CHAPTER III

TECHNIQUES OF REMOTE SENSING FOR GLACIAL GEOMORPHIC MAPPING

TECHNIQUES OF REMOTE SENSING FOR GLACIAL GEOMORPHIC MAPPING

III. 1. INTRODUCTION

The existing glaciers of India are occupying highest, inaccessible and rugged reaches of the inner Himalayas. Their mapping and monitoring through conventional survey techniques have rather been very difficult prepositions. However, this constraint was largely overcome by Survey of India by employing the technique of Remote Sensing (aerial photogrammetry) in surveying the glaciated regions of Himalaya. Remote sensing is defined as the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand and Kiefer, 2002). Remote Sensing and GIS have been used world over as tools which enhance and broaden the opportunities of Geomorphological studies.

The advent of satellite remote sensing and their continuing advancements with respect to high spatial and spectral resolution as well as increasing repetivity have given new dimensions towards mapping and monitoring of glaciers. Snow was first observed by satellite in eastern Canada from the Tiros-1 satellite in April 1960. Launching of Indian Remote Sensing Satellite IRS-1A in 1988, heralded a new era in the utilization of satellite remote sensing data in natural resources survey, including glacier surveys. Since then the potential for operational satellite based mapping has been enhanced by the higher temporal – frequency satellites and sensors such as WiFS to high spatial resolution such as Cartosat and LISS IV of Resourcesat. In addition other countries satellite system such as NOAA also does snow mapping with better radiometric resolution. The Spot 5 satellite with very high spatial resolution is also measuring glacier extent and thickness over Himalayas. The Geoscience Laser Altimeter System (GLAS) on ICESat operating since 2004 also measures ice sheet elevations, changes in elevation through time, height profiles of clouds and aerosols, land elevations and vegetation cover, and approximate sea ice thickness. The primary goal of ICESat being quantifying the ice sheet mass balance and understand how changes in the Earth' atmosphere and climate affect polar ice masses and global sea level. So today a large number of satellites are collecting terrain data at regular intervals. Hence, it is possible to get imagery of an area for mapping of glaciers at an interval of 24 to 5 days from IRS satellites. Thus, getting suitable satellite data for glacier mapping pertaining to the end of ablation season may not be difficult. Therefore, periodical monitoring of glaciers, at required intervals, now seems to be a comparatively easier task.

III. 1.A. Satellite data specifications

Table 3.1. The Specifications of IRS P6 and IRS 1D w.r.t spatial resolution

Basin	Sensor	Satellite	Spatial Resolution (m)	Date of Acquisition
Baspa	LISS III	Resourcesat (IRS-P6)	23.5	28 August 2005
Baspa	LISS III + Pan merged	IRS 1D	5.8	18 October 2001

LISS-III (Linear Imaging Self Scanner) has a spatial resolution of 23 m, with the exception of the SW Infrared band, which is 70 m. Bands 2, 3, and 4 have a swath width of 142 kilometers; band 5 has a swath width of 148 km. Repeat coverage occurs every 24 days at the Equator. The panchromatic sensor has 5.8 m spatial resolution, as well as stereo capability. Its swath width is 70 m. Repeat coverage is every 24 days at the Equator.

Table 3.2. The Specifications of IRS P6 and IRS 1D w.r.t spectral resolution

Specifications	Band	IRS P6 LISS III	IRS 1D LISS III	IRS 1D Pan
Spectral bands wavelength(μm)	2,Green	0.52-0.59	0.52-0.59	0.5-0.75
	3,Red	0.62-0.68	0.62-0.68	
	4,NIR	0.77-0.86	0.77-0.86	
	5,SWIR	1.55-1.70	1.55-1.70	

We can see that the data interpretation aspect of remote sensing can involve analysis of pictorial (image) or digital data. Visual interpretation of pictorial image data has long been the *workhorse* of remote sensing. Visual techniques make use of the excellent ability of the human mind to qualitatively evaluate spatial pattern in an image. The ability to make subjective judgements based on selective image elements is essential in many interpretation efforts.

III. 2. VISUAL IMAGE INTERPRETATION

Image interpretation is defined as 'the art of examining images for the purpose of identifying objects or surface features and judging their significance. Interpreters study remotely sensed data and attempt through logical processes in detecting, identifying, classifying, measuring and evaluating the significance of physical and cultural objects, their patterns and spatial relationships'(Manual of Remote Sensing, Vo. L, p. 369). There are certain fundamental photo-elements or image characteristics seen on image which aid in visual interpretation of satellite imagery.

Tone/Colour – Different surface objects reflect and emit different amounts of radiant energy. These differences are recorded as tonal/colour or density variations on the imagery. In black and white images, objects appear in different gray tones. These gray tones often fail to provide the interpreter a clear perception of objects. Whereas, true colour or false colour imagery increase interpretability by providing a subtle tonal contrast between them, eg. distinction of snow and ice is mainly based on tonal changes.

Texture – refers to the frequency of tonal change on an image and is produced by an aggregate of unit feature too small to be discerned individually on the image. Although tone is a fundamental element of texture, the conditions affecting tone may vary and yet permit such texture to be diagnostic recognition element. In fact, texture is a really composite of tone, shape, size, and pattern. The texture of exposed ablation is fine as compared to debris covered ice which shows medium texture.

Shape and Size – Shape refers to appearance of landform or relief or topographic expression. It is very important in identification of type of landforms such as shape of a Lateral moraine is linear to curvilinear while that of a terminal moraine is crescent shape with convex at down valley end. Size refers to the spatial dimension of object on ground. Size of an object is a function of scale of the image and is also measurable. There are different objects with varying sizes and shape.

Pattern – It refers to the spatial arrangements of surface features which are characteristic of both natural and man-made objects. Similar features under similar environmental conditions reflect similar patterns of recurrence, eg. moraines in deglaciated areas.

Shadow – Shadows resulting from subtle variations in terrain elevation and low sun angle images topographic variations that may be diagnostic of various geologic landforms. Identification of glacier snout on images is difficult due to high debris cover at lower ablation zone. Snout is generally marked with an ice wall which creates a shadow depending upon the position of the sun. Hence, shadow can be considered as one of the indicator for identification of snout.

Location and associated features – The relation of one feature to its surroundings is commonly important because a single feature by itself may not be distinctive enough to permit its identification. Lateral moraines are mostly identified by its location i.e., along the margins of the glaciers and is commonly in association with debris fans and rock falls.

Table 3.3. Visual interpretation key

Sr. no	Geomorphic Features	Colour	Texture	Shape and Size	Location/Associated Features
1.	Accumulation zone	White	Fine	Circular to semi-circular, small-medium	cirques
2.	Permanent snowfields	White	Fine	Irregular, small	Top of the mountain ridges
3.	Exposed Ablation zone	Grayish white	Fine	U-shape, small-medium	Below accumulation zone,
4.	Moraine covered ablation zone	Brown	Medium	U-shape, small-medium	Below exposed ablation zone
5.	Snout	Black	Fine	Irregular, small	End of ablation zone, emergence of stream from terminus of glacier
6.	Crevasses	Bluish white - black	Fine to Medium	Linear-curvi linear, small	Accumulation zone
7.	Medial moraines	Bluish-White to Brown	Medium	Linear/Small-medium	Middle part of glacier, Ablation zone
8.	Lateral moraines	Brown	Medium-coarse	Linear/ small-large	Margins of glacier/valley walls
9.	Terminal moraine	Brown	Medium	Convex/small - medium	Terminus of glacier, deglaciated valley
10.	Deglaciated valley	Grey/brown	Medium	U shape/medium-large	Below ablation zone
11.	Maximum glacial limit	Grey/brown	Medium	Convex/small - medium	End of deglaciated valley
12.	Lakes	Blue to black	Fine	Circular-Irregular/small	Deglaciated valley valley
13.	Hanging valley	Brown	Small - medium	U shape	Horns and aretes
14.	Debris fans	Gray	Fine-medium	Triangular/small-medium	Foot of the valley

A combination of above mentioned recognition elements is utilized for glacial geomorphic studies and a visual interpretation key has been generated (Table 3.3) from a standard FCC of band green, red, and near-infrared.

Visual interpretation techniques have certain disadvantages, however, in that they may require extensive training and labour intensive. In addition, spectral characteristics are not always fully evaluated in visual interpretation efforts. This is partly because of the limited ability of the eye to discern tonal values on an image and the difficulty for an interpreter to simultaneously analyze numerous spectral images. In applications where spectral patterns are highly informative, It is preferable to analyze digital, rather than pictorial, image data.

Delineation of glacial features is easy to demarcate but, identification of snout, is a difficult exercise on account of moraine cover at lower ablation zone of glacier. At the same time two dimensional satellite data does not give clear cut idea about erosional features like cirques, aretes and horns. To overcome this lacuna and for precise mapping various techniques of image processing along with SRTM DEM have been used with help of ERDAS imagine and ARC VIEW GIS software. The characteristics of satellite data and the various techniques of image processing are explained in the pages to follow.

III. 3. SPECTRAL CHARACTERISTICS OF IRS P6 LISS III

Concepts of wavelength dependency plays key role in mapping the different geomorphic features i.e. i) different features reflect different amount of energy in the same wavelength and ii) Same feature reflects different amount of energy in different wavelengths.

III. 3. A. Accumulation Zone

The glacial geomorphic studies have always been carried out from the satellite data for the period of mid august to mid October, as the glaciers are exposed to its maximum. One of the common problem faced in using this data is presence of cloud cover and sometimes cloud cover can be wrongly classified under the category of accumulation zone. Therefore, it is very essential to separate out cloud cover from the snow and ice. As the DN values for cloud cover and snow cover shows less variation in band no. 1, 2 and 3, it is very difficult to differentiate between two. The band no.4 i.e., SWIR band shows DN value of 28 for snow cover and DN value of 255 for cloud cover allows the separation in this band (Fig.3.1).

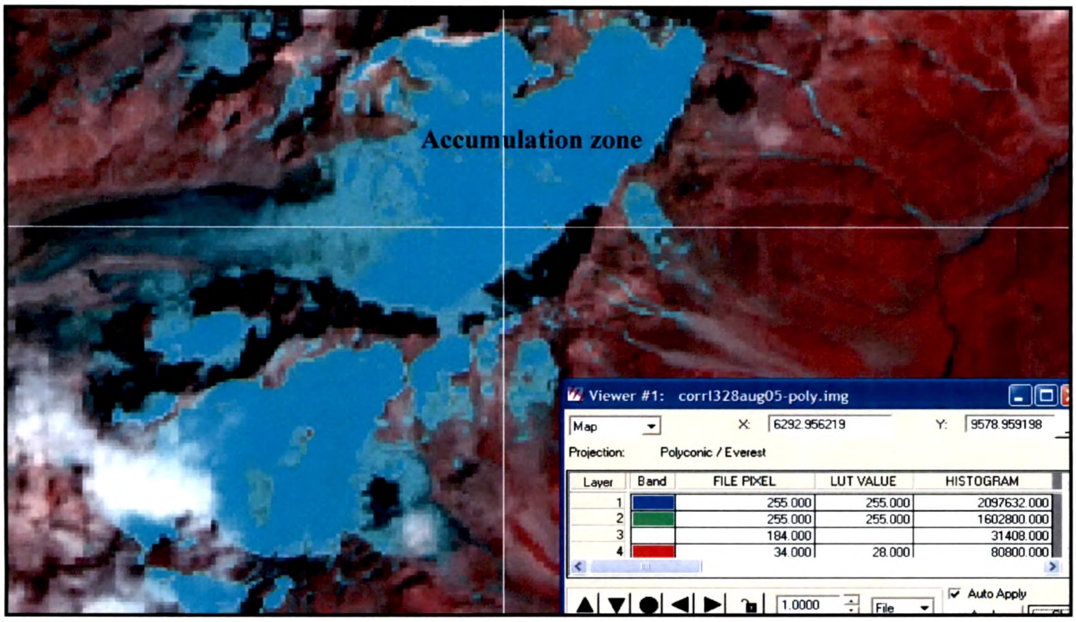


Fig.3.1. DN values for Accumulation zone in band - 4,2,1

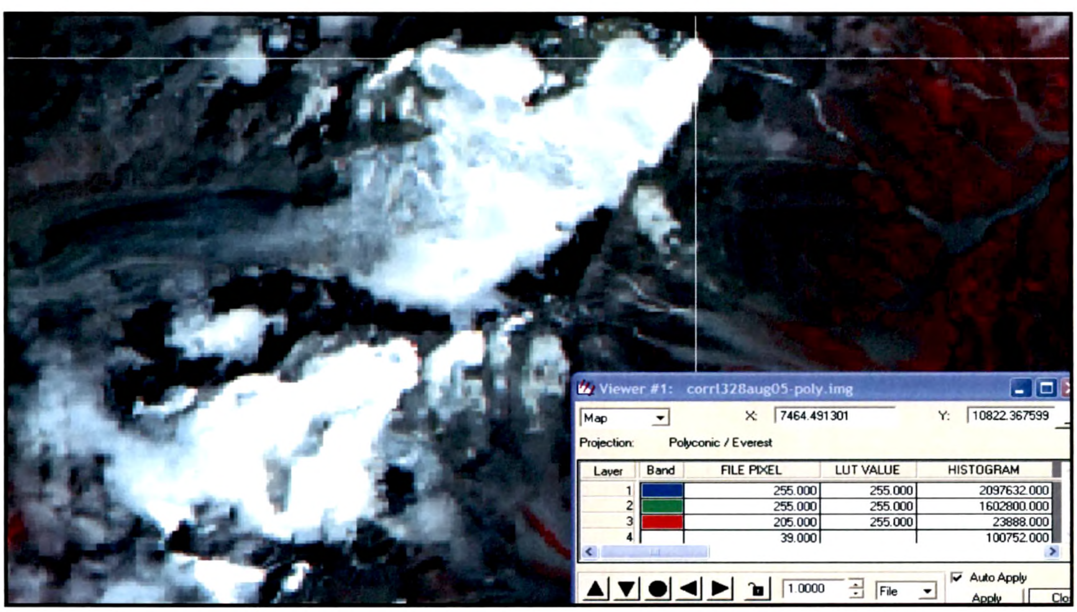


Fig.3.2. DN values for Accumulation zone in band - 4,2,1

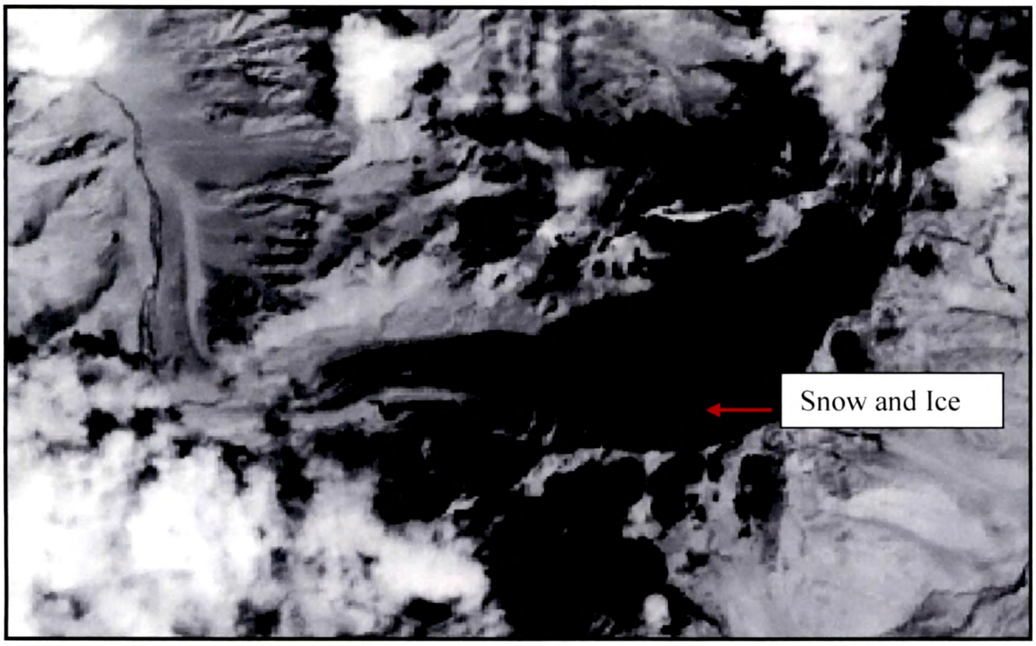


Fig.3.3. Accumulation zone in SWIR band

III. 3. B. Ablation zone

The DN values for snow (255) is much higher than the exposed ice (51-184) because the reflectivity of pure snow is higher than that of glacier ice. Therefore the boundary between snow and glacier ice can easily be identified on the image which is nothing but the snow line. Below the snow line up to glacial extent is all ablation zone. Glacier ice has lower reflectance than snow but higher than rocks and soil of surrounding area therefore it can be easily discriminated on satellite image. Sometimes there is fine debris cover on glacier ice in ablation zone which matches with exposed ice making the differentiation difficult.

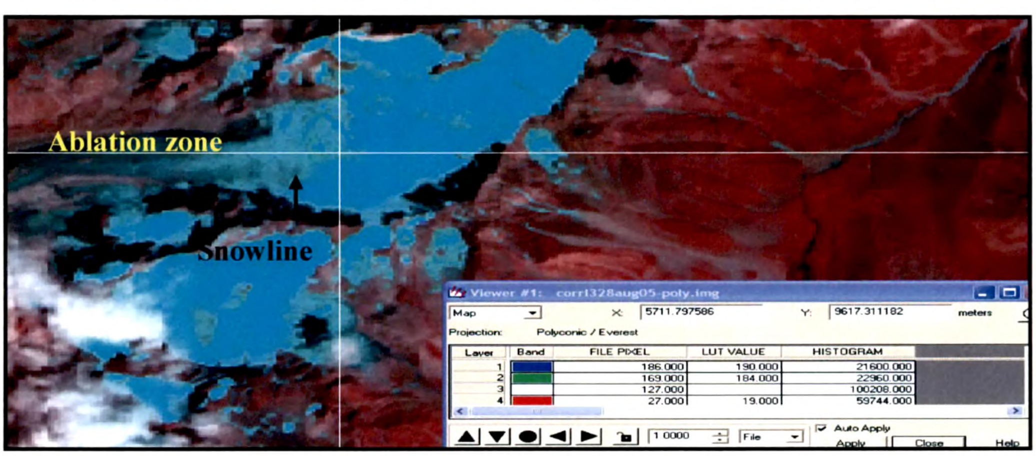


Fig.3.4. High DN values of Ablation zone near accumulation in band - 4, 2, 1

In SWIR band the energy will be absorbed by exposed ice while it will be reflected by soil and rocks, thereby, making the difference between exposed ice and debris covered ice more discernable.

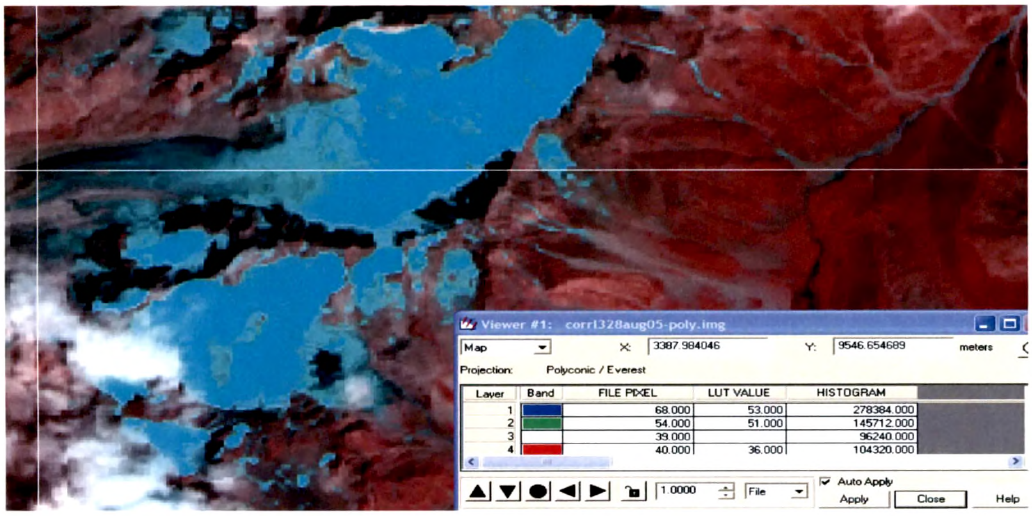


Fig.3.5 Low DN values of Ablation zone away from accumulation in band - 4,2,1

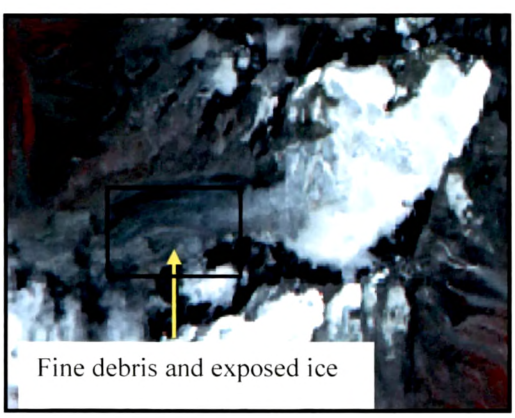


Fig.3.6. Indistinct discrimination in band 3, 2, 1

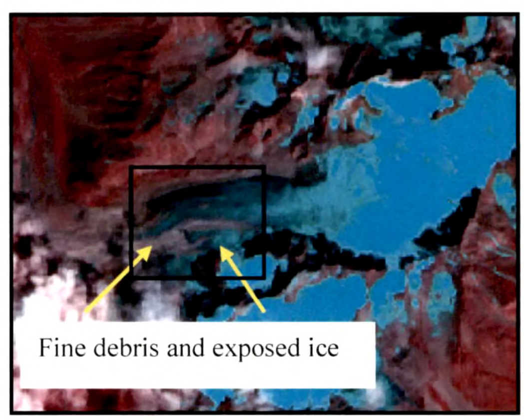


Fig.3.7. Distinct discrimination in band 4, 2, 1

III. 3. C. SNOUT

SWIR band also plays an important role in discrimination of snout because, at the terminus of glacier the stream emerging from the ice absorbs the wavelength as compared to surrounding rocks and soil, making it more discernable on the satellite image. In case of band 3,2,1 the contrast between snout and surrounding rocks and soil is not remarkable as in 4,2,1 thereby making the snout identification more difficult. The (Fig.3.8 and 3.9) shows comparison of snout visualization from band 3,2,1 and 4,2,1.

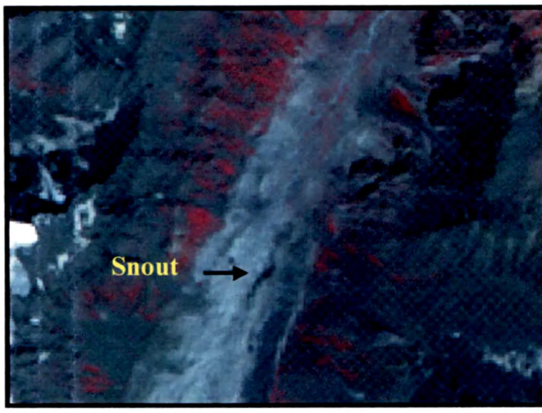
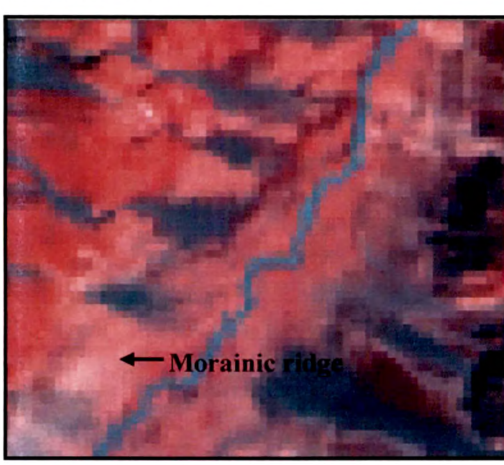


Fig.3.8. Indistinct Snout of Jorya in band 3,2,1 **Fig.3.9.** Distinct Snout of Jorya in band 4,2,1

III. 4. SPATIAL CHARACTERISTICS OF LISS III

There are certain features which are demarcated more significantly on the basis of spatial resolution than the spectral resolution e.g. morainic ridges. Spatial resolution is a measure of the smallest object that can be resolved by the sensor, or the area on the ground represented by each pixel (Simonett et al., 1983). The finer the resolution, the lower the number. For instance, a spatial resolution of 79 meters is coarser than a spatial resolution of 10 meters. Hence, Panchromatic sensor of IRS 1D is considered to have finer spatial resolution of 5.8 m. In order to get both spatial and Spectral resolution merged FCC product of IRS 1D LISS III and PAN sensor was obtained to get the advantage of spectral as well as spatial resolution. The (Fig. 3.10 & 3.11) shows comparison of LISS III+PAN merged data with LISS III data.



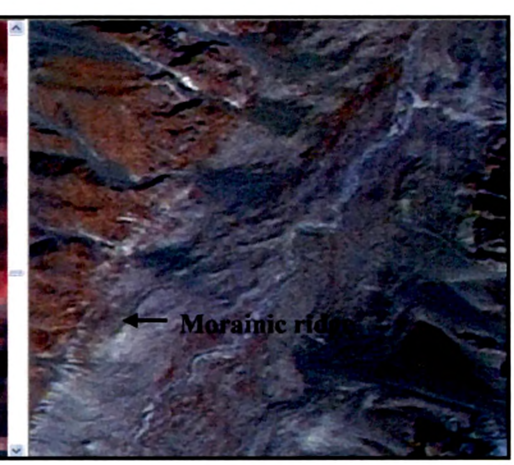


Fig.3.10. Morainic ridges from LISS III dat **Fig.3.11.** Morainic ridges from LISS III + Pan data

III. 5. GEOREFERENCING OF SATELLITE IMAGES

Any raw remotely sensed data needs to be projected in a particular system (depending upon the geographic location of study area) designed to represent the surface of a sphere or spheroid (such as the Earth) on a plane. Hence, the images were initially georeferenced by projecting it to Geographic lat/long using 1st order polynomial transformation as it is the most widely accepted projection system to represent the latitude and longitude of the earth on the image. In order to make an image conform to another image, image-to-image registration was done with already georeferenced data. Appropriate GCPs were taken where features and stream confluences were quite distinct. Also the GCPs were equally distributed covering the entire area with rms error less than 1. Now, as the image is assigned map coordinate system pertaining to the true location on the earth, so the image enhancements can be applied.

III. 6. IMAGE ENHANCEMENTS

Image enhancement is the process of making an image more interpretable for a particular application (Faust, 1989). Enhancement makes important features of raw, remotely sensed data more interpretable to the human eye. Enhancement techniques are often used instead of classification techniques for feature extraction—studying and locating areas and objects on the ground and deriving useful information from images. It improves the visual interpretability of the image by increasing the apparent distinction between the features in the scene. The mind is excellent at interpreting spatial attributes on an image and is capable of selectively identifying obscure or subtle features. However, the eye is poor at discriminating the slight radiometric or spectral differences that may characterize such features. Computer enhancement aims to visually amplify these slight differences to make them readily observable. The range of possible image enhancement and display options to the image analyst is virtually limitless. Choosing the appropriate enhancements for any particular application is an art and often a matter of personal preference (Lillesand and Kiefer, 2002). Accordingly various image enhancement techniques applied for present glacial Geomorphological studies is described in brief.

III. 6. A. Radiometric Enhancement

This process includes the enhancement of images based on the values of individual pixels. Methods of radiometric enhancement are discussed below.

III. 6. A.i. Contrast Stretching

The contrast stretch expands the narrow range of brightness values typically present in an input image over a wider range of gray values. The result is an output image that is designed to accentuate the contrast between the features of interest. A linear contrast stretch is applied to present image to expand the narrow range of DN to value of 0-255. This process does not provide any additional information for mapping the various landforms (Fig.3.13)

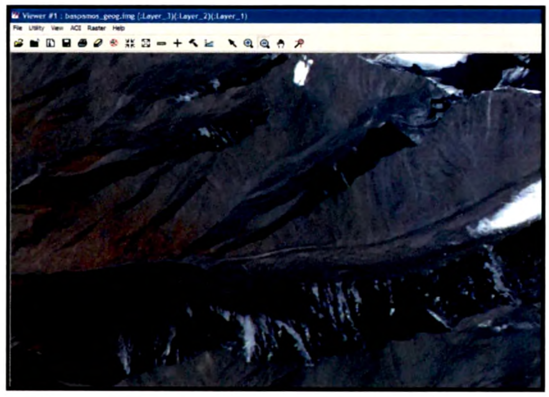


Fig.3.12. Original image

Fig.3.13. contrast stretch image

III. 6. A.ii. Histogram equalization

It is a type of nonlinear stretch in which image values are assigned to the display levels on the basis of their frequency of occurrence. More display values are assigned to the frequently occurring portion of the histogram thereby revealing its additional radiometric detail. The histogram equalization which is applied to LISS III + PAN data, reflect increase in the visibility of morainic ridges and deglaciated valley for Shaune garang glacier (Fig.3.14).

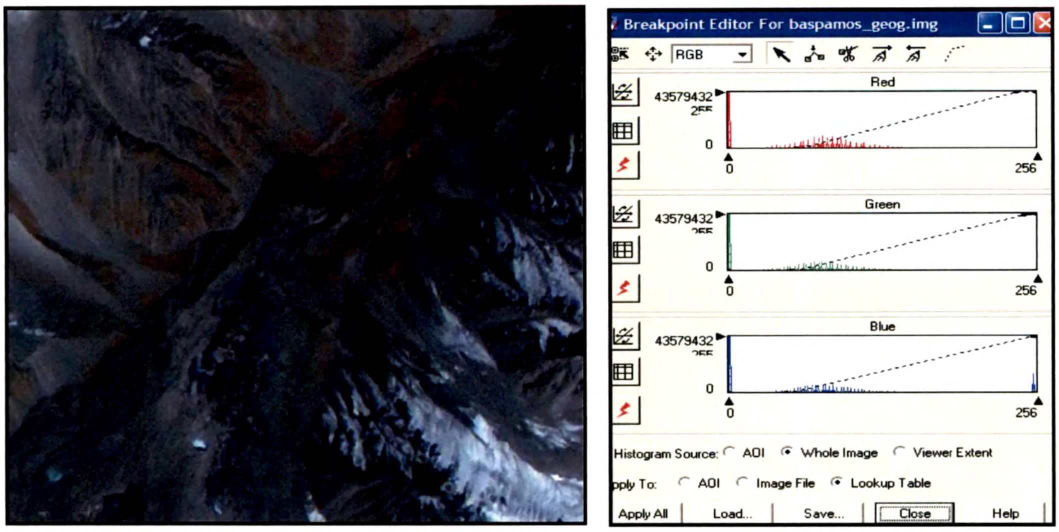


Fig.3.14. Indistinct morainic ridges and deglaciated valley in original image

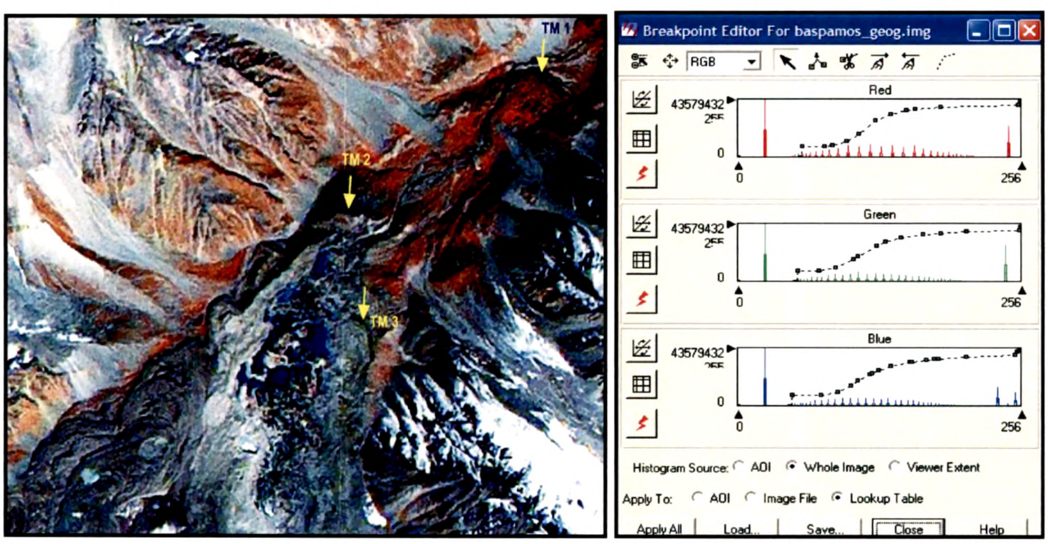


Fig.3.15. Distinct morainic ridges and deglaciated valley after Histogram equalization

III. 6. B. Spatial enhancement

Spatial frequency refers to the roughness of the tonal variations occurring in an image. Image areas of high spatial frequency are tonally "rough" i.e., the gray levels in these areas change abruptly over a relatively small number of pixels (e.g. rivers, morainic ridges, glacial boundaries, snout). "Smooth" image areas are those of low spatial frequency where gray levels vary only gradually over a relatively large number of pixels. (e.g., accumulation zone, water bodies, deglaciated valleys).

Low pass filters are designed to emphasize low frequency features and deemphasize high frequency components. High pass filters emphasize high frequency components and deemphasize more general low frequency detail (Lillesand and kiefer, 2002). The result of above filters applied on the image is as shown in (Fig. 3.17 and 18)

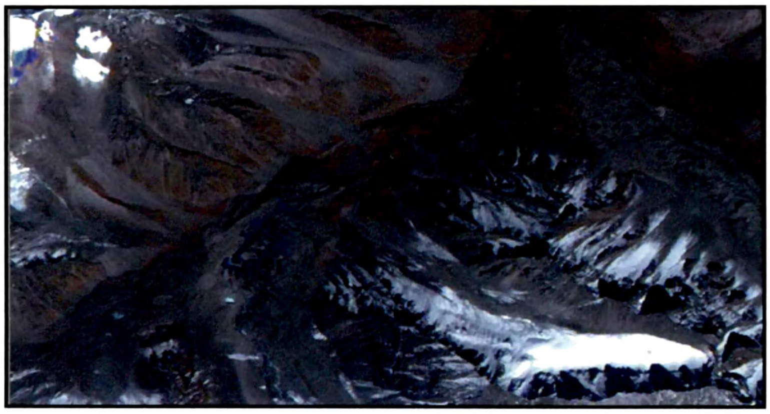


Fig.3.16. Original image before enhancement

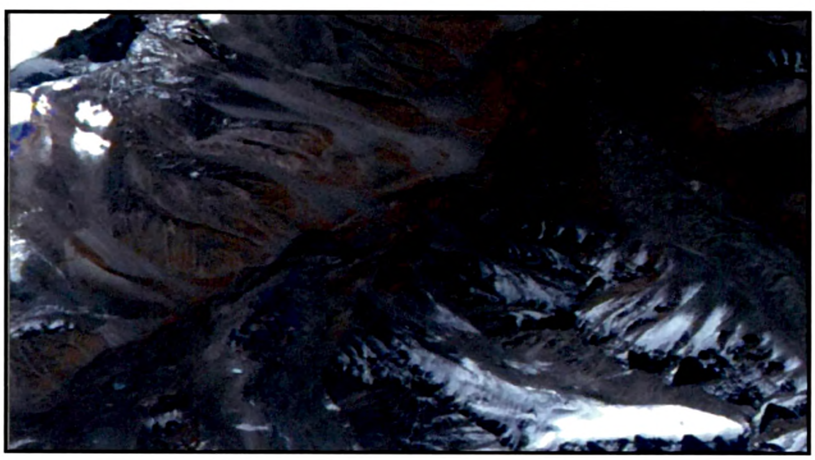


Fig.3.17. Low frequency component image.

After applying low pass filter no significant additional information can be generated except smoothening of the image (Fig.3.16).

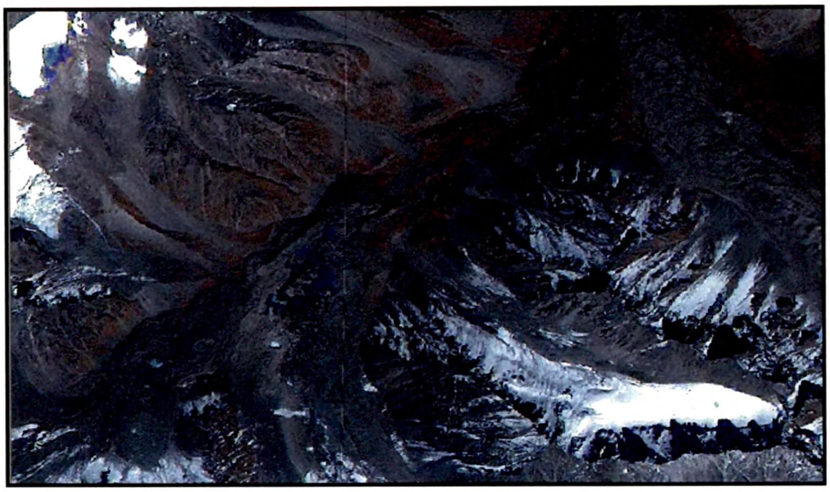


Fig.3.18. High frequency component image.

After applying high pass filter to the original image, the image has sharpened and gained some contrasts. Hence, interpretation of deglaciated valleys and morainic ridges becomes much a easier task (Fig.3.17).

III. 6. B.i. Edge enhancement

It is an image enhancement which includes local contrast enhancement of high frequency features that also preserves the low frequency brightness information contained in the scene. Edge enhanced image shows better identification of linear/non-linear glacial geomorphic features such as morainic ridges, drainages and glacial maxima for Jorya garang glacier. (Fig.3.19 and 3.20).

Fig.3.19. Indistinct stages of Lateral and Terminal moraines before edge enhancement

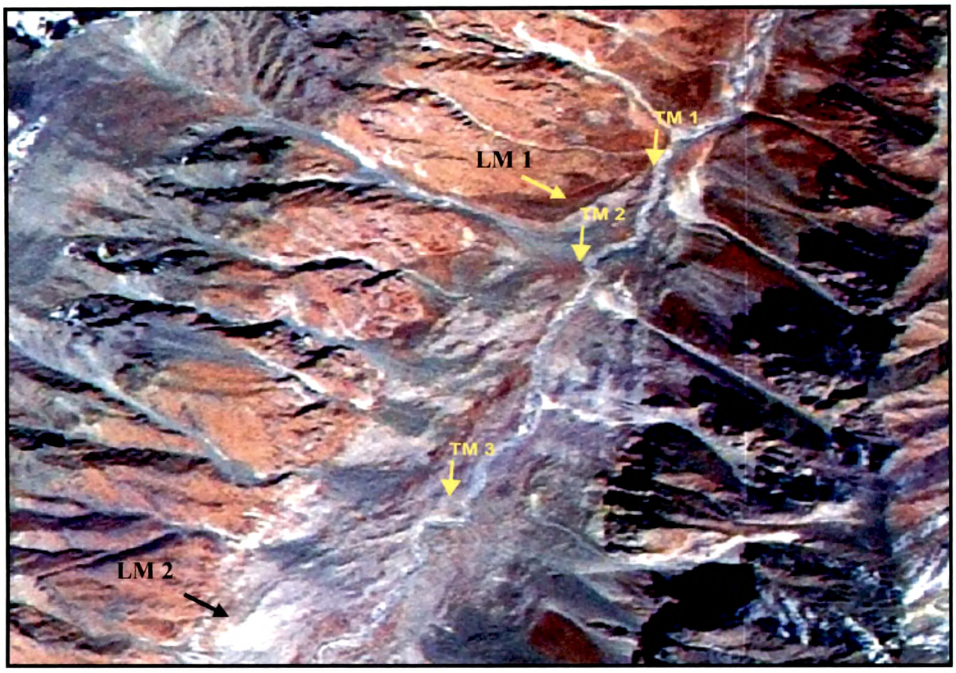


Fig.3.20. Distinct stages of Lateral(LM) and Terminal moraines (TM) after edge enhancement

III. 6. C. Principal Component Analysis

Principal components analysis (PCA) is often used as a method of data compression. It allows redundant data to be compacted into fewer bands—that is, the dimensionality of the data is reduced. Although there are *n* output bands in a PCA, the first few bands account for a high proportion of the variance in the data—in some cases, almost 100%. Therefore, PCA is useful for compressing data into fewer bands.

In other applications, useful information can be gathered from the principal component bands with the least variance. These bands can show subtle details in the image that were obscured by higher contrast in the original image. The principal component analysis was applied to LISS III data of IRS P6 for Shaune garang glacier with an idea to bring out certain geomorphic features such as snout which is usually difficult to identify in presence of high debris cover. The results obtained after applying pca upto level 4 is as shown in (Fig.3.22)

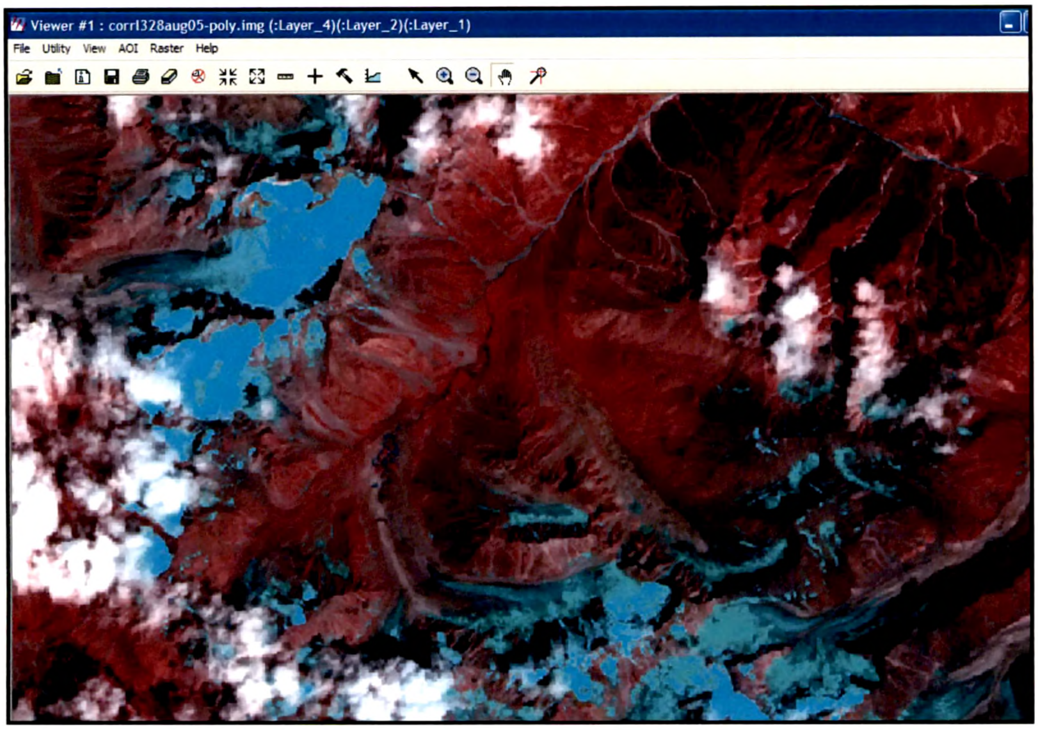


Fig.3.21. Original image before applying Principal Component Analysis

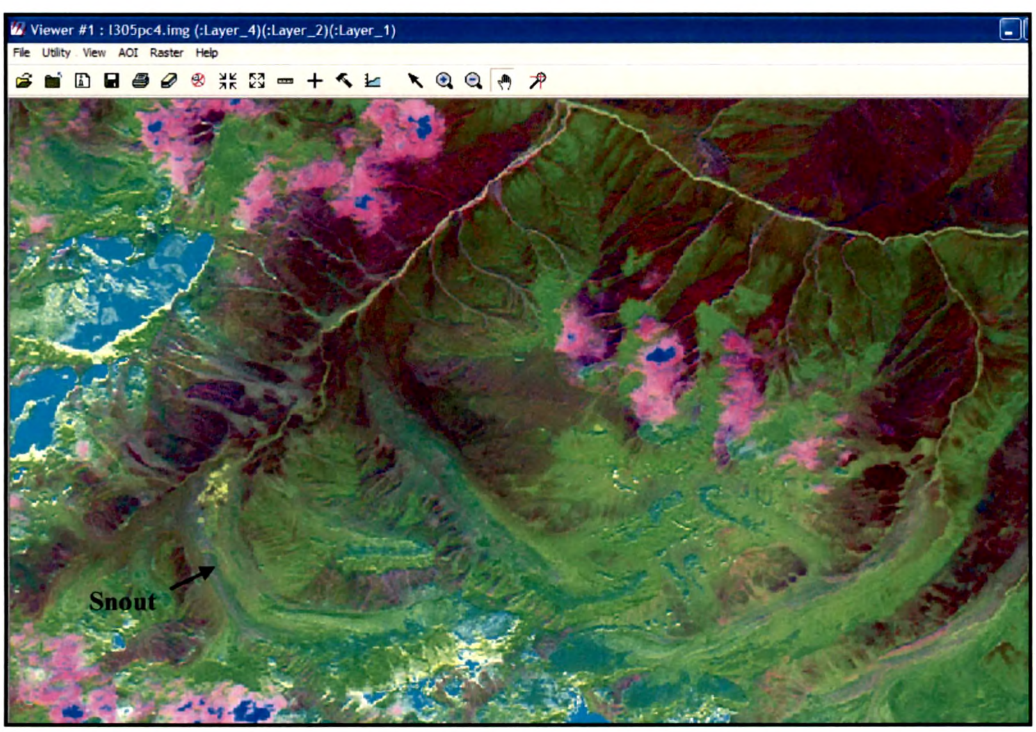


Fig.3.22. In PC-4 Snout becomes more distinct

III. 6. D. INDICES

Indices are used to create output images by mathematically combining the DN values of different bands. These may be simplistic:

*(Band X - Band Y)*or more complex:

$$\frac{Band\,X - Band\,Y}{Band\,X + Band\,Y}$$

In many instances, these indices are ratios of band DN values:

$$\frac{Band\,X}{Band\,Y}$$

These ratio images are derived from the absorption/reflection spectra of the material of interest. The absorption is based on the molecular bonds in the (surface) material. Thus, the ratio often gives information on the chemical composition of the target. Here, we have used band ratioing using NDVI but with changing band combinations to see the changes in image and try to see if any meaningful information is coming out of it or not.

The formula for NDVI is:

$$\frac{IR - R}{IR + R}$$

But, we have used various combinations for IRS P6 LISS III whose results are shown in (Fig. 3.23, 3.24 and 3.25)

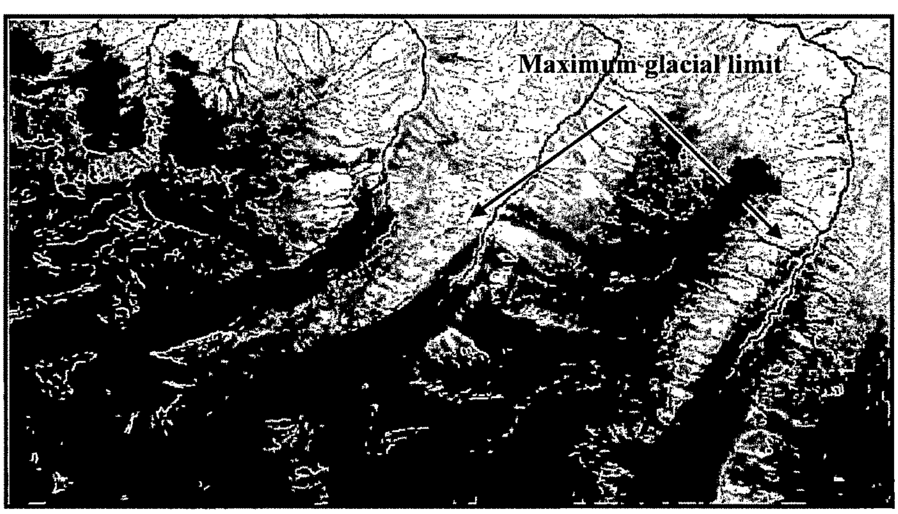


Fig.3.23. Extent of maximum glacial limit is very clear.
In this case band ratio of 4-2/4+2 was used due to which glacial limit became distinct.

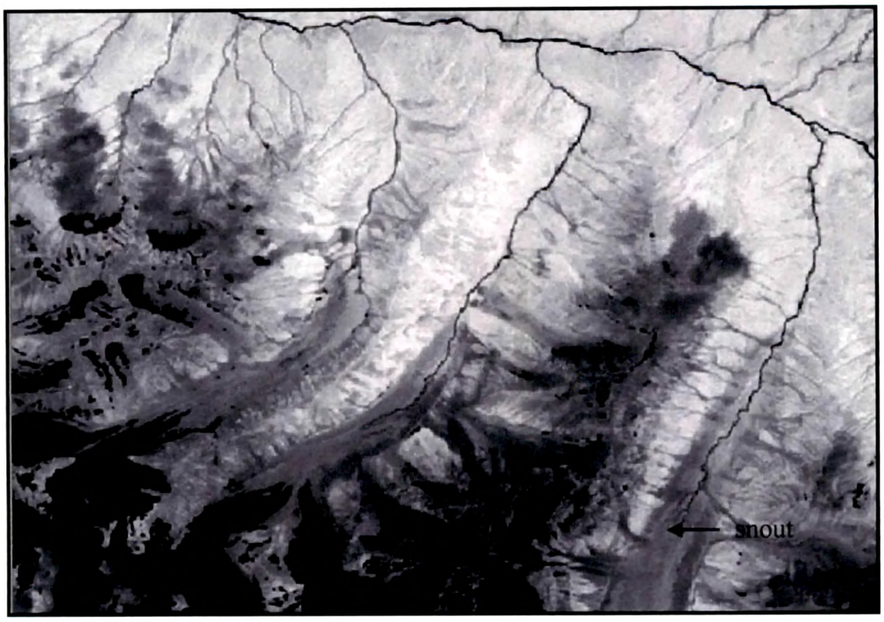


Fig. 3.24. Stream becomes more prominent .
In this case band ratio of 4-1/4+1 was used due to which streams became distinct.

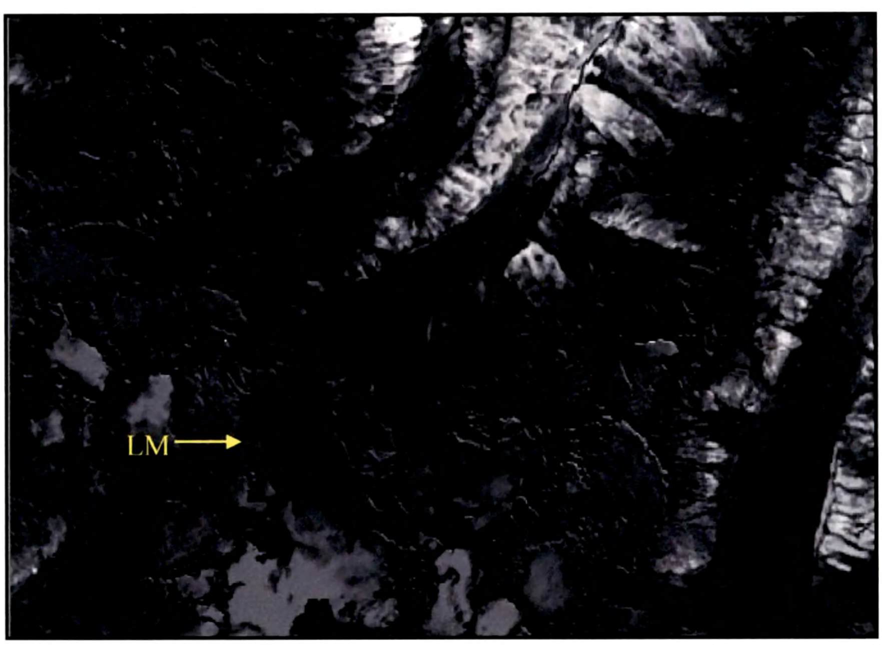


Fig. 3.25. Lateral moraines becomes more prominent .
In this case band ratio of 3-1/3+1 was used due to which Lateral moraines became distinct.

III. 7. CONCLUSION

The final glacial geomorphological maps and glacial geomorphic inventory was generated taking into account above mentioned visual interpretation key as any single technique of image processing failed to give all the required information about all glacial geomorphic features which we now already know from the results described in image enhancements used for this study. Cirques, hanging glaciers, and slope were difficult to be identified on the two dimensional satellite data so the help of SRTM DEM was incorporated which made its identification and interpretation easy. Maximum glacial limit became more distinct by using ndvi in Indices of spectral enhancement. Stages of moraines were easily demarcated after using Histogram equalization. So the technique in which the best result was obtained in terms of feature identification was selected and accordingly interpreted giving appropriate results.

III. 8. GEOGRAPHIC INFORMATION SYSTEM (GIS)

GIS is defined as "A powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world" (Burrough, 1987).
In present study the vectorization over raster data have been carried out in ARC VIEW-GIS Environment. Here, all the area features (accumulation zone, ablation zone,deglaciated valley etc), point features (snout), linear features (terminal moraines, crevasses, etc) have been digitized in ARC VIEW environment. The non-spatial attribute data for each geomorphic features was stored and retrieved in the database.

SRTM DEM was downloaded from (http://srtm.csi.cgiar.org) and it was then imported to img. format in ERDAS imagine. A Slope map was prepared in topographic analysis module of ERDAS. Here the DEM image was given as input and output option was selected for slope to be in degrees. After that the module was run and it gave the slope of Baspa valley (Fig 3.26).

In ERDAS itself using GIS different themes were prepared viz.,

1] Satellite data of LISS III + PAN

2] Satellite data of LISS III, 2005

3] Satellite data of LISS III, 2001

4] Geomorphic features prepared from satellite data

5] DEM and

6] Slope map

An area – area overlay analysis was carried out in order to know the changes and to retreive the information. The Geomorphological maps are prepared in ARC VIEW while 3D view of each glacier is shown by draping satellite data over SRTM DEM to visualize the geomorphic features like cirques, horns and aretes. The results obtained and the information generated after using remote sensing and GIS techniques, is presented in the form of maps and Glacier Geomorphic Inventory under Chapter IV.

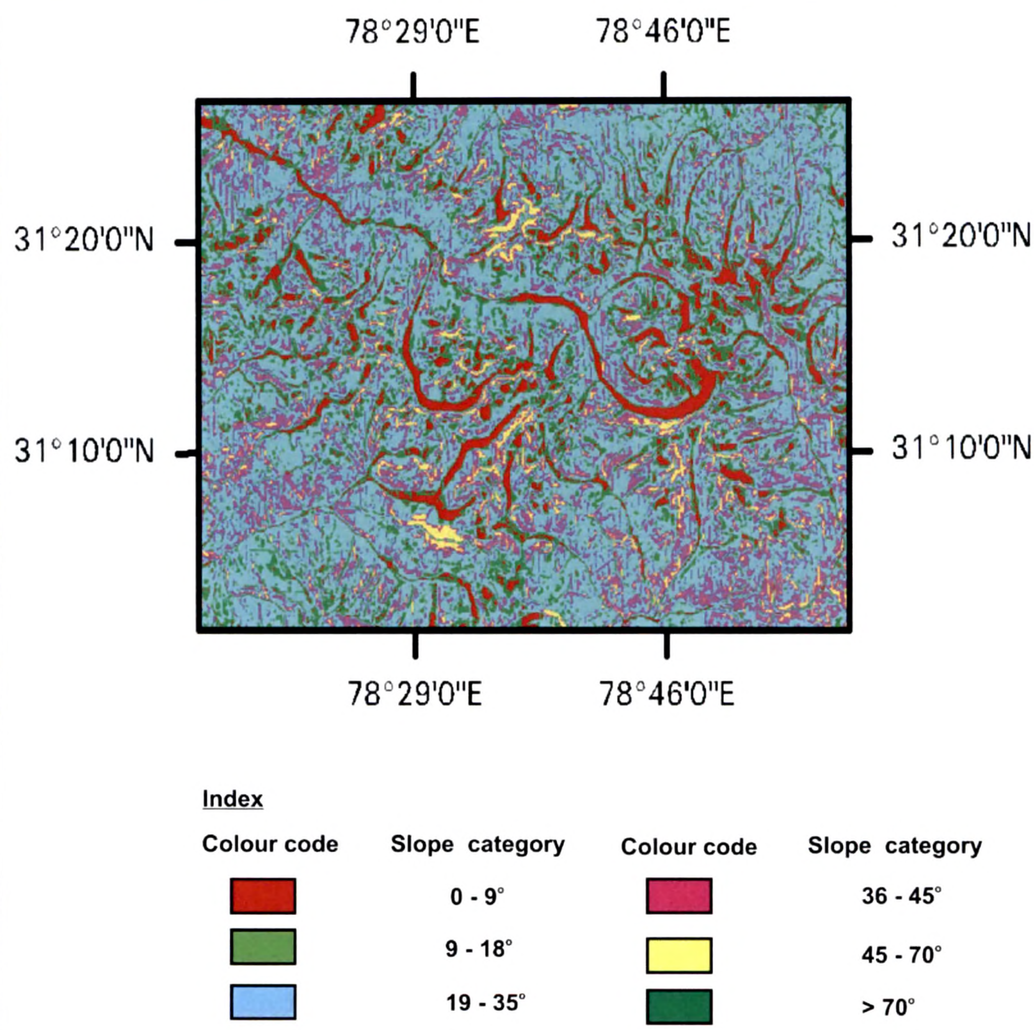


Fig. 3.26 Slope map of Baspa valley