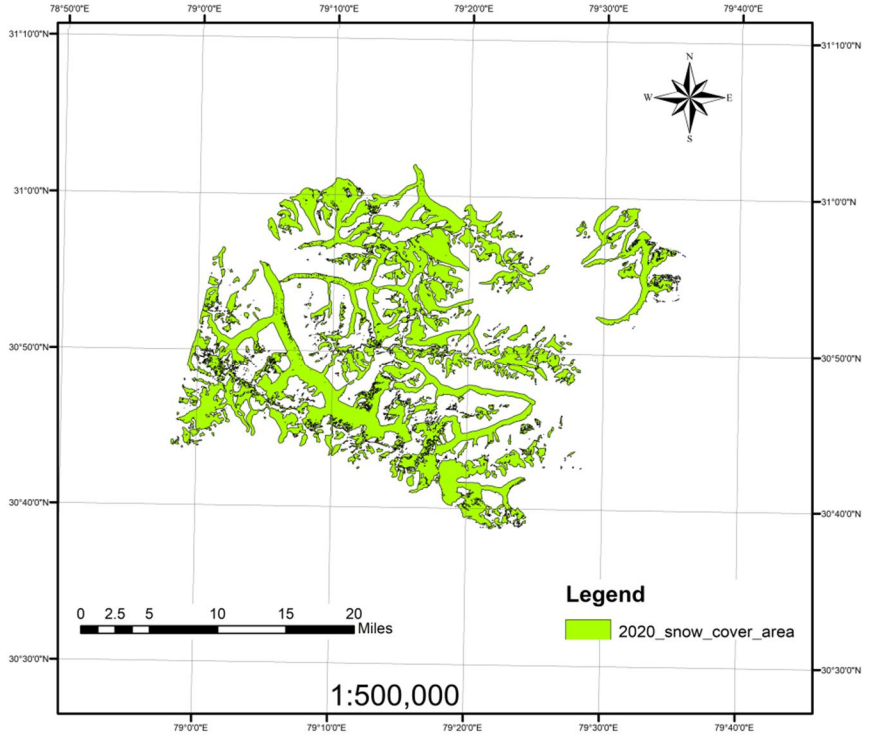


Fig 13. Snow Cover Area of Gangotri and Surrounding Glaciers (GSG) Area for Year 2020

2020_snow_cover_area

FID	Shape *	GRIDCODE	area
0	Polygon	1	561.868

Table 3. Table showing Snow Cover Area of 2020

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B. Data Set 2 : LANDSAT 8 [2019-02-16]

1) Extended NDSI 2019

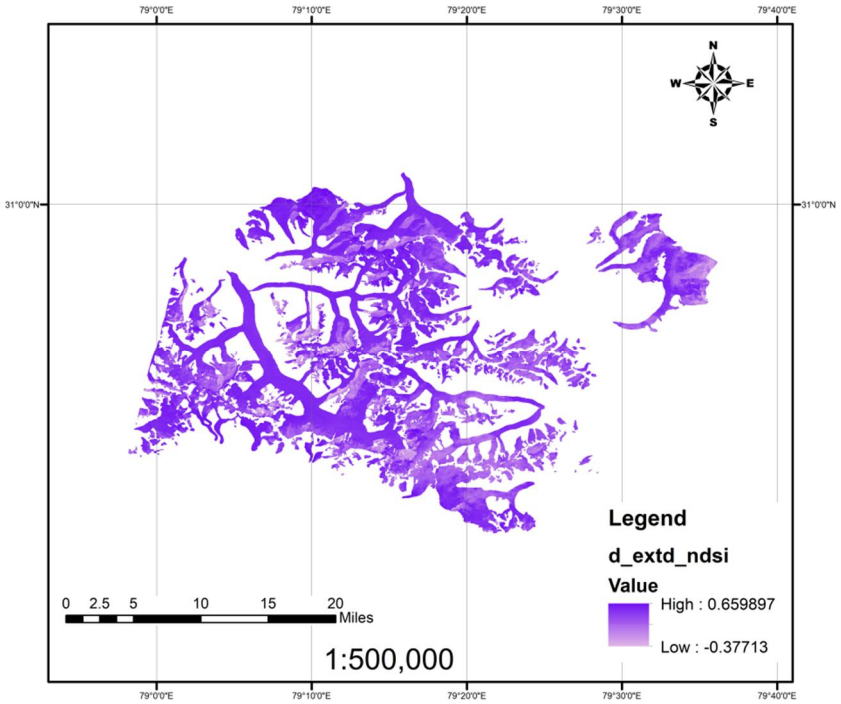


Fig 14. Extended NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2019

2) Threshold NDSI 2019

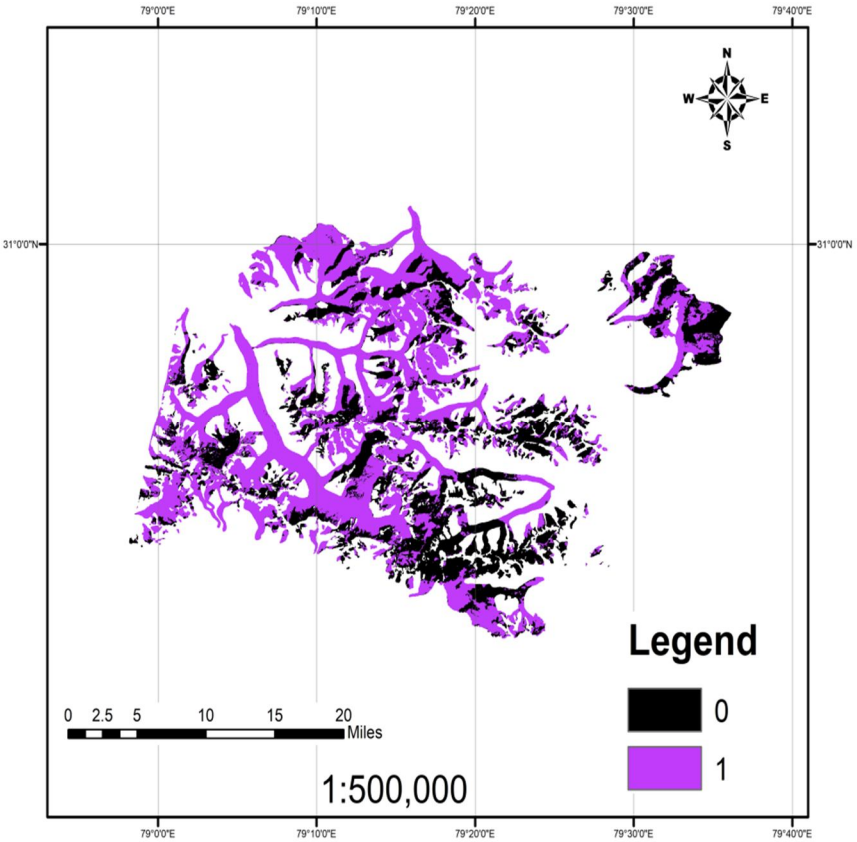


Fig 15. Threshold NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2019

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3) Snow Cover Area 2019

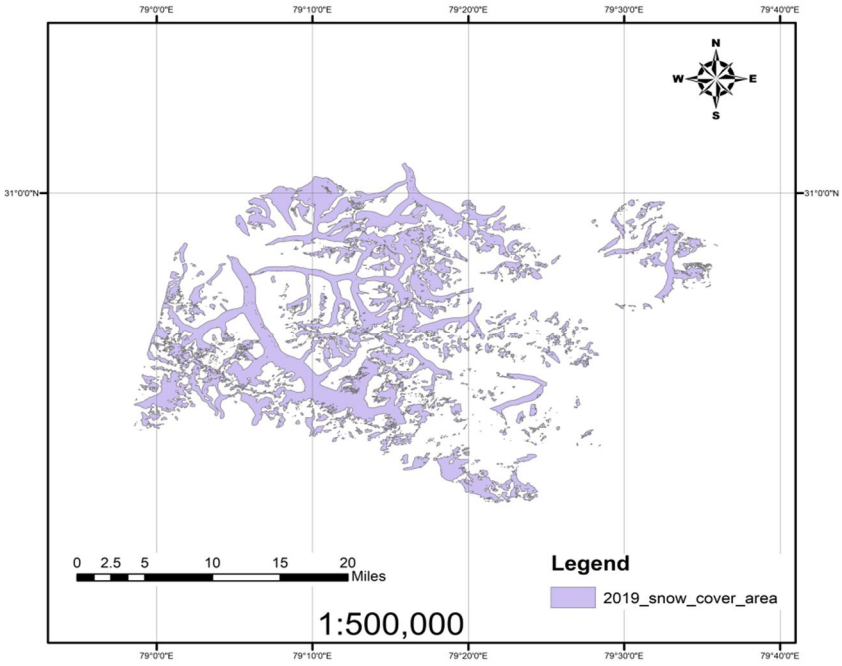


Fig 16. Snow Cover Area of Gangotri and Surrounding Glaciers (GSG) Area for Year 2019

2019_snow_cover_area

FID	Shape *	GRIDCODE	area
0	Polygon	1	475.067

Table 4. Table showing Snow Cover Area of 2019

C. Data Set 2 : LANDSAT 8 [2018-01-28]

1) Extended NDSI 2018

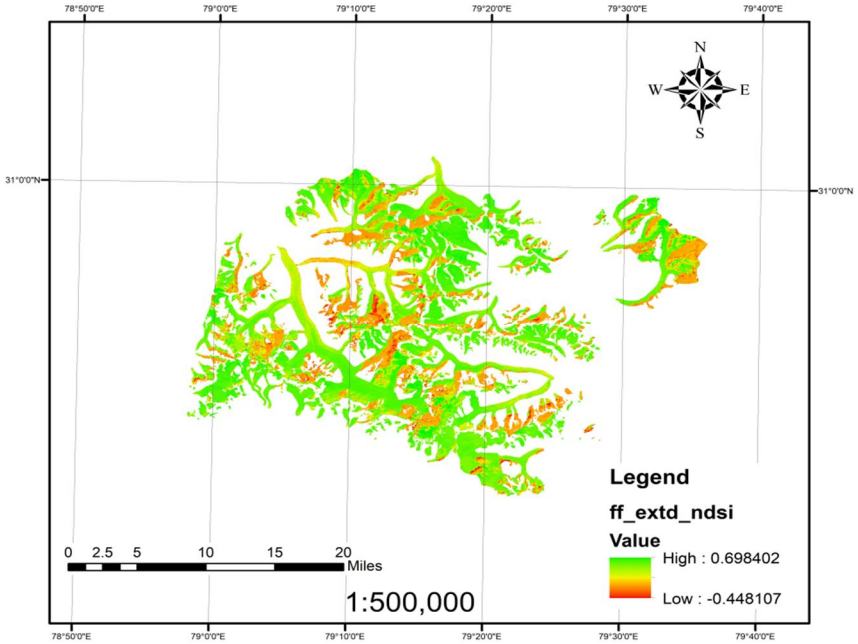


Fig 17. Extended NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2018

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2) Threshold NDSI 2018

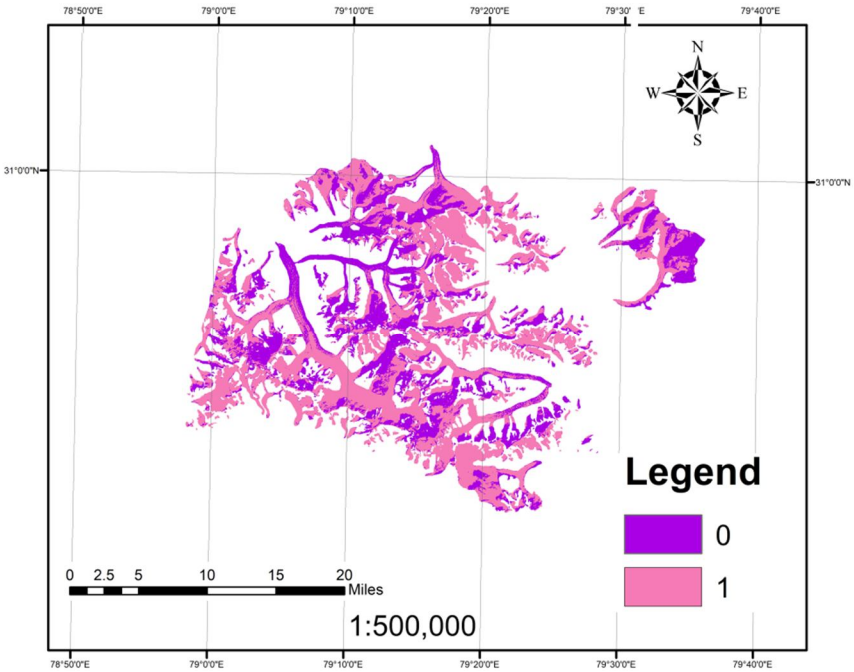


Fig 18. Threshold NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2018

3) Snow Cover Area 2018

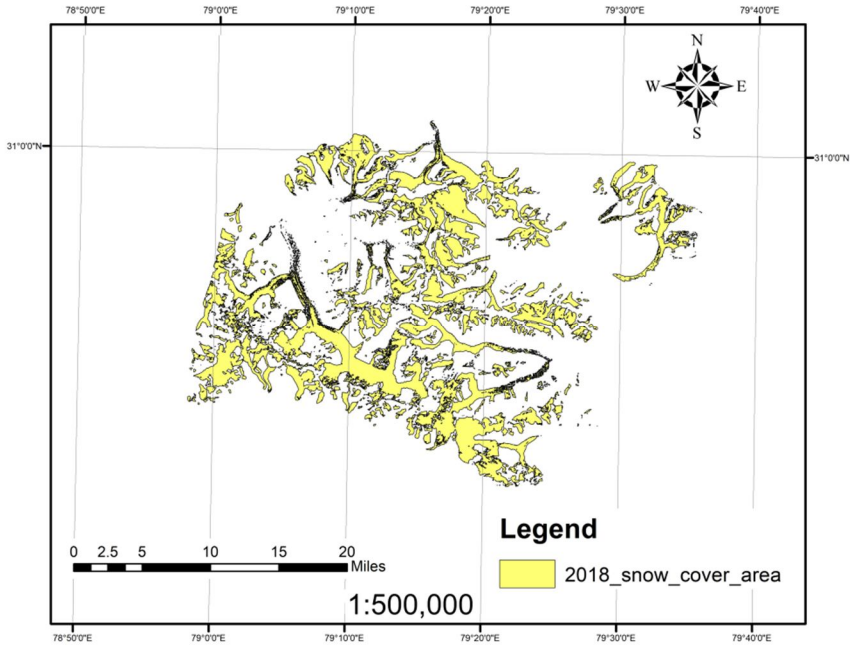


Fig 19. Snow Cover Area of Gangotri and Surrounding Glaciers (GSG) Area for Year 2018

2018_snow_cover_area

FID	Shape *	GRIDCODE	area
0	Polygon	1	475.75

Table 5. Table showing Snow Cover Area of 2018

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D. Data Set 2 : LANDSAT 8 [2017-02-10]

1) Extended NDSI 2017

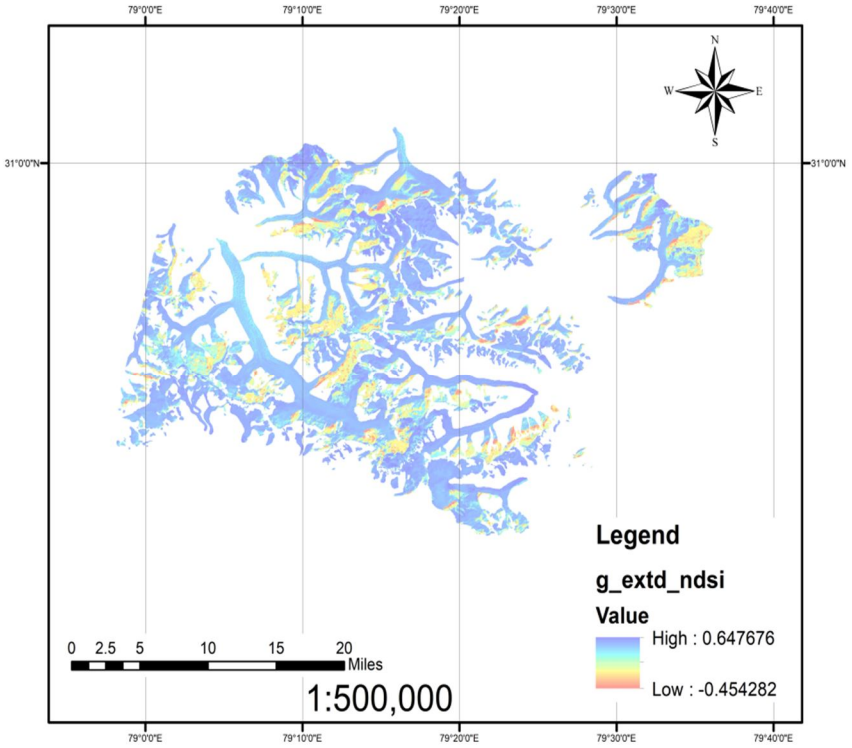


Fig 20. Extended NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2017

2) Threshold NDSI 2017

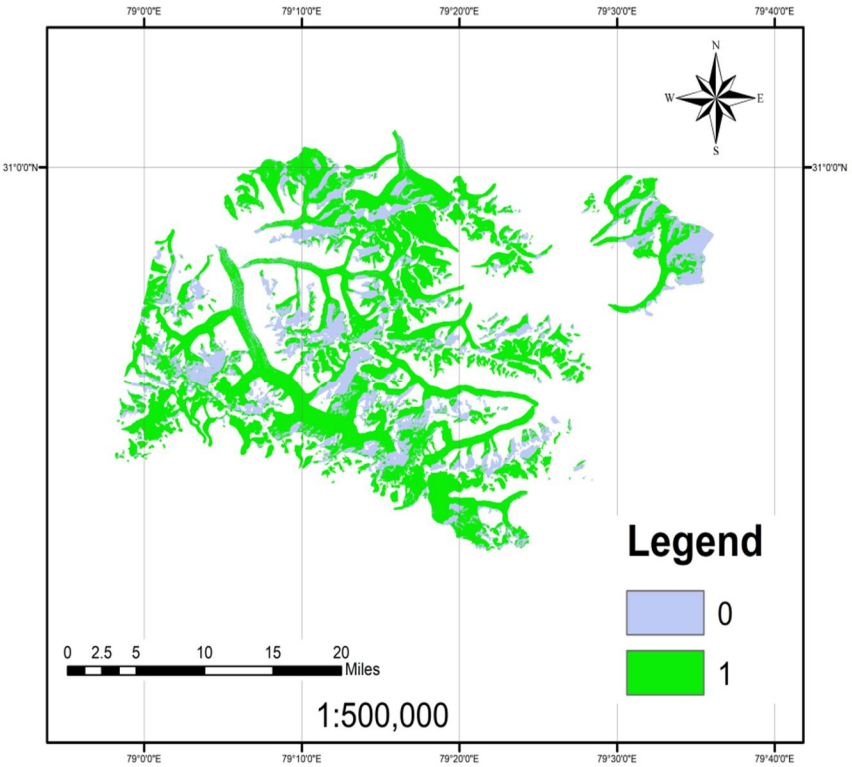


Fig 21. Threshold NDSI of Gangotri and Surrounding Glaciers (GSG) Area for Year 2017

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3) Snow Cover Area 2017

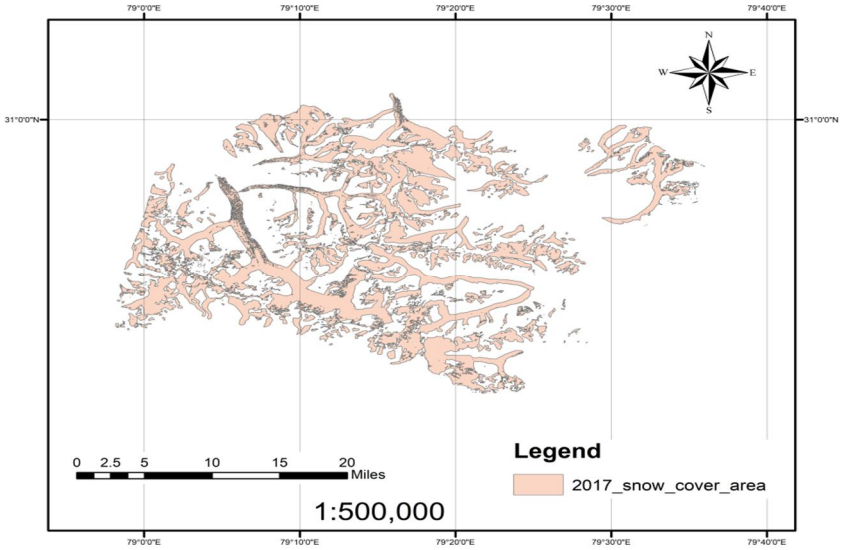


Fig 22. Snow Cover Area of Gangotri and Surrounding Glaciers (GSG) Area for Year 2017

2017_snow_cover_area

FID	Shape *	GRIDCODE	area
0	Polygon	1	559.131

Table 6. Table showing Snow Cover Area of 2017

V. RESULTS

YEAR	SNOW COVER AREA (Sq. km)
2017 [Table 6]	559.131
2018 [Table 5]	475.750
2019 [Table 4]	475.067
2020 [Table 3]	561.868
2021 [Table 2]	534.445

Table 7. Table with all 5 Years of Snow Cover Area of the Gangotri and Surrounding Glaciers (GSG) Area

The Gangotri and Surrounding Glacier (GSG), one of the largest glaciers in the Himalayas. Numerous small sized glaciers also join the main Gangotri glacier from all sides and form the Gangotri group of glaciers. The main glaciers as well as its tributaries are valley glaciers. Table 7 shows the results for the area change in snow cover for last 5 years. The total ice cover is approximately 520 sq km.

VI. CONCLUSION

All the data has been chosen on the behalf of the early spring when snow cover starts to melt into streams. From the above data it could be seen that there has been a down fall around 83.381 sq km of the Snow Cover of the Gangotri and Surrounding Glaciers (GSG) Area in the years of 2018 and 2019 respectively from the year 2017. But in 2020 huge recovery has occurred with a drastic increase in scow cover area by approximately the same amount which has been previously depleted. After 2020, it seems that a gradual drop of 27 sq km occurred. This changes might have occurred due to differential quantities of snow fall or precipitation or can be a reason of increasing rate of global warming. An average of 520 sq km of Snow Cover Area over that last 5 years is maintained. As some part of Gangotri and Surrounding Glaciers (GSG) lies between to separate LANDSAT Data Sets, the map which was covering the maximum coverage has chosen and conducted for the Analysis. So around 76% of the Gangotri and Surrounding Glaciers (GSG) has been analyzed because Gangotri glacier is divided into 2 different LANDSAT 8 Datasets of different timeings and results are shown on behalf of this region. A graph with per year Snow Cover Area is been shown in Fig 23.

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Fig 23. Graph showing the Last 5 Years of Change in Snow Cover Area of the Gangotri and Surrounding Glaciers (GSG)

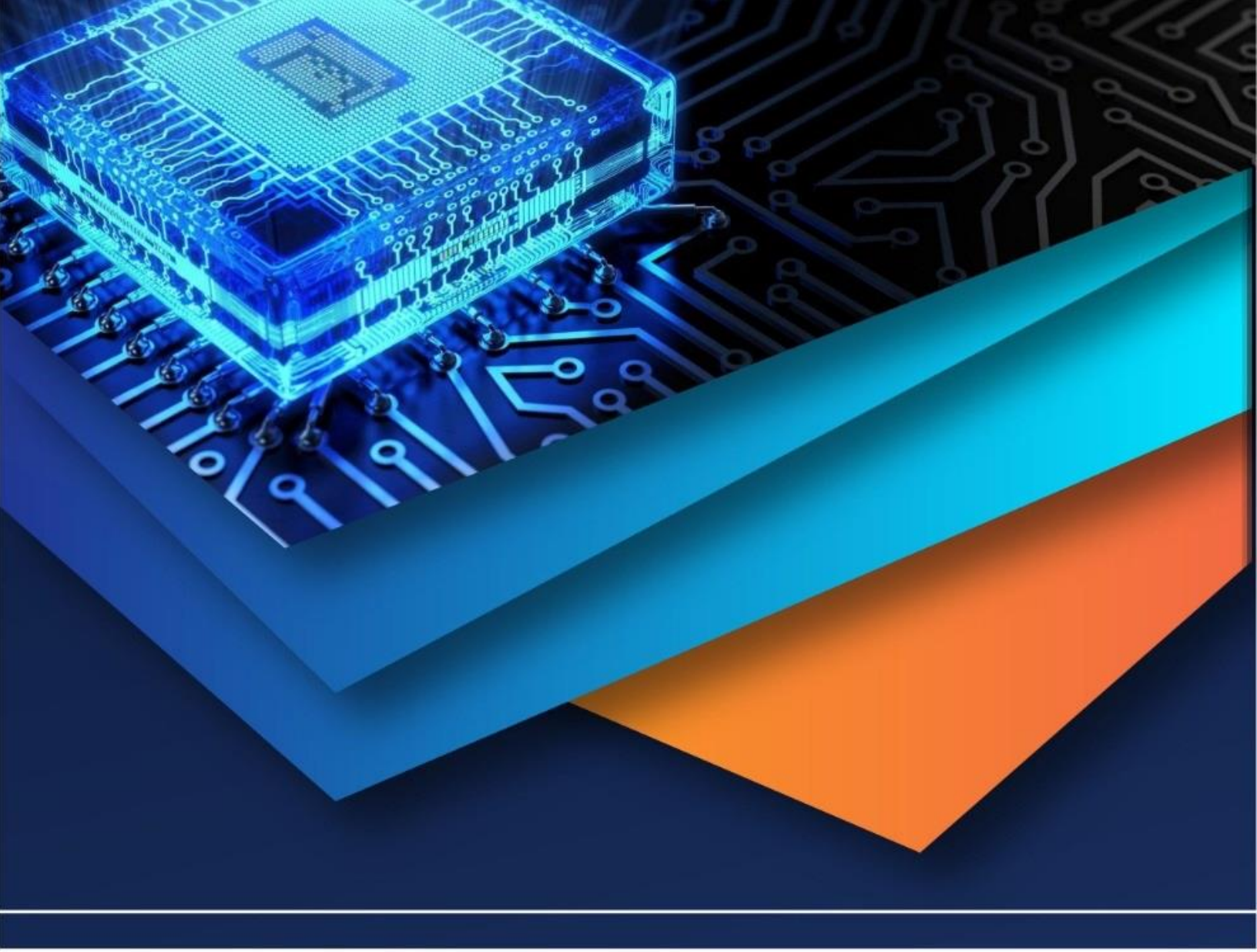
VII. ACKNOLEDGEMENT

I am very thankful to USGS Earth Explorer for providing us LANDSAT 8 Images free of cost.

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