International Journal of
Georesources and Environment
Journal home: http://ijge.camdemia.ca. Articles at http://ojs.library.dal.ca/ijge
Geo-Environment and Geo-hazards
IJGE 2021 **6:** 84

Study of Flash Flood in the Rishiganga and Dhauliganga Catchment in Chamoli District of Uttarakhand, India

M.S.Rawat and R. Dobhal
Uttarakhand State Council for Science & Technology
Vigyan Dham, Jhajra, Dehradun

Abstract: The present study is an attempt to investigate a flash flood that occurred on the morning of 7th February 2021 in the Rishiganga and Dhauliganga Catchments in Chamoli District of Uttarakhand. A catastrophic flood was triggered due to a massive rock-cum-snow avalanche caused by Antecedent Snow falls in the region. A huge flash flood was generated as a tremendous quantity of rockslide, comprising deposited ice and snowmelt, rolled down the Ronthi Glacier and flowed downstream into the glacier valley. This massive flash flood hit the NTPC's Tapovan-Vishnugad hydel project and the Rishiganga Hydel Project, bridges, roads, and communities in and around Raini, Tapovan and Joshimath regions in the Chamoli district of Uttarakhand. The mud and slush-inducing elements resulted in the development of a dammed lake, which momentarily blocked one of the Rishiganga's tributaries. Temporal satellite image has been used to access the information of disaster damage assessment in the region. The high-resolution satellite image clearly showing flash flood watermarks in the region and on the avalanches site rock outcrops reaching up to 50–130m height on the way to Raini Gaon. As part of our analysis, we have also looked at the valley's slope profile, which clearly shows the valley's height following the destruction. It is estimated that more than Rs 4,000 crore infrastructures loss due to this flash flood in the region. Besides, two bridges have also been lost. Hydometeriological analysis was also carried out in order to obtain the trend of rapid increase in temperature in the valley where disaster occurred. Using remote sensing (RS) and Geographic Information System (GIS) techniques, thematic layers were generated for obtaining information on the flash flood.

Keywords: Rishiganga, Glacier Snow Avalanche, Flash flood and Satellite data

1. **Introduction: The flash floods due to the burst of an artificial lake created by a huge landslide including rock, frozen mud, and ice in the Rishi Ganga, inside Nanda Devi Sanctuary, is the latest alarm soughed by the Himalayas indicating it as a fragile mountain.**

The cost in terms of lives, property, and a dam projects is enormous. According to estimates, the impacted area is expected to suffer a loss of more than Rs 4,000 crore. Besides, two road bridges have also been swept away on 7th February 2021 due to this harsh flood.

According to Planet Labs, ice along with frozen mud and rocks fall from a high mountain inside the Nanda Devi Sanctuary, from a height of 5,600 m to 3,300 m.

This created an artificial lake within the sanctuary in Rontigad, a tributary of Rishiganga. Water from this lake surged through the Rishi Ganga Gorge which opens near Reni just eight hours after it broke open.

A landslide formed lake known as Birahi tal was created in Rishiganga and burst at the time of the 1970 Alaknanda floods (Pal 1986). This type of events has already been reported in several other higher Himalayan rivers. As a mountain system, the Himalayas have had reported earthquakes, avalanches, landslides, soil erosion, forest fires, and floods, in the past.

Except for earthquakes, anthropogenic activities directly contributed towards aggravating the entire disturbance in the Himalaya (Wasson et al. 2013).

The developmental activities i.e., roads, dams, bridges, tunnels, for which more appropriate and less destructive methods, technologies, and rules are available but not followed, resulted into increased destructive powers of the above calamities (Kimothi et al. 1996).

The Mandakini Valley of Rudraprayag district has witnessed unprecedented damage to life, property, infrastructure, and landscape during the 16th and 17th of June, 2013 (Rawat et al 2015) through torrential rainfall.

Runoff discharge data are indicating (Rawat et al 2015) that antecedent rainfall (15th to 17th June 2013) suddenly exceeded the limit and the overflow of rivers led to landslides and subsequently flash floods in the downstream areas.

* Corresponding Author: M.S.Rawat

Received April 15, 2021; revised July 26, 2021; accepted Sept 15, 2021.

DOI: 10.15273/ijge.2021.06.084

Fragile geology of the area, nearer to Main Central Thrust (MCT), degradation process, and torrential rain are responsible for triggering the process of landslides and flash floods.

2. Study area

Rishiganga watershed lies in the Chamoli district of Uttarakhand state Fig.1 covering an area of about 696 sq. Km lies among latitude 30^0 15'8.217 to $30^0$32'33.693 and longitude $79^0$40'48.099 to 80^0 04'.397 Survey of India toposheets Nos. 53N /10, 53N/11,53N/14 and 53N/15.

The climate in this region is mainly governed by monsoon. Rishiganga and Dhauliganga are the major rivers of the watershed having many tributaries. The altitude of Rishiganga river catchment extends from 2561m to 6445m from above mean sea level (a.m.s.l). During the last decade extensive expansion of roads, settlements and Dams have taken place in this catchment.

The roads have been constructed without considering scientific measures, leading into triggering for several landslides. Rock/debris fall and minor snow avalanches along the roadside is a common feature.

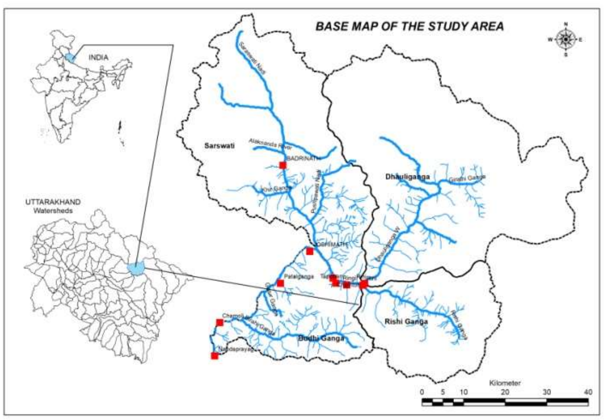

Figure 1. Location map of the study area.

3. Data used for present Study

The data used in the present study is Land viewer imagery, Planet Scope imagery, Landsat-8 imagery and IRS-CARTOSAT satellite data, topographic maps of the Survey of India (1:25,000 and 1:50,000 scale), and information from published geology map.

The topographic maps and false-color composites (FCCs) of satellite data are used as the base maps for field data collection. Data about rock types, structural lineaments, slope, geomorphology, wasteland, land use, and landslides were collected for cross-checking and improving the input data layers. Satellite data were processed using ERDAS Apollo (Version 15) software.

4. Analysis

Many hypotheses were circulating on the possible causes of the massive flood in the Chamoli district of Uttarakhand on February 7, 2021, that has killed 56 people till now, with 144 people still missing. The hypotheses include a glacial lake outburst flood, low snowfall, an avalanche, and a landslide.

Slowly, the consensus is increasingly pointing towards a landslide being the primary cause even as researchers conduct a detailed study that makes clear the exact conditions prior, during, and post the event. A landslide usually occurs because of extreme rainfall events, earthquakes, or changes (sudden or slow) to the geology of an area. The first two reasons are not applicable in the current case. According to the India Meteorological Department, the district of Chamoli had 26 percent less rainfall than average from January 1, 2021 to February 7, 2021.

There were no major earthquakes in the area according to data from the National Centre for Seismology, Union Ministry of Earth Sciences.The third reason is that the thawing and re-freezing of ice affects the properties of the rock and soil in the area with glaciers. Pre-satellite image on 6th February, 2021 showing intact condition of the snow covered area in Fig.2.

Figure 2. PlanetScope imagery of 6th February, 2021, showing pre disaster image.

The landslides that could have occurred due to earthquakes were removed from the dataset. The landslide scar also identified in the satellite imagery, combined with the dust plume visible in the imagery, is a pretty convincing argument that a large landslide occurred Fig.3.

This leaves me wondering where all the water came from. There are multiple possibilities. First, the landslide itself was a combination of rock and glacier ice.

There is a tremendous amount of (frictional) heat generated in these types of landslides and that would have melted a fair bit of the ice. When the mass hit the ground, it may also have melted any ice that was buried in the area in front of the Dakshini Nanda Devi Glacier to the east. But the volumes of water in the videos are a lot and so I am leaning towards there being another source of water.

It is possible that the landslide temporarily blocked the Rishiganga that caused a lake to form, which then burst. Rishiganga was blocked due to Ronthi Gad still there is a blockage and a little discharge in the river.

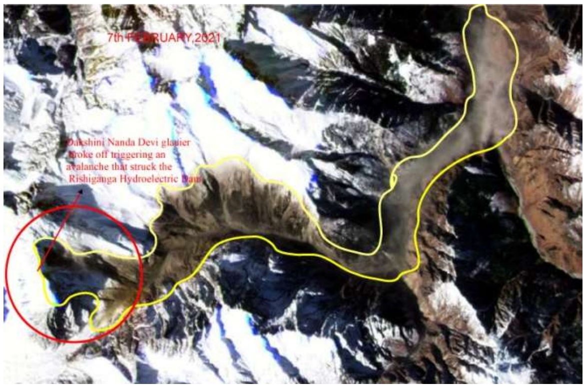

Figure 3. PlanetScope imagery of 7th February, 2021, showing the high rock face where a slab of rocks and ice broke away, and debris filled valley below. Airborne dust from the rockslide was visible when the February 7 image was collected at roughly 11:00 am.

4.1 Geomorphology

The altitude varies from 2561m to 6930 m above mean sea level (a.m.s.l.). The Rishiganga valley has moderate dissected hills and valleys to the highly dissected valley as well many denudational hills in the region Fig.4a.

The State's climatic condition is determined almost exclusively by the difference in altitudes.

Almost all the rivers and streams in this area are in the boulder stage and have not attained a permanent regime even before entering the plains.

Urbanization in the road vicinity and also in the catchment areas is one of the major causes inducing unstable conditions, especially surface scour and thereby allowing water to percolate and create pore pressure conditions that cause movement of large-scale debris creating the blockage.

A DEM (Digital Elevation Model) for the study area was built based on ASTER (30m) elevation data. GCPs were added to the ASTER imagery and processed under the GIS.

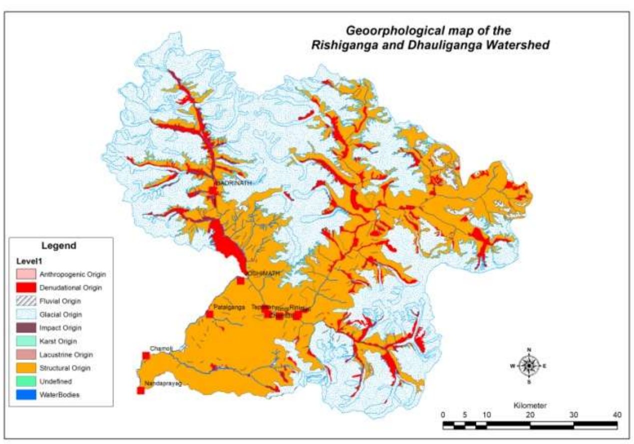

Figure 4(a). Geomporphological map of Rishiganga & Dhauliganga Watershed.

The most common methods of landslide hazard assessment using weighted overlay are heavily dependent on 3-dimensional terrain visualization and an analysis satellite image from the ASTER high-resolution imagery are used for this study Fig.4b.

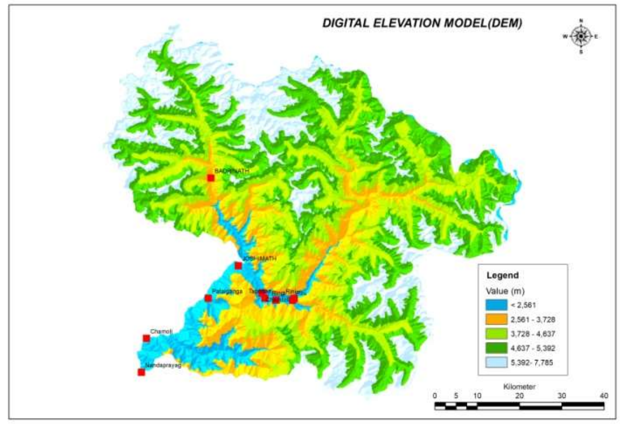

Figure 4(b). Digital Elevation model of Rishiganga & Dhauliganga Watershed.

4.2 Lake Formation:

Following the catastrophe, a field tour was conducted in and around the Rishiganga and Dahuliganga valleys; we noticed a lake formed after a flash flood in the Ronthi Gad Fig.5a.

High-resolution satellite images has identified the exact spot where a "dangerous" lake was formed by the debris of the avalanche Fig.5b that left dozens dead and 200 missing on 7th February 2021.

Scientists of the Defence Research and Development Organisation (DRDO), the National Disaster Response Force (NDRF), and others are working on a plan to avoid another disaster. This issue has been taken into consideration.

The teams are en route to the lake to examine the situation and conduct a review. Ariel survey has been conduct by the different Government agency to observe the threat from the lake.

Even drones, unmanned flights, stakeholder agencies are doing the review of the exact situation on the ground.

The total area of the lake is covered 0.44 km^2 in the High-resolution satellite image which still is a threat to the downstream areas.

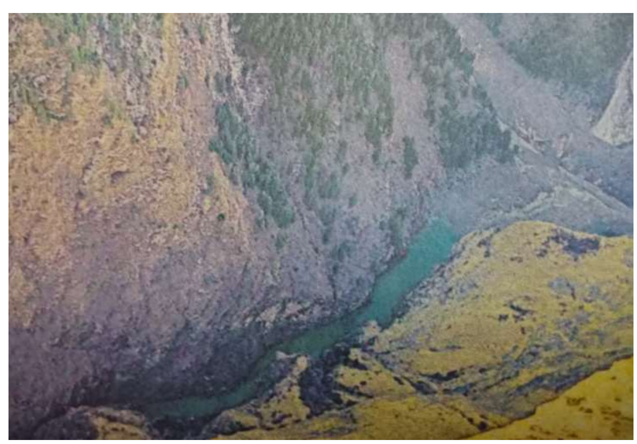

Figure5(a). Field photograph showing Lake formed after Flash flood in the Rishiganga River.

Figure 5(b). Satellite image showing Lake formed after Flash flood in the Rishiganga River.

4.3 Damage Assessment

Rapid damage assessment was carried out in and around disaster-affected areas based on temporal satellite images. Pre-satellite image used of Landsat 8 on 5th February 2021 for showing before disaster condition of the Dam along with other infrastructure present in the area Fig.6a.

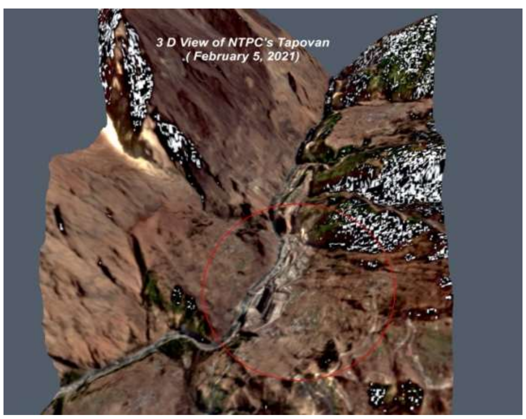

Figure 6(a). Satellite image showing pre disaster image on 5th February, 2021 image.

Post-satellite image clearly showing destructions NTPC Power project at Tapovan in the Fig.6b in Gray colour. The following images show the damages. A field survey was conducted to know the actual condition after the disaster in the Rishiganga and Dhauliganga valley (Photo.1).

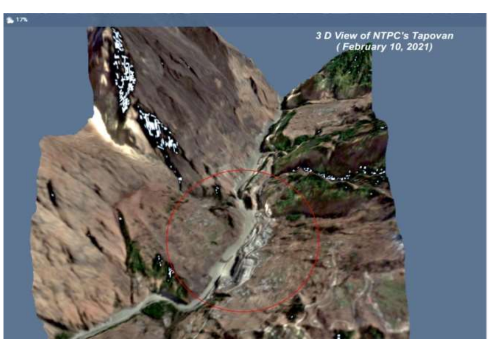

Figure 6(b). Satellite image showing post disaster image on 15th February, 2021 image.

Photo.1 Photographs showing field photographs of the disaster affected areas on 7th February,2021 morning.

4.4 Snow Avalanche

A pre-and post-change analysis from the satellite imagery has shown that the large rockslide incurred along the western slope of the Trishul glacier.

Analysis of pre-event imagery from Sentinel-2 satellite on 31st January 2021 and 5th February 2021 shows an overhanging rock formation with existing cracks on the flank of the western peak of the glacier the central part of the glacier was sitting over the steep and plain bedrock.

A close look at the surface conditions of the glacier shows a certain degradation of the glacier with the development of multiple cracks in the pre satellite image in Fig.6.

The havoc resulted in the formation of ice and rock-laden unstable the area of the upslope. On the 7th February 2021 this block of snow, ice and debris collapsed, due to the melting of snow and consequent percolation of meltwater into the cracks/joints resulting from the landslide/snow avalanche.

The entire snow/ice melted rapidly as the landslide moved northward along the Rishiganga valley resulting in a huge surge of water to the downstream areas, eventually turning westward into Dhauliganga valley causing massive loss of life and property.

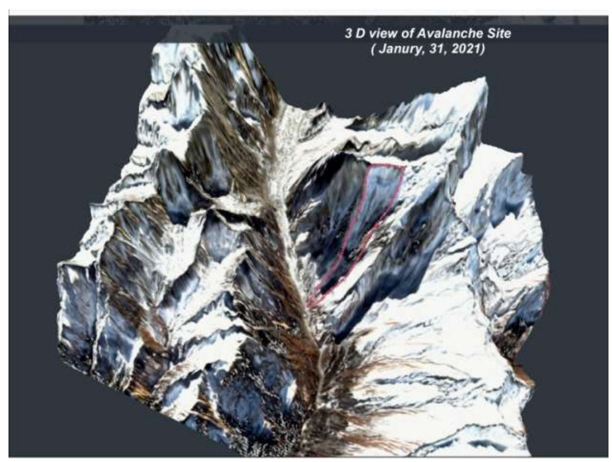

Figure 7. Avalanche site pre-satellite image on 31 January, 2021.

Figure 8. Avalanche site Post-satellite image on 10 February, 2021.

4.5 Flash flood

The Rishiganga valley and Dhauliganga valley received a large volume of flash flood in the downstream areas. A total area was covered of 18.68sq.km upto Joshimath Fig.9.

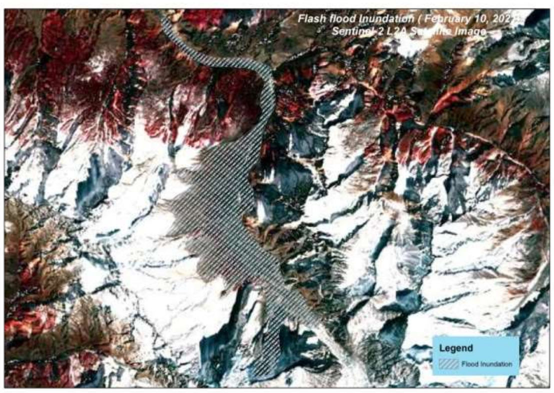

Figure 9. Satellite image showing Flash flood Inundation areas.

The maximum simulated water depth varied from 24-15 m from Rishiganga to Joshimath and 1-2m water depth was observed from Nandprayag to Karnprayag.

Fig.10 showing the elevation profile drawn from the ridge top of the Raunthi glacier area to Tapovan, traversing a distance of 22 km.

The avalanche travelled a distance of ̴1.85 km through bedrock before striking the valley floor 3800 m a.m.s.l. The Ice/snow/rock avalanche converted into a debris flow during its transport through the valley.

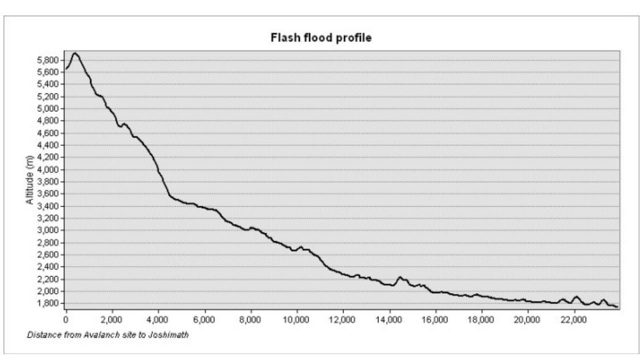

Figure 10. Elevation profile for the stretch between ridge top to Tapovan.

Simulation results clearly showed major impact upto few km downstream of Joshimath, however no water level rise was estimated beyond Rudraprayag, Srinagar, Rishikesh and Haridwar. Many theories going on in every mind in the area that this disaster incurred due to hydropower dams.

This is a very significant event not only in terms of the catastrophic disaster it caused along its flow path but also in terms of breaking of a large glacier mass which is a very rare phenomenon in the glaciated regions of the world and more so in the Himalayas.

The facts, we have seen that the big landslide occurred at the place where cracks are already formed and antecedent snowfalls occurred before a couple of days which play a crucial role to induce this phenomenon which have tremendous loss of the life and property in the area which may take a lot of time to forget this event.

A big road bridge breach completely during the flash flood. Live photos clearly showing the velocity of the runoff Photo 2(a-d).

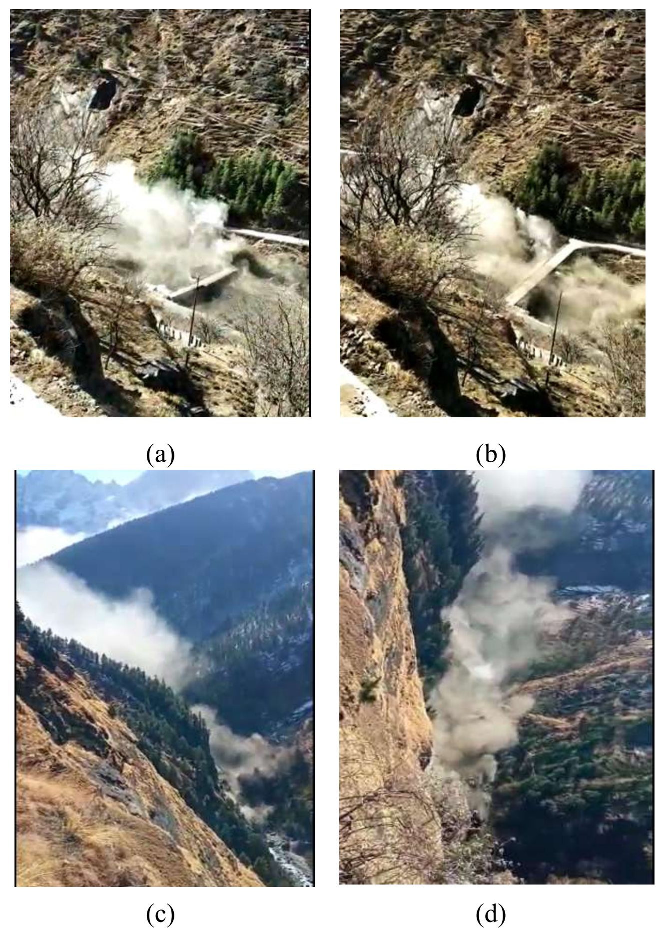

Photo2(a-d). Photographs showing live flash flood in the Rishiganag River.

4.6 NDWI

The Normalized Difference Water Index has been used to make use of reflected near-infrared radiation and visible green light to enhance the presence of features for eliminating the presence of soil and terrestrial vegetation features Fig.11.

The NDWI index is most appropriate for water body mapping. The water body has strong absorbability and low radiation in the range from visible to infrared wavelengths. The index uses the green and Near Infra-red bands of remote sensing image based on this phenomenon.

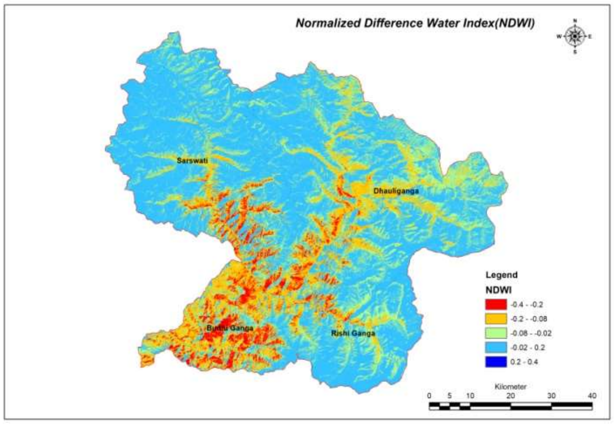

Figure.11. NDWI of the Rishiganga and Dhauliganga Watershed.

The NDWI can enhance the water information effectively in this disaster. The spatial Analyst tools has been used to obtained by Map Algebra through Raster calculation using the below mentioned formula. The NDWI has been classified in 5 classes 0.2 to-0.4 and the area is indicating flooding humidity in the region. Landsat 8 and L2A satellite images have been used to find out NDWI.

The following calculation has been used to obtain the water Index in the disaster affected areas.

$$\text{NDWI} = \frac{(B03 - B08)}{(B03 + B08)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (1)$$

where B3 is Green Band and B8 is Infrared Band.

Also L2A showing Water surface indicated 0.8 to 1µm and flooding humidity of the site of the avalanche was observed 0.1 to 0.2µm (EOS Data Analytics 1906).

5. Meteorological predictions from Weather Forecast Model

As per the Land viewer model forecast, the rise in snow precipitation is identified during 4-6, February 2021 in Rishiganga and Dhauliganga areas and reduced significantly thereafter.

The chart showing the moisture content of the soil and, based on this, more accurately predict.

On 7th February 2021 temperature was increased and accelerates the avalanche on 4th February 2021 maximum temperature was -1.54C^0 minimum temperature was-13.15C^0 and on 6th February 2021 maximum temperature was -0.33C^0 minimum temperature was-16.55C^0.

On 7th, February 2021 the maximum temperature Fig.12 was observed 1.23C^0 minimum temperature was-15.4C^0 Fig.12.

Wind speed was on 7th February 2021 is 1.57m/s and reduced significantly thereafter Fig.13.

The chart shows the daily precipitation in mm in the Rishiganga and Dhauliganga valley. The Chart showing Humidity in the disaster-affected areas which is quite high on the Disaster morning Fig.14.

The chart showing the frequency of anomalies in the precipitation on the field: flooding, and lingering precipitation, this can lead to the development of harmful soil erosion Fig.15.

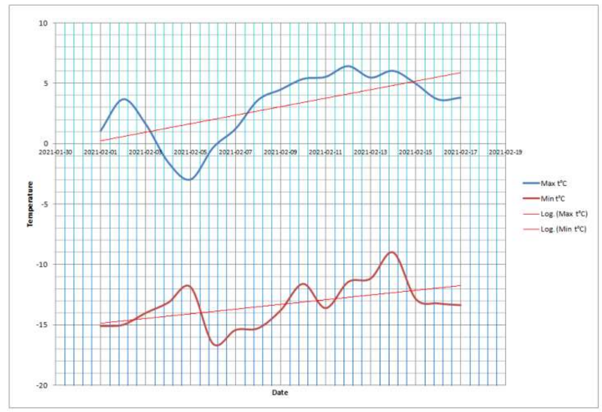

Figure 12. Maximum and Minimum temperature of the Disaster affected areas.

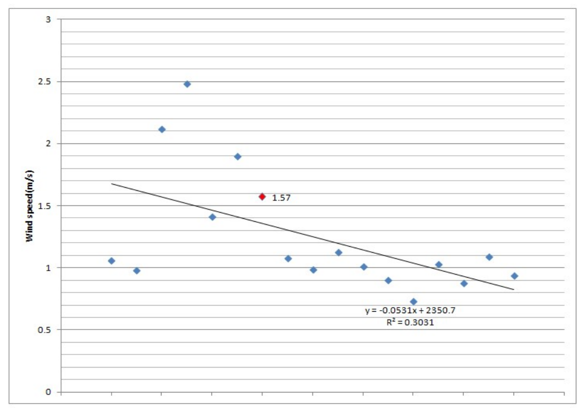

Figure 13. Wind Speed (m/s) of the Disaster affected areas.

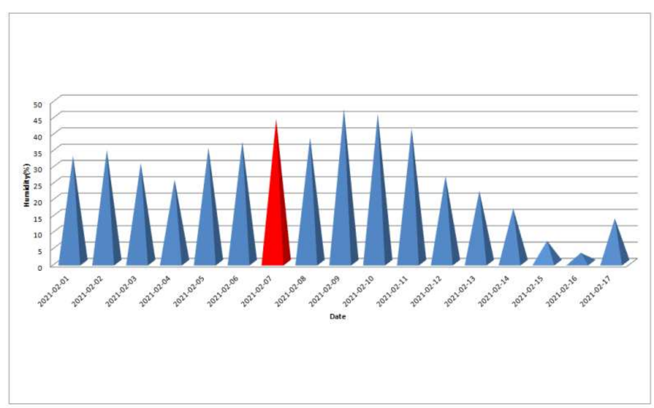

Figure 14. Humidity (%) of the Disaster affected areas.

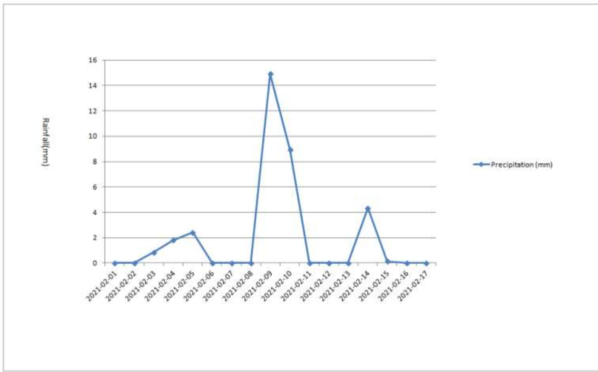

Figure 15. Daily precipitation of the Disaster affected areas.

6. Conclusion

A Remote Sensing and GIS approach has been used to find out the causes of the flash flood in the Riashiganga and Dhauliganga Catchments in the Chamoli district of Uttarakhand.

Geomorphological analysis was carried out in and around disaster-affected areas using Landsat 8 satellite image with the help of Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS).

After analysis of satellite image along with field information of the disaster affected areas, we have find out that avalanche area already is very sensitive as it belongs to the denudation Hills and Valley in terms of landforms process, where avalanches and landslides are continued process in the past.

Rainfall data has been used for the affected areas to know the exact causes of the avalanche, the data suggest that before the disaster there was continuous rainfall/snowfall received for 3-4 days. Here Antecedent rainfall may be saturated the area, where cracks already developed. The snow, ice, and rock mass fell to 3,800 m downstream areas flank pulverizing on the impact the Powerhouse.

The major landslide/rock avalanche also produced a huge and widespread dust cloud along the valley seen on some videos of the event and captured on the Planet Labs satellite images.

As per RS&GIS analysis of pre and post satellite, it is thought at this preliminary stage that the landslide/rock avalanche collapsed onto the floor of the valley about 2 km downstream from the adjacent glacier snout.

Active temperature plays a vital role in inducing a big avalanche in the region along with wind speed observed to high. The slope of the valley is high which to accelerate the mud/debris flow in the form of flash flood in the downstream areas.

7. Recommendations:

1) An avalanche is a rapid flow of snow down a hill or mountainside. Although avalanches can occur on any slope given the right conditions, certain times of the year and certain locations are naturally more dangerous than others. Wintertime, particularly from December to April, is when most avalanches tend to happen. However, avalanche fatalities may occur in between these months. My suggestion is this is a new type of disaster that happed in the Chamoli district, Uttarakhand which is a threat to the planners and decision-makers.
2) The scientific approach to be followed to make any project in the hilly terrain. Developmental activities are the backbone for any state but whenever doing any construction activities there should be a proper study done before construction.
3) Early warning systems should be developed for monitoring Glacier and river discharge flow so that alarms alert the people of the downstream areas.
4) In the Tapovan Hydropower project site flash flood enter the tunnel and lost the life of workers. It was a Sunday otherwise many death trolls might be increased. For the construction of any tunnel for there should be a proper emergency shutdown.
5) Uttarakhand people face many disasters even in the year 2013 Kedarnath Disaster more than 5000 pilgrims along with local works, inhabitants lost their life.
6) My studies show that Glacier monitoring should be daily so that loss of disaster can be minimized, the disaster we cannot stop but the loss can be minimized to take some preliminary precautions.
7) Hight of the Dam barrier should be increased, so that dam can stop the flow of the river. There should be a more intact method to stop such kind of disaster happed in Raini village and Tapovan.

Acknowledgement

We thank the Uttarakhand State Council for Science & Technology, Department of Information Science & Technology, Govt. of Uttarakhand. It is my privilege to express my deep sense of indebtedness and reverence to Prof. Joshi for his expert advice, valuable suggestions, and incessant encouragement.

We also extend our sincere thanks to Land viewer for providing and sharing images with us for the betterment of the disaster assessment. Last not least I also thank to Dr. Malik for his technical support for the revision of the manuscript.

References

Rawat, M.S.et al.,2015, *Current Science*, 2015,109, 1,158-170.

Pal, S. K., *Geomorphology of River Terraces along Alaknanda Valley, Garhwal Himalaya*, BR Publishing Corporation, Delhi, 1986, p. 158.

Kimothi, M. M. and Juyal, N., *Int. J. Remote Sensing*, 1996, **17**, 1391–1405.

Wasson, R. J., Sundriyal, Y. P., Chaudhary, S., Morhtikai, P., Sati, S. P. and Juyal, N., Quaternary Sci. Rev., 2013, 77, 156–166.

EOS Data Analytics, Inc 1906 El Camino Real, Suite 201, Menlo Park, CA 94027, USA.www://eos.com/landviewer/ ?utm_source=Email&preset=highResolutionTmsSensors.