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Digital Elevation Model Generation and Retrieval of Terrain Attributes using CARTOSAT-1 Stereo Data

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ABSTRACT

Terrain analysis is a very important part of the study of surface processes. Although several techniques have been used historically to study terrain, the use of satellite imageries has become one of the optimum methods now. Presently there are lots of satellite imageries available for extraction of elevation features microwave optical etc. The stereo pair images have a great potentiality in the study of terrain analysis. The present study deals with the generation of Digital Elevation Model (DEM) using CARTOSAT-1 stereo data and retrieval of terrain attributes thereof for western Dehradun area. Initially the DEM is generated and the vertical accuracy was analysed. Additionally, contour and primary attributes (slope and aspect) are derived for further analysis. A three dimensional view is also generated in order to visualize the terrain perspective view.

Keywords: *DEM, CARTOSAT-1, Slope, DEM accuracy, Terrain*

I. INTRODUCTION

In earth sciences, the morphology of terrain plays a significant role. Therefore, a proper understanding of the terrain characteristics is essential for any scientific pursuit. Historically, several techniques have been used for this purpose. Some of these techniques include field-based methods like triangulation, interpolation, extrapolation etc. Despite the high accuracy that is achievable, a major drawback of these methods is that they are time-taking and often, cumbersome. In the last few decades, however, the advent of geospatial technologies has provided a simpler way of characterizing terrain attributes through the use of satellite imageries. Light Detection and Ranging (LiDAR) is highly accurate but the data is not easily available and the cost is often prohibitive. Various open source Digital Elevation Models (DEMs) are available, but their resolution range from being moderate to coarse. The Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) was released on October 17, 2011 by the Ministry of Economy, Trade, and Industry (METI) of Japan and the National Aeronautics and Space Administration (NASA). These elevation model data covers almost the entire world. It has a spatial resolution of 30 meters which is very effective for terrain analysis studies, especially in comparison with the previously available Shuttle Radar Topography Mission (SRTM) data which has a spatial resolution of 90 m for the rest of the world, except USA [1].

Optical stereo images as well as Synthetic Aperture Radar (SAR) images are being used to extract the terrain information. High-resolution stereo imaging satellites are a valuable tool for topographic mapping and map updating [2]. There are stereo optical satellite images like IKONOS and CARTOSAT, which have high spatial resolution and the accuracy of the derived products is also very good. The DEMs derived from these images and the attributes extracted from them are important parameters for gathering information regarding a phenomenon and predicting its future behaviour using geospatial modeling.

2. DIGITAL ELEVATION MODELS

A DEM is a quantitative, three-dimensional representation of the earth surface derived from elevation data. It provides basic information regarding terrain characteristics. The primary attributes, which can be derived from the DEMs, are slope, aspect, profile curvature and catchment area. The secondary attributes, which can be derived from a DEM, are upslope area, topographic index, stream power index, radiation index and temperature index [3]. A DEM is typically given in one of the three formats: the raster-based grid DEM, the vector-based Triangular Irregular Network (TIN) and contour-based storage structure. The TIN is considered to be a primary (measured) DEM while the grid DEM is considered to be a derived (secondary) DEM [4]. When a DEM represents the Earth’s surface including object height (tree height, building height etc.), it is often referred to as a Digital Surface Model (DSM). A model of the bare Earth surface is referred to as a Digital Terrain Model (DTM) [5]. Several methods have been applied for DEM generation such as photogrammetry using stereo data, interferometry, airborne laser scanning and interpolation of contour maps. In this paper, an attempt has been made to generate a DEM and derive some of the terrain characteristics for the western part of Dehradun area in Uttaranchal, India using CARTOSAT-1 data. After an assessment of accuracy of the generated DEM and the attributes derived from it, some preliminary observations about the surface configuration of the study area are made using these attributes.

3. STUDY AREA

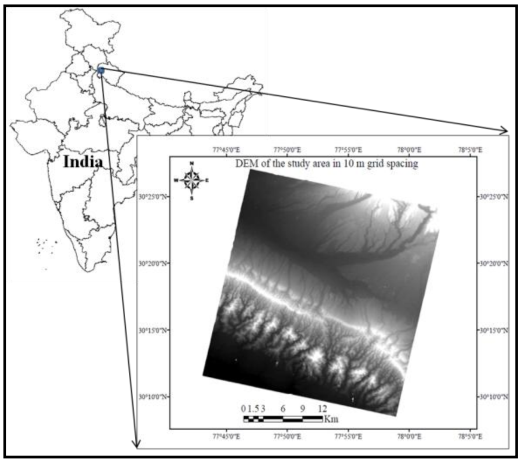

Figure 1: Study Area

The western part of Dehradun area in the state of Uttaranchal (Fig. 1) has been selected as the study area for this paper. Geographically, it extends from 30˚8′30″ N to 30˚27′3″ N and 77˚43′2″ E to 78˚2′52″ E. The entire area is composed of hills and valleys and consequently, significant relief variations are present in it. Therefore, it is a very suitable area for the derivation of terrain attributes.

4. METHODOLOGY

The present study demonstrates the process of DEM generation using CARTOSAT-1 stereo data and the primary terrain attributes retrieval. The process and algorithm used are discussed in detail.

4.1 DEM Generation

High resolution (2.5m) CARTOSAT- 1data was used in this study. CARTOSAT- 1 satellite is a dedicated along-track stereo mission that provides high quality data for topographic and cartographic applications [6]. It has a forward (F) and aft (A) panchromatic camera which gives the along track stereo, with a tilt in flight direction of +26º and -5º respectively [7]. The high-resolution stereo data beamed from twin cameras on board enables the Cartosat-1 mission facilitates topographic mapping up to a scale of 1:25 000. A stereo imagery, dated 2nd October 2005 (path / row: 0526 / 0258) and having a swath of 27 km x 27 km was used for generation of DEM. To generate DEM out of a stereo pair, it is first necessary to orientate the pair. It solves the basic problem of determining the space coordinates (x, y and z) of a point in the image. Two main types of orientation are needed- interior and exterior orientations. Interior orientation reconstructs the position of perspective centre of the sensor with respect to image. It usually defines the internal geometry of a camera or sensor as it existed at the time of data capture. It includes parameters for detector positions, principal point, focal length optical distortion etc. [8]. Exterior orientation reconstructs the position, inclination and rotation of the sensor with respect to terrain coordinate system for each line of data. It defines the position and angular orientation associated with an image and builds the relationship between sensor and ground. The exterior orientation parameter includes position and altitude. The Global Positioning System (GPS) receivers that are on the satellite are used for determining the satellite ephemerides i.e. camera position with time, star tracker and gyros onboard measures camera attitude as function of time [8].

CARTOSAT-1 stereo data comes with Rational Polynomial Coefficients (RPCs). RPCs comprise of satellite ephemerides as well as Ground Control Points (GCPs). It has an advantage that it allows satellite vendor to withhold certain confidential sensor information without denying the public use of the satellite imagery [9]. Leica Photogrammetry Suite (LPS) 9.2 has been used in this paper for the orientation of the stereo block. Initially stereo block is oriented with RPCs. Then GCPs were added in the stereo model to avoid systematic error. 31 well distributed GCPs over the scene were collected using a Differential Global Positioning System (DGPS) system in the Dehradun area. 15 GCPs were used as control points and 5 GCPs were used as a check points in order to orient the stereo model. Using the oriented stereo block, DEM at 10 m grid size has been generated.

4.2 Computation of Terrain Attributes

The main terrain parameters derived from DEMs are slope and aspect. These parameters are local description of downhill slope; in that sense they are magnitude and direction of the vector tangent to the downhill. In this study only magnitude of the terrain inclination i.e. accuracy of slope is evaluated from multiple DEM representations. The algorithm for calculation of terrain attributes are discussed in this section.

4.2.1 Slope

At a given point on a surface, height value is Z = f (x, y). The first derivative of elevation describes the rate of change of elevation, which is the slope. Together, the slope in the x direction and slope in the y direction (partial derivatives of z with respect to the x and y directions), define the gradient vector of the surface. The maximum slope can be determined by taking the norm of this vector. On a grid DEM, slope calculation is performed using 3x3 moving window to derive finite differential. In this study second order finite difference is being used. Four Closest Neighbors (FCN) algorithm (*Guth, P. L. 1995,Raaflaub and colloins. 2006*) has been used for computing the slope. It takes into account two orthogonal components of slope, slope in x direction and slope in y direction. In other words, the algorithm used the four cardinal neighbors i.e. North, South, East and West representing a second order finite difference relationship. This defines the steepness and downhill direction. The algorithm is described below:

$$\text{Slope} = \sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2}$$

$$\text{where, } \frac{dz}{dx} = (z_8 - z_2)/2g \;\&\; \frac{dz}{dy} = (z_6 - z_4)/2g$$

4.2.2 Aspect

Aspect is the direction of the maximum slope. It is the angle between the slope defined in x and the slope defined in the y direction. Aspect calculation is carried out based on Four Closest Neighbors (FCN) algorithm [11] using 3x3 moving window. This defines the steepest and downhill direction. The algorithm is described below:

$$\text{Aspect} = \tan^{-1}\left(\frac{dz/dx}{dz/dy}\right)$$

$$\text{where, } \frac{dz}{dx} = (z_8 - z_2)/2g \;\&\; \frac{dz}{dy} = (z_6 - z_4)/2g$$

5. RESULTS & DISCUSSION

5.1 DEM validation and visualization

After orientating the CARTOSAT-1 stereo pair using RPCs and GCPs, a DEM at 10 m resolution is generated. As the GCPs have been used to orient the stereo block, systematic error is minimized and 1.06 pixels triangulation accuracy has been achieved. The DEM is shown in Fig. 2.

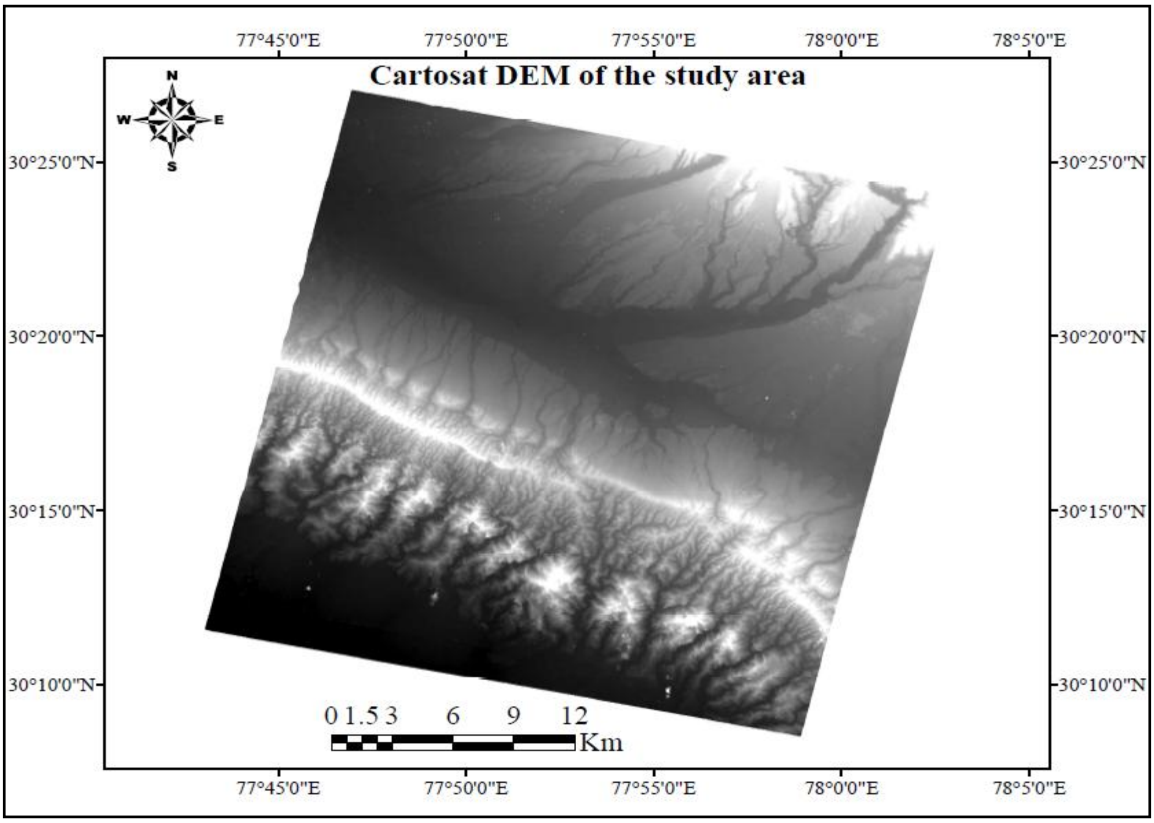

Figure 2: The 10 m Resolution DEM Generated from CARTOSAT- 1 Data

The vertical accuracy of the DEM affects the calculation of terrain attributes. In the present study, the vertical accuracy of generated DEM is checked using the remaining 11 GCPs (those not used for DEM generation). The result is shown in the Table 1. It has been found that the average vertical error is 3.6 m (calculated from absolute difference) with standard deviation of 2.04 m.

Altitudinal zone of the entire study area has been created using DEM. The entire scene area is divided into 6 altitudinal zones and the % of area to total area failing within the zone is calculated (Fig. 3). It appears that most of the area is located at 500 m above mean sea level. The mean and variance of elevation in each altitudinal zone is given in the Table-2. The variance of elevation increases with higher altitudinal zones signifying an increase in the surface roughness.

Table 1: Vertical Accuracy of the Generated DEM

POINT_ID	Z - GCP	Z - DEM	Error in DEM
Point 1	454.65	456.28	-1.63
Point 2	648.50	643.32	5.17
Point 3	492.87	494.12	-1.25
Point 4	490.26	482.76	7.50
Point 5	480.39	482.69	-2.30
Point 6	467.71	464.66	3.05
Point 7	371.58	373.54	-1.96
Point 8	371.40	376.57	-5.17
Point 9	775.17	768.77	6.39
Point 10	364.73	366.36	-1.63
Point 11	433.73	437.28	-3.55

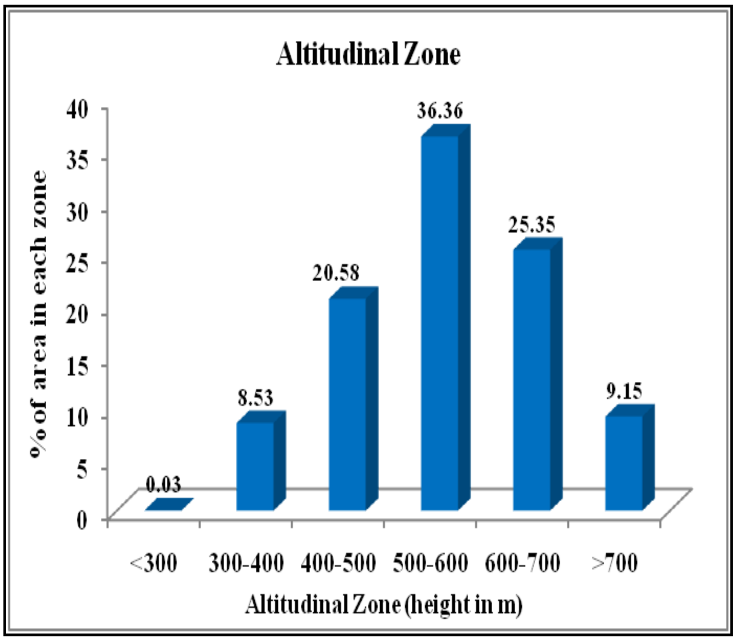

Figure 3: Altitudinal Zones of the Study Area

Table 2: Statistical Characteristics of the Altitudinal Zones

Altitudinal Zone (m)	Mean Elevation (m)	Variance of Elevation (m)
<300	295.02	6.02
301-400	330.66	15.29
401-500	411.57	31.78
501-600	511.38	29.41
601-700	602.20	28.42
> 700	714.16	47.28

Visualization of the terrain is also an important aspect of terrain analysis. Hence, a three-dimensional view of the study area is generated (Fig. 4). It shows that northern part of the study area is hill and the middle part is dominated by the ridge which is dissected by the rivers. The foot hill zone is the river valley region and the southern part is plain region.

Contour maps of the study area are generated from the DEM. As the resolution of the DEM is 10 m, the contour intervals are selected at 10 m, 20 m and 50 m resolution. Contour map is superimposed on DEM and a part of the study area is shown in Fig. 5. It shows that as the contour interval increases, the representation of the details becomes difficult. In the 10 m contour map, all the minute details can be mapped but in 50 m contour map, only the major variations can be seen. From the 10 m and 20 m contour maps river valley, channel and hills can be easily identified which is difficult from the 50 m contour map.

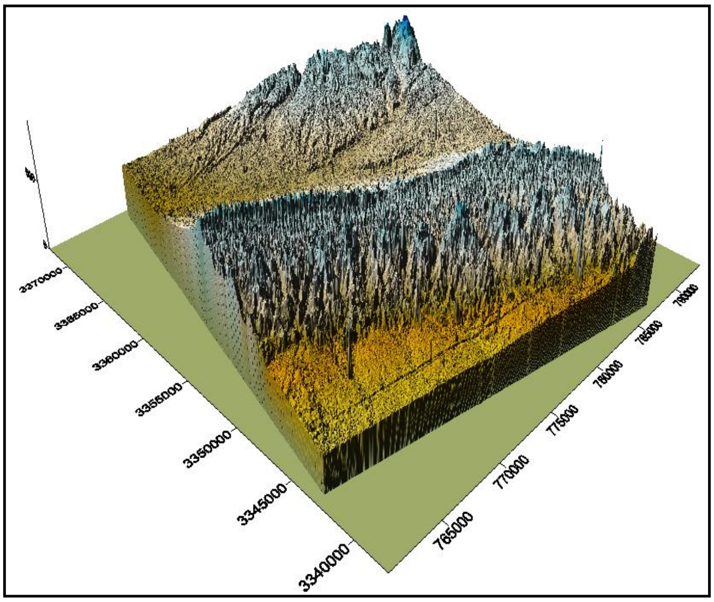

Figure 4: Three-Dimensional Visualization of the Study Area

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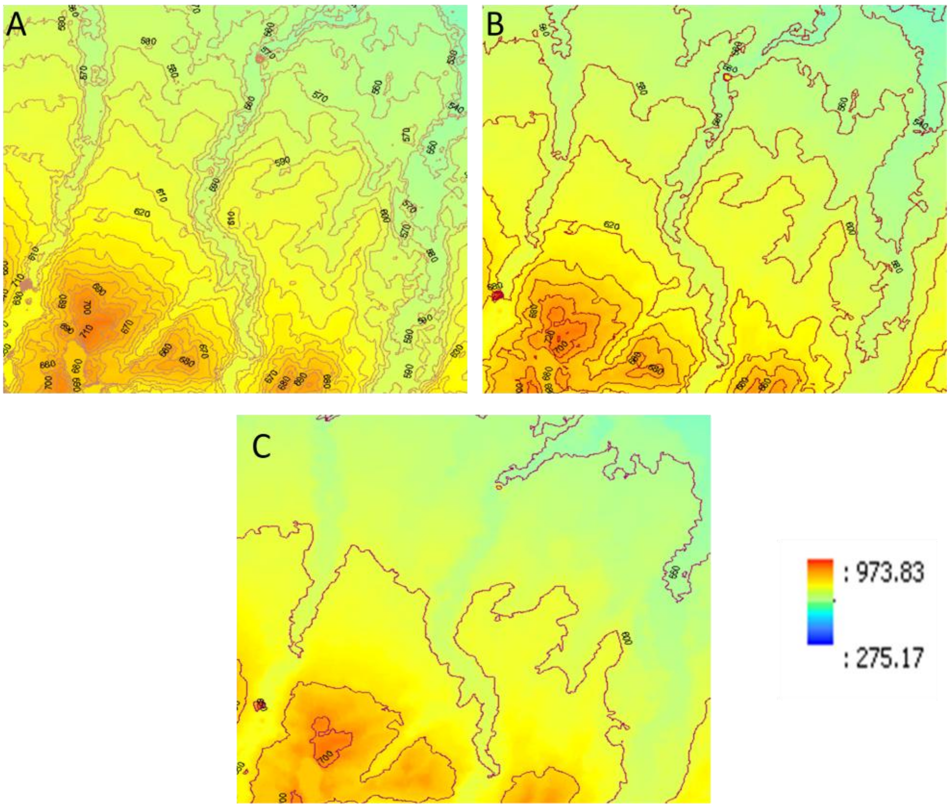

Figure 5: Contour Maps for the Study Area at 10 m (A), 20 m (B) and 50 m (C) Contour Intervals

5.2 Retrieval of Terrain Attributes

Slope and aspect are the most important primary attributes that can be derived from a DEM and are used widely in geomorphometric analysis and hydrological modeling. A slope map for a part of the study area is generated from the DEM and is shown in Fig. 6. It is seen that the slope varies from 0° to 85°. The mean slope is 10.82º and standard deviation is 11.77. The terrain is dominated by hills and ridges and thus the slope of the surface is higher. The variation of slope is also high which indicates that the terrain is rugged. The terrain is classified based on slope and five classes are considered. The areal distribution of the slope is given in the Fig. 7, which shows that 44% area is having less than 5º slope and 72% of the whole scene is having slope value less than 15º. Approximately 3% area is located in high slope (>40º).

An aspect map, for the same part as for slope, is also derived from the DEM and is shown in Fig. 8. Aspect shows the direction of the maximum slope which is essential for the hydrological process simulation. Eight cardinal directions of 45º apart (N, NE, E, SE, S, SW, W and NW) are considered in this study. The distribution of the aspect (number of pixels represents each direction) is shown (Fig. 9) in the star diagram.

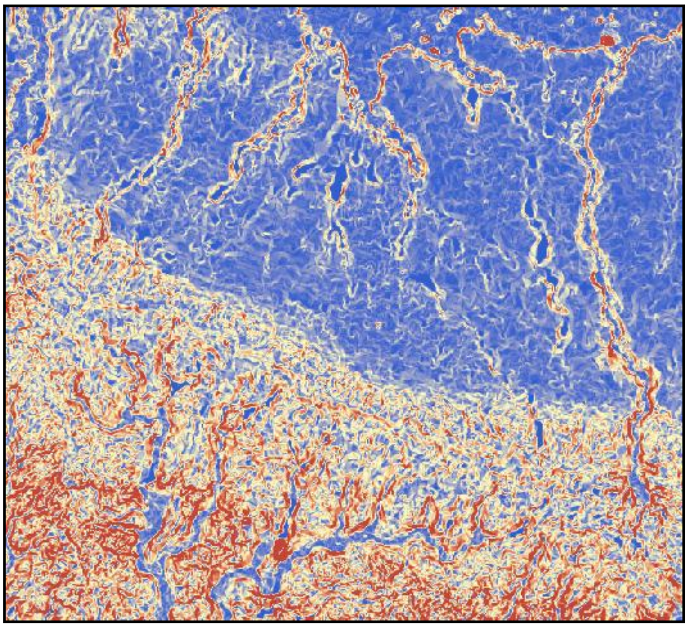

Figure 6: Slope Map of a Part of the Study Area Generated from the DEM

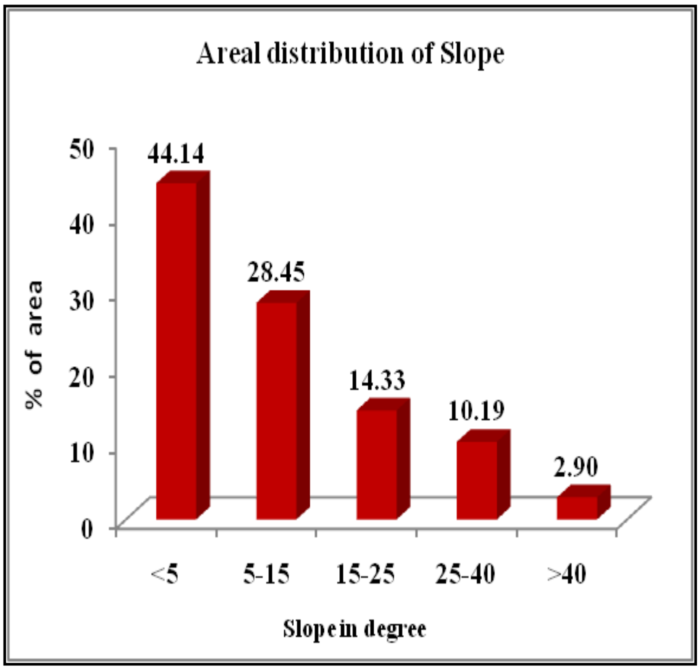

Figure 7: Percentage of Study Area Falling Under Each Category of Slope

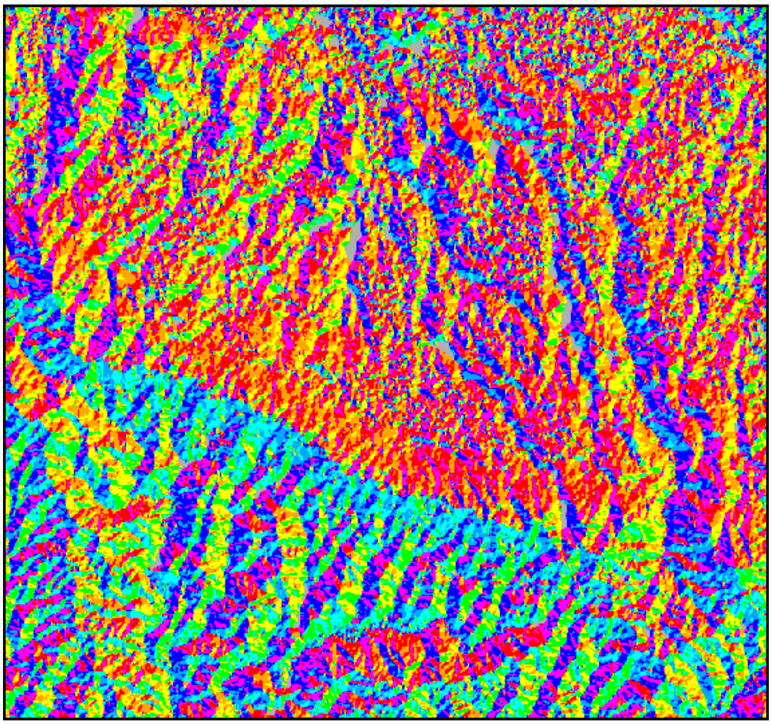

Figure 8: Aspect Map for the Part of the Study Area in Figure 6 Generated from the DEM

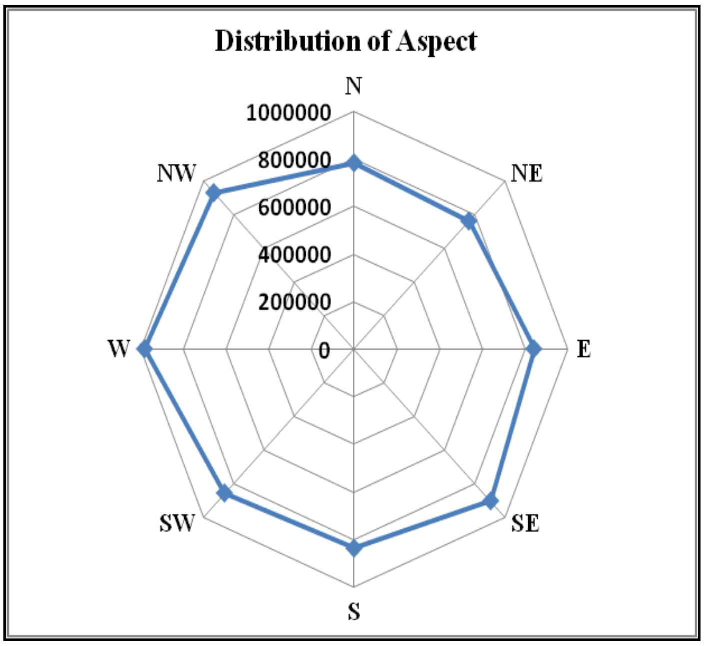

Figure 9: Distribution of the Aspect

6. CONCLUSIONS

The advantage of the CARTOSAT-1 data is that it gives along-track stereo pair at same time, which is used for DEM generation. The DEM could be used for terrain mapping, map updating, natural hazard monitoring, large construction work and hydrological studies. The accuracy of the CARTOSAT-1 DEM is much higher and it is also depends on morphology of the terrain. GCPs are needed to achieve the higher accuracy during the orientation of stereo block to avoid the systematic error.
The importance of DEMs in earth sciences can hardly be overemphasized. However, higher the spatial resolution of the DEM, the more accurate and realistic is the representation of the actual surface condition. From that perspective, CARTOSAT-1 DEM scores over other open source global DEMs like ASTER and SRTM. It has been shown in this study that with such high resolution DEMs, several attributes of the terrain can be quantified easily. For example, the statistical characteristics indicate the roughness and homogeneity of the terrain. Even better visualization is possible. Thus, such DEMs should be used in geomorphic studies more often.

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