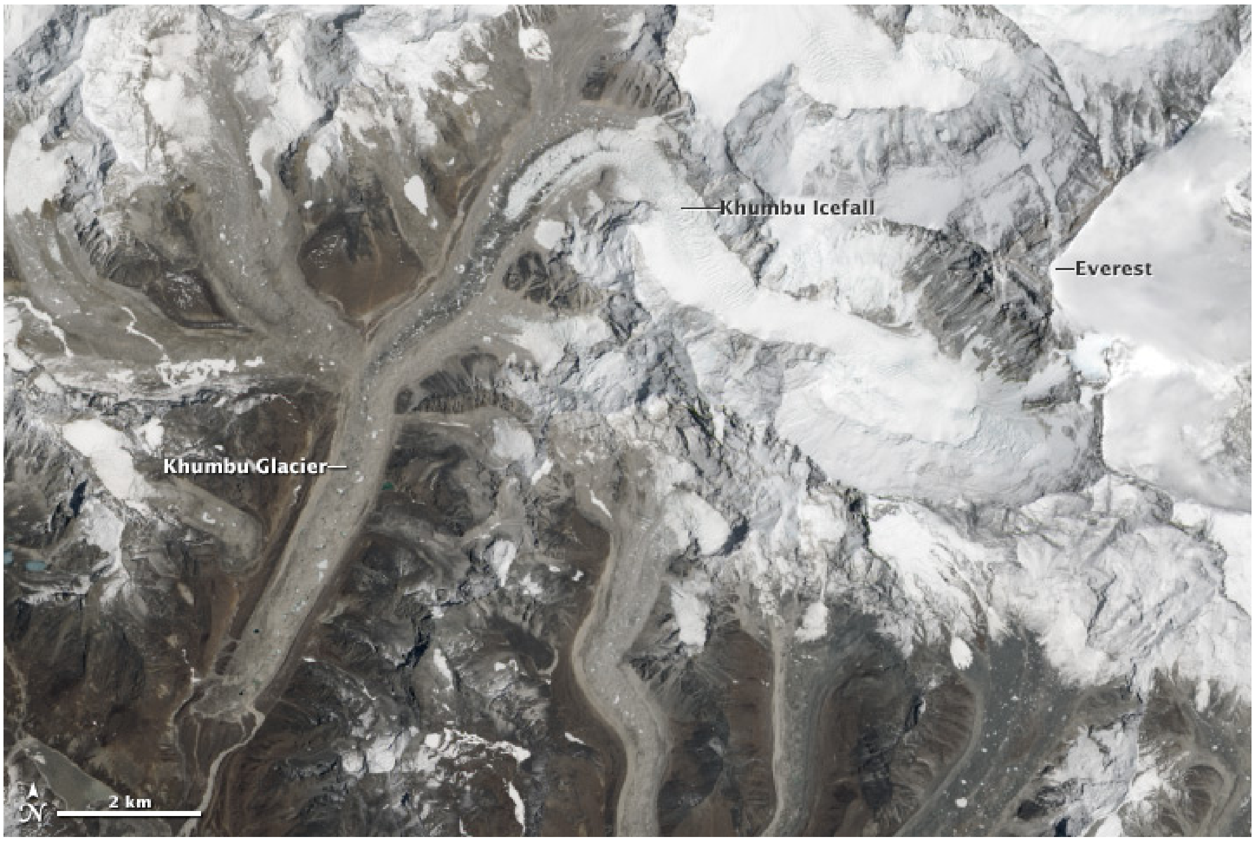
Research Title:

Monitoring Khumbu Glacier of Nepal Using Remote Sensing



Researcher

Rudra Raya

ADGIS Student (GIS307 Project)

Selkirk College

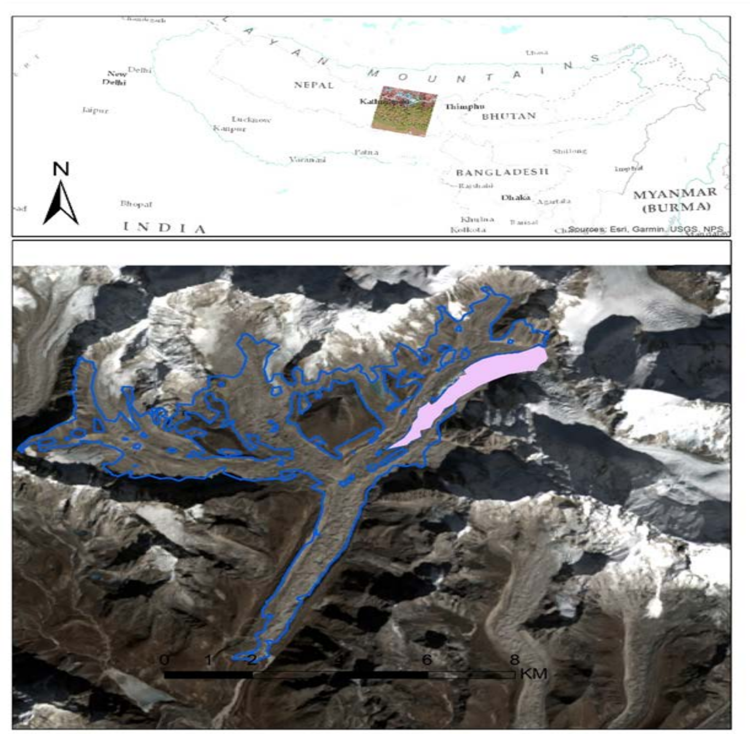
Abstract:

Changing the climate, the glacier is melting rapidly around the world. Nepal is a mountainous country which has more than 83% of the total area is covered by the high mountains, and 13% by permanent snow and glaciers. Some glaciers have already disappeared, and some are on the phase of melting. The causes of melting glaciers haven't been clearly revealed yet. The objective of this research is to see how much of the Khumbu glacial area has changed from 1990 to 2018. The Landsat images from different years were main data for this research which is free available in united state geography of survey department webpage. I looked into the glacier with debris and without debris glacier using Remote sensing and Geographic information system. I used high resolution satellite images to analyze the glacier area change. The normalization difference of snow index and the supervise classification were main tools to analyze this research study. I found a total area of 0.671 square kilometer shrunk from the Khumbu Glacier and 532.19 meters glacier with debris line retreated in the last 28 years. We need to do further research to figure out the main cause of this glacier melting problem because many people depend on this fresh water.

Kew words: glacier, shrink, retreat, and Landsat

1. Methodology:

6.1 Study Area:



(Figure 1 : Khumbu glacier Study area)

Khumbu Glacier, a typical debris-covered glacier more than 15 KM long, drawn mainly from the Mt. Everest in the eastern part of Nepal. The elevation of the apparent terminus is about 4900 meters from sea level. The glacier has attracted much attention because it is located along a route to the highest peak of the world. The amount of information on the glacier is therefore large compared to other debris-covered glaciers.

The above map shows the satellite image of the lower half of the glacier, covering both debris as well as the clean glacier. The main accumulation basin lies to the east, and the glacier flows to the ablation area through an icefall just above Everest base below Everest base camp. In the middle of the pinnacle zone, there is a transverse debris layer by big landslide event, according to local people plus by my field observation.

Flow Diagram of methodology

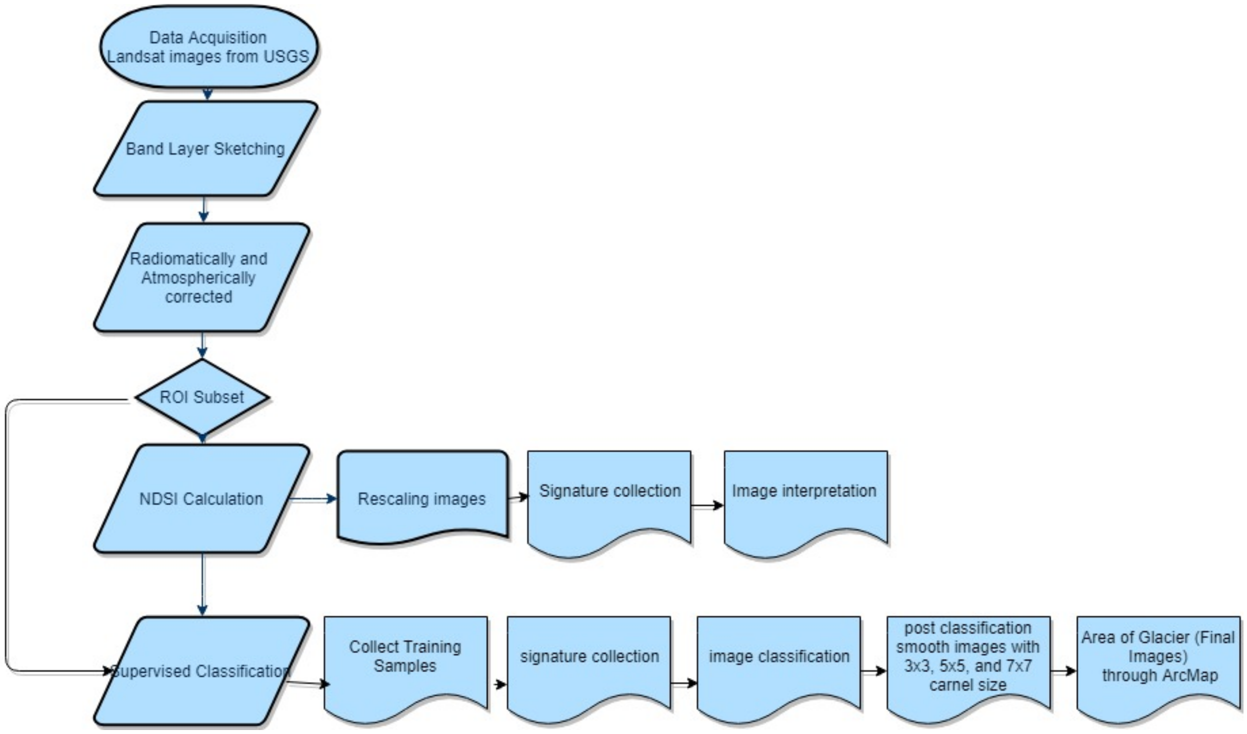


Fig. 1: Diagram of the complete methodology

6.2 Data:

All required data (images) were downloaded from the Earth Explorer platform, ran by the U.S. Geological Survey (USGS). As listed below, I used Landsat 5, 7, and 8. Four Landsat images used for the years 1990, 2000, 2010, and 2018.

Table 2: Data detail table

Date	Landsat	Bands
1990	5	1,2,3,4,5,7
2000	7	1,2,3,4,5,7
2010	5	1,2,3,4,5,7
2018	8	1,2,3,4,5,6,7

1. **Result and Discussion:**

7.1 Normalized Differences of Snow Index (NDSI)

In the NDSI calculation, all of my data is characterised by 11 spectral bands operating in the visible, near-infrared, shortwave infrared and thermal infrared spectral regions. The imagery is further characterised by 30m spatial resolution bands from the visible and shortwave infrared, 100m for thermal infrared and 15m spatial resolution for the panchromatic band. I got the detail description of the characteristics of all Landsat images from the United States Geological Survey (USGS) Landsat Missions website at http://landsat.usgs.gov.

I calculated the NDSI value by dividing the difference in reflectance observed in the green band and the shortwave infrared band (SWIR) by the sum of the two bands as shown in the equation below.

NDSI = Green – SWIR(band5)/Green+SWIR(band5)

I decided to use those bands for calculating the recommended in various papers by Hall et al., (1995), Kulkarni et al., (2006) and Xiao et al., (2002). I used the minimum NDSI threshold value of greater than 0.08 to 1.17 which highlight the clean glacier area. As suggested by Kulkarni et al., (2006) and Xiao et al., (2002) a near-infrared reflectance value greater than 0.11 was used to mask other areas like, out shadow and alpine ice pixels so as to improve NDSI classification accuracy.

7.2 NDSI calculation Images:

Year 1990

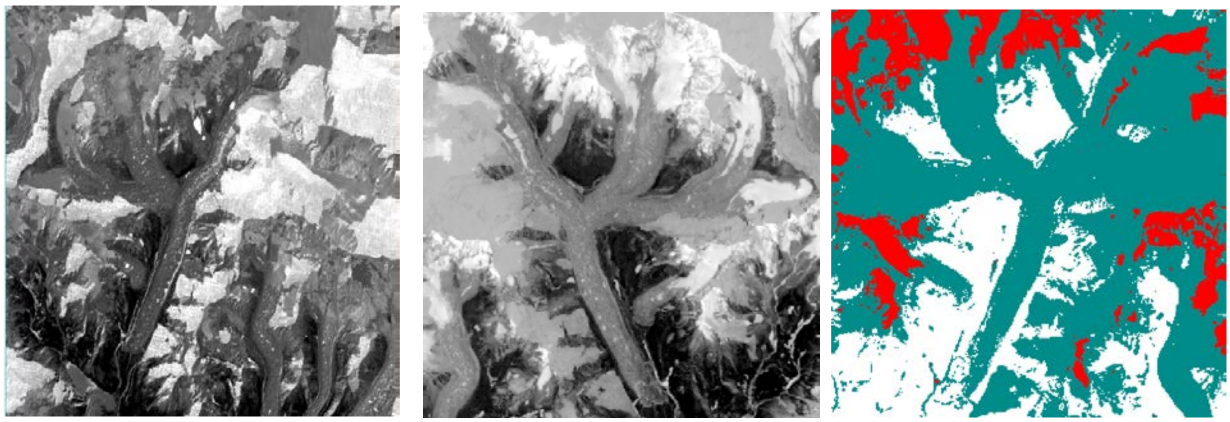


Figure: 4 a. before band calculation, 4b. after band calculation, 4c. after mask of another area.

Year 2000

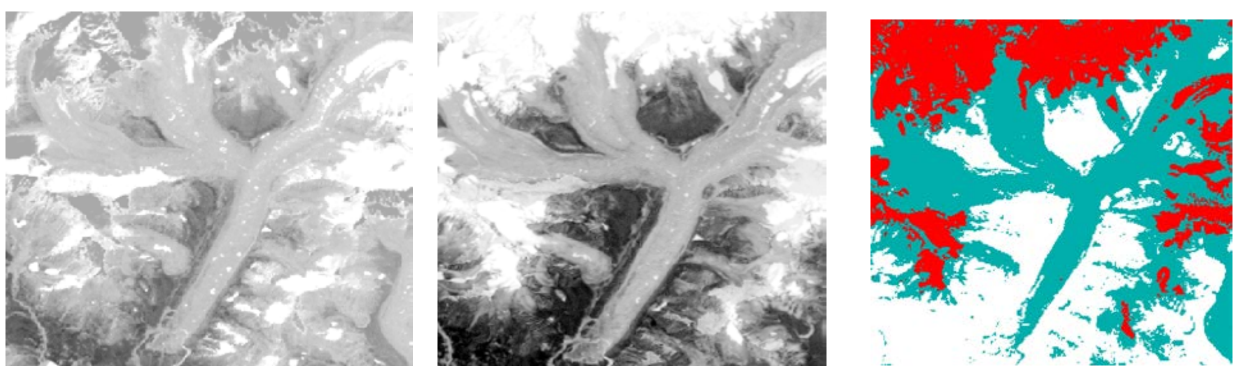


Figure:4d. before band calculation, 4e. after band calculation, 4f. after mask of other area.

Year 2010

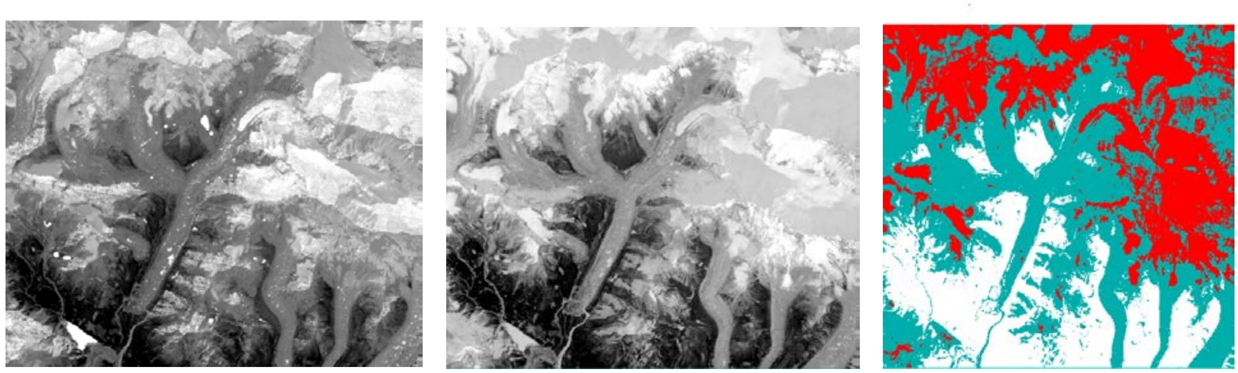


Figure:4g. before band calculation,   4h. after band calculation,   4i. after mask of other area

Year 2018

Figure:4j. before band calculation,   4k. after band calculation,   4l. after mask of other area

7.3 Classified Image

7.3.1 Supervised classification

It is a process to assign a land class to the pixel. I used the spectral signature defined in the training sample. It can be used to determine land cover classifications (Aniya et al. 1996; Brown et al. 1998; Sidjak and Wheate 1999); however, it is hard to get precise and effectively delineated debris _covered glaciers (Bishop et al. 2001; Bolch et al. 2007). Before I classified, I visually interpreted all images in ENVI and figured out the number of classes needed. The radiometrically corrected images already show the amount of glacier and its changes within thirty years' time series. I used the supervised classification method for the classification of my study area. The scene divided into seven classes: Clean glacier, Glacier with Debris, Bare land, Shadow with Snow, Dark shadow, and Alpine Lake Ice.

7.3.2 Classified Images

Year 1990

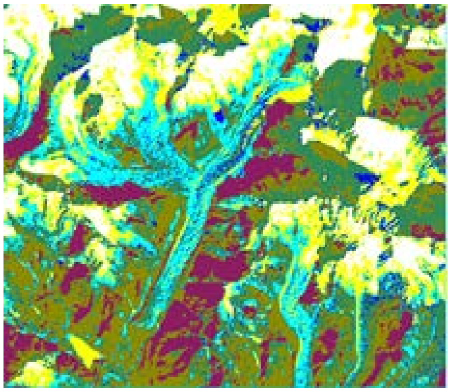


Figure 5 a Supervise classification 5x5 cornel size *figure 5b. area of classified image 1990*

Year 2000

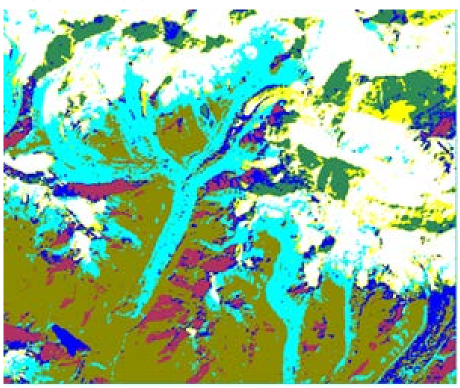


Figure 5 c Supervise classification 5x5 cornel size figure 5d. area of classified image 2000

Year 2010

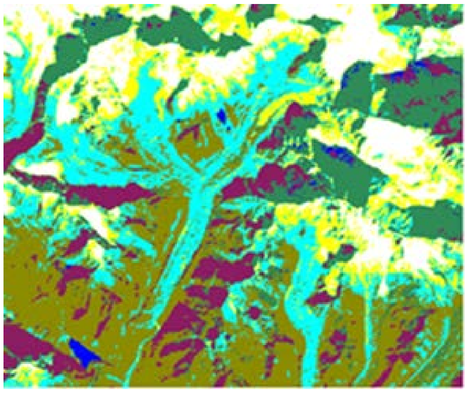


Figure 5 e Supervise classification 5x5 cornel size

figure 5f. area of classified image 2010

Year 2018

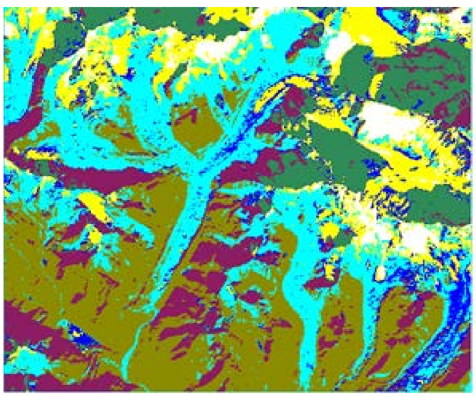


Figure 5 g Supervise classification 5x5 cornel size

figure 5h. area of classified image 2018

After using the supervised classification method and post-classification refinements, the resulting images showed a great number of differences in the classified area as shown in Table 4 and Figure 6. It showed that a great amount of glacier retreated from 1990 to 2018. The glacier with debris and clean glacier had rapid changes every ten years. The glacier with debris converted to bare land and the area was shrinking down.

The total area of a clean glacier in 1990 was 2.153 square kilometers, but this area shrunk to 1.482 square kilometers in 2018.

Year	Area (km^2)	Changes (km^2)
1990	2.153	
2000	2.051	-0.102
2010	1.593	-0.458
2018	1.482	-0.111

Table: 4: Total area changes of Clean glacier

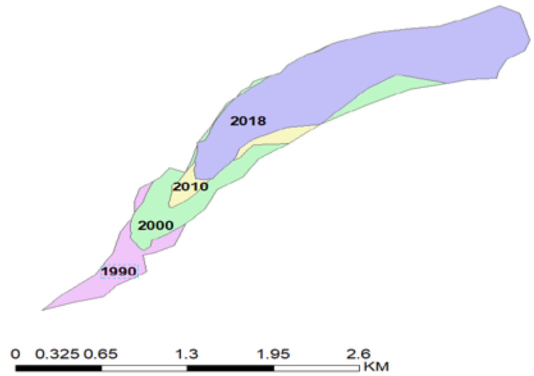
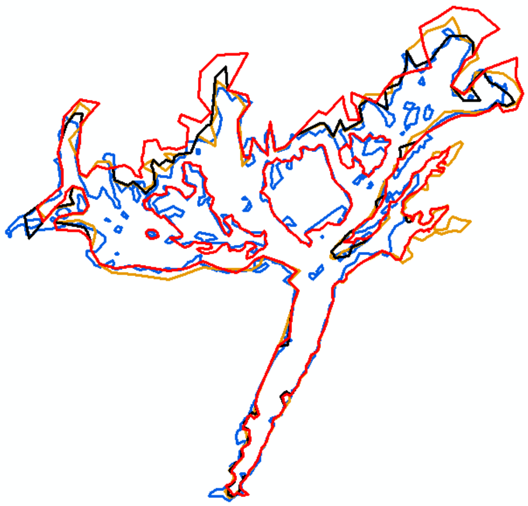


Figure:6, the area changes in different ten years

I also calculated the area of the glacier with debris. The line of the glacier with debris was retired and converted to bare land.As shown in Table 5 (retreat line), it clearly shows how much snow glacier was converted to bare land. In 2000, the glacier line was changed by 420.88 meters, and the glacier line continuously retreated and shrunk by 532.10 meters in 2018.

Year	Glacier with debris from 1990 in meters	Total retreat in meters
1990	0	0
2000	420.88	420
2010	470.69	50
2018	532.88	62.19

Table: 5, total line retreat change of debris glacier



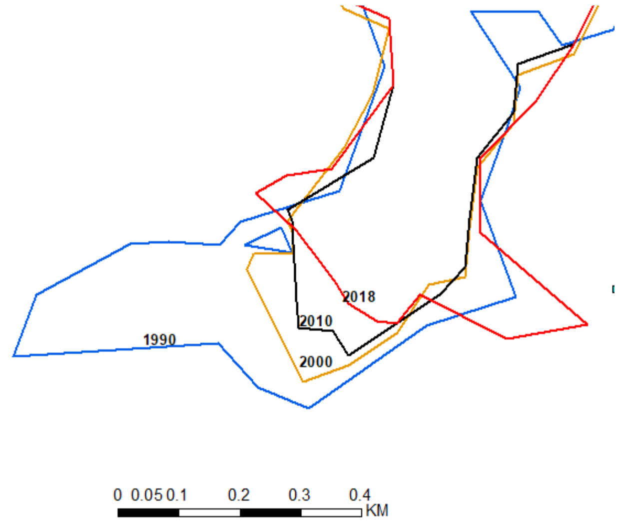


Figure 7 Shape area of year(1990,2000,2010, and 2018) Figure 8, total area line change between 1990 to 2018

I was not able to find any previous classified images; therefore I have only one option like image interpretation through eyes observation to check the accuracy assessment. In my observation, the classified images are valid with ground truth values.

1. Conclusion

The remote sensing technique is a useful tool to analyze the change in glacial areas in different years. The remote sensing technique is an effective way to monitor glacier area where the ground-based research is impossible. This study shows the shrinking trend in the glacier, which is converted to bare land. It is very hard to say the actual reason for the rapid shrinking of the glacier area. The clean glacier area of Khumbu glacier shrunk significantly, some area of the glacier with debris was already converted to bare land and also the clean glacier is continuously shrinking.