

Algorithms for 3D Modeling and Visualization of Digital elevation models

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Abstract

The traditional 2D map expression has gradually given way to 3D visualization in Geographic Information Systems (GIS). The merging of visual approaches and geographic information systems (GIS) is a multidisciplinary and leading-edge field that requires advancement in a variety of fields. This work discusses related theories, practical approach and algorithms for three Dimensional visualizing of Digital Elevation Models (DEMs). The current research demonstrates algorithms for 3D visualization of slope maps, Aspect maps, and Hillshed maps, as well as their practical implementation in a real-world setting. The current article also includes a 3D elevation map of India, complete with elevation values for each location. These maps can also be used in urban planning, geologic analysis, hazard monitoring, natural resource research, and agricultural management etc.

Keywords: 3D Modeling, GIS, Remote Sensing, 3D Visualization, DEM

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I. Introduction

The terrain can be visualized in two ways: two-dimensionally and three-dimensionally. The two-dimensional technique uses two-dimensional maps such as contour maps, layered maps, and so on to represent three-dimensional topography. This is the customary way of doing things. With the advancement of computer graphics and power in recent years, traditional 2D map expression has steadily given way to 3D representation. Three-dimensional maps, as opposed to two-dimensional maps, give visitors a more realistic and vivid experience [1][2].

Remote sensing, SAR, aerial laser scan, and photogrammetry are examples of Earth observation technologies that have improved quickly in recent years. The amount of data collected by these devices increases in a geometric series. The major source of GIS data would be raster data. Many studies on big raster data management have been conducted, and many GIS software packages for managing multi-resolution image data using the pyramid file system have been developed [3].

In topographic expression and GIS applications, the digital elevation model based on a three-dimensional surface model is the most extensively employed. DEM is a data or image with X, Y, and Z coordinates that is used to digitally depict terrain. Several processes, such as visualization, enhancement, and manipulation, can be used to obtain valuable information from this data or image. These procedures are referred to as image processing.

Interpolating digital topographic data, such as contours, spot heights, rivers, and lakes, is a frequent and successful approach to create a DEM. The precision of this method of DEM extraction is dependent on the quality of the input data, the interpolation algorithms utilized, and the parameters provided to the algorithm. With the advancement of remote sensing technologies, a plethora of new data sources for generating moderate resolution DEMs have become available. High-resolution airborne image pairs can be used to generate topographic data. Topographic data can be obtained via interferometry, radar, or laser altimetry [4].

An elevation map depicts the different altitudes of a region on a map. With reference to sea level, elevations are commonly measured in meters or feet. It might be either above or below the surface of the water. Elevation map (fig. 1) with bands of the different colours or numerical values indicating specific elevation details. Different colours bands are used to show differences in elevation in a color-coded map, also known as a relief map. Topographic maps are another name for elevation maps. Elevation maps are becoming increasingly important in the development of urban populations, modern infrastructure, and natural resource exploitation. Elevation maps are now created for large scale data utilizing photogrammetric analysis of aerial pictures obtained using technology such as Lidar or other remote sensing techniques. Handheld equipment such as GPS devices and smartphones can also be used to acquire elevation data. The fundamental benefit of an elevation

map is that it depicts the topography in three dimensions on a two-dimensional map. These maps are quite useful for navigating the terrain, as well as urban planning and catastrophe management. Geological studies, hazard assessment, military, urban planners, and a variety of other professions all benefit from elevation maps.

3D Digital Elevation Map of India

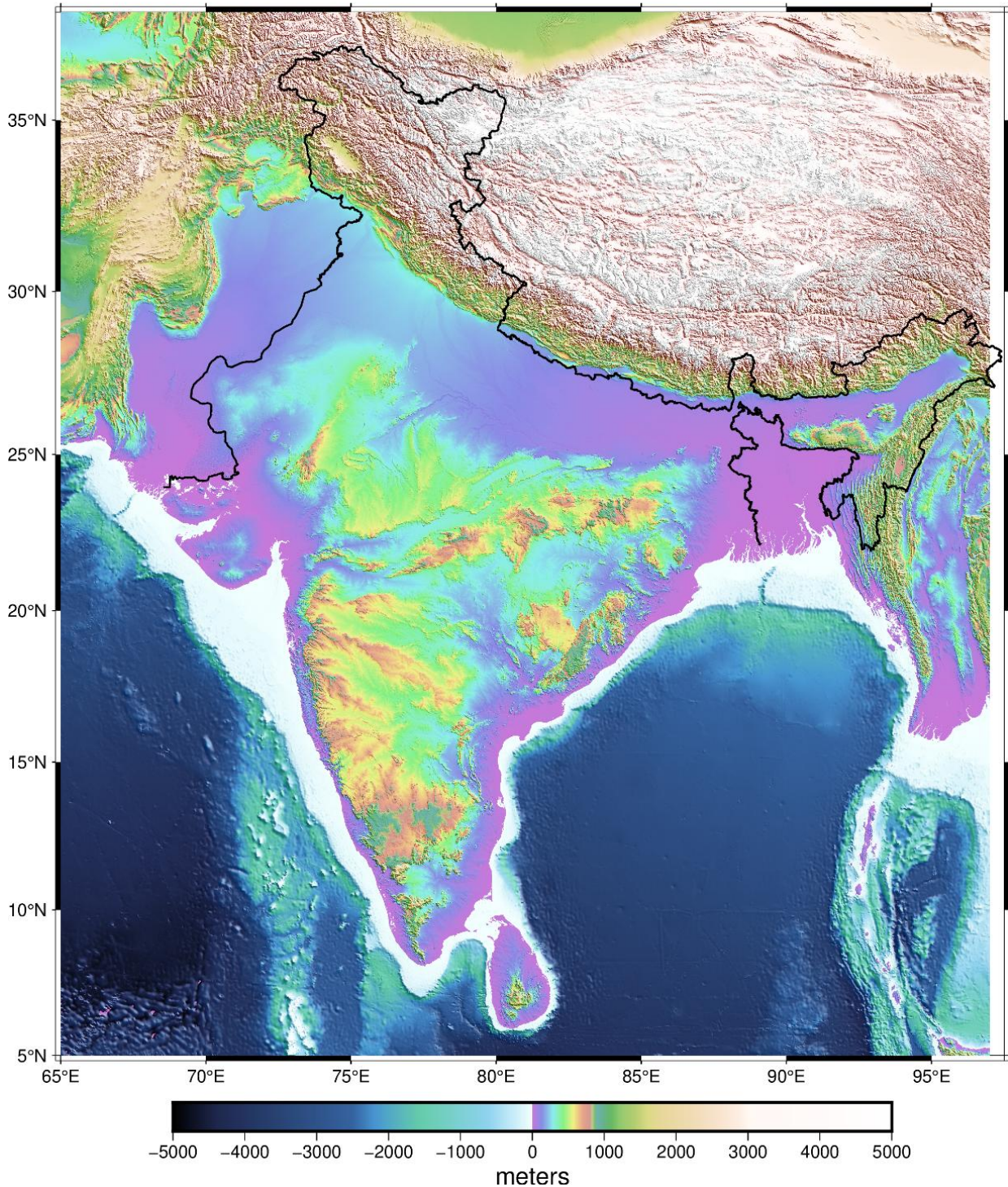


Fig.1 Digital Elevation Map of India Prepare from SRTM DEM 90m

II. Material

The present work is based on the 3 Dimensional algorithms for Visualization of Digital Elevation Model. We use SRTM DEM 30m resolution to Prepare Slope map, Aspect map, Hillshed map and CGIAR SRTM DEM 90M Resolution for Visualization of 3D DEM map of INDIA (Fig.1).

2.1 3D Modeling from SRTM Data

The Shuttle Radar Topography Mission (SRTM)- DEM data with 30m resolution was downloaded and used for study purposed from <http://edc.usgs.gov>. [4]

SRTM acquired elevation data on a nearly worldwide scale. SRTM was a specially modified radar system that flew on the Space Shuttle Endeavor in February 2000 for an 11-day mission. The National Geospatial Intelligence Agency (NGA) and the National Aeronautical Administration and Space Administration (NASA) are leading an international effort called SRTM (NASA).

During the 11-day mission, Endeavor orbited Earth 16 times per day and completed 176 orbits. With data points presented every 1 arc glob second, SRTM has successfully collected radar data between 60° north and 56° south latitudes on more than 80% of the earth's land surface.

2.2 3D Modeling of CGIAR SRTM DEM:

Everyone can get 90m SRTM digital elevation data from the GeoPortal CGIAR-CSI. The SRTM digital elevation data, developed by NASA, is a breakthrough in digital mapping of the world and in the production of high-quality elevation data for huge areas of the tropics and mountains in other developing countries. The digital elevation SRTM data on this site was processed to fill in data gaps and make it easy to use for a large number of people. These data are supplied to promote the use of geosciences and applications in developing nations for sustainable development and resource conservation. All countries in the world have digital elevation models (DEMs) that can be downloaded. The 90m DEM SRTM has a resolution of 90m at the equator and can be downloaded and used as 5-degree × 5-degree tiles. For easy mosaicking, they're all built from a built-in dataset. They come in Arc Info, ASCII, and Geotiff formats, making them compatible with a wide range of GIS and image software [6].

III. Methodology And Algorithms

3.1 Slope and Algorithm

Slope tool determines the gradient of the pixels on a raster surface. The value of slope decreases as the ground becomes flatter; the slope value increases as the terrain becomes steeper. The slope raster's output can be calculated in degrees or percentages. By dividing the rise by the run and multiplying by 100, you may get a better idea of the percent increase. Look at triangle B in the diagram below. When rise is equal to the run an angle is 45 degrees, and the percent rise equals 100%. Triangle C shows how the % growth approaches infinity when the slope angle approaches vertical (90 degrees).

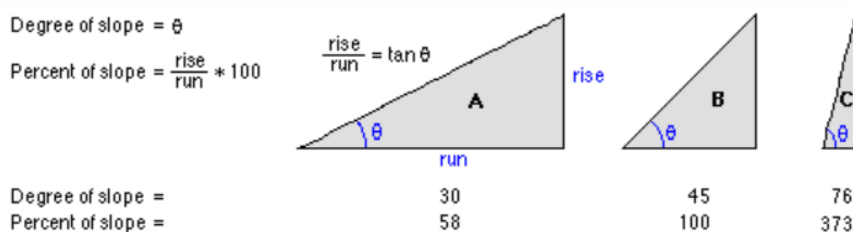


Figure 3 compares slope values in degrees against %. (Source Help tool in Arc Map 10.3)

Methods of calculation and the edge effect

For calculating slope, two approaches are available. The Method parameter allows you to choose between Planar and Geodesic calculations.

The slope is calculated using the planar approach as highest rate of change in value from one cell to its immediate neighbours. A 2D Cartesian coordinate system is used to execute the calculation on a projected flat plane. The average maximum technique is used to calculate the slope value (Burrough, 1998).

A 3D Cartesian coordinate system using the geodesic method, which considers the earth's shape to be an ellipse. The angle between the referenced datum the topographic surface is measured to determine the slope value.

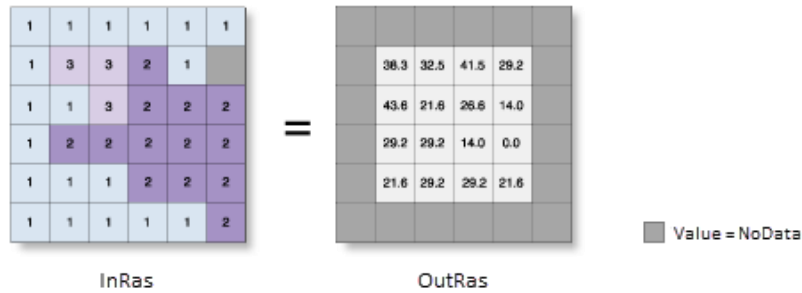


Fig.2 shows 3 by 3 cell moving window (Source Help tool in Esri Arc Map 10.3)

The tool, according to the concept, fits a plane around the processing or centre cell to the z-values of a 3 x 3 cell neighborhood. Using the average maximum technique, the slope value of this plane is computed. The plane's orientation determines which aspect of the processing cell is used. The terrain is flatter when the slope value is low and steeper when the slope value is high [7].

If neighborhood cell location has a No Data Z-value, the z-value of the central cell will be assigned. At least three cells will have No Data as their z-values at the raster's boundary (outside the raster's extent). These cells will receive the centre cell's z-value. As a result, the slope is reduced because the 3 x 3 plane fitted to these edge cells flattens out.

algorithm for Planar Slope

The slope is determined by the rate of change (delta) of the surface in the horizontal (dz/dx) and vertical (dz/dy) directions from the center cell. The following is the basic formula for calculating the slope:

$$\text{slope_radians} = \text{ATAN} (\sqrt{([\text{dz}/\text{dx}]^2 + [\text{dz}/\text{dy}]^2)})$$

The slope is measured in degrees and is computed using the formula below.

$$\text{slope_degrees} = \text{ATAN} (\sqrt{([\text{dz}/\text{dx}]^2 + [\text{dz}/\text{dy}]^2)}) * 57.29578$$

The result of 180/pi, 57.29578, is a truncated version of the 180/pi result.

The algorithm of slope is written like this as shown below:

$$\text{slope_degrees} = \text{ATAN} (\text{rise_run}) * 57.29578$$

Whereas:

$$\text{rise_run} = \sqrt{([\text{dz}/\text{dx}]^2 + [\text{dz}/\text{dy}]^2)}$$

Horizontal and vertical deltas are determined by the core cell's and its eight neighbours values. The neighbours are denoted by letters ranging from a to i with the letter e denoting the cell for which the aspect is calculated.

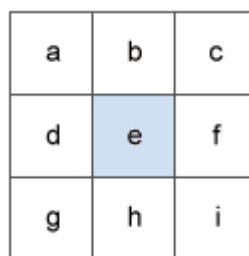


Fig.4 Surface Scanning window (Source Esri Arc Map 10.3)

The following algorithm is used to calculate the rate of change in the x direction for cell e:

$$[\text{dz}/\text{dx}] = ((c + 2f + i) - (a + 2d + g)) / (8 * x_cellsize)$$

The following algorithm is used to compute the rate of change in the y direction for cell e:

$$[\text{dz}/\text{dy}] = ((g + 2h + i) - (a + 2b + c)) / (8 * y_cellsize)$$

3.2 Aspect Algorithm

Aspect is used to identify the downslope direction of the highest rate of change in value from one cell to its neighbours. Slope direction is another term for it. The values of each pixel in the output raster correspond to the compass direction that the surface faces at that location. From 0 (north) to 360 (south), it takes 360

degrees to complete a full circle (north). Flat land with no downslope direction receives a -1 grade. In an aspect dataset, the value of each cell specifies which way the cell's slope is facing.

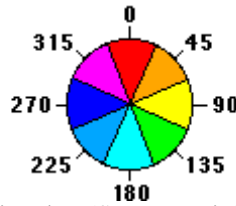


Fig.5 Aspect Direction (Source Esri Arc Map 10.3)

Algorithm for Planar Aspect

A moving 3 x 3 window examines each cell in the input raster, and an aspect value is produced for each cell in the window's center using an algorithm that considers the values of the cell's eight neighbours. The cells are labelled with letters a to i with e representing the cell for which the aspect is calculated. (fig.4).

The following algorithm is used to calculate cell e for the rate of change in the x direction:

$$[dz/dx] = ((c + 2f + i) - (a + 2d + g)) / 8$$

The following algorithm is used to compute cell e for the rate of change in the y direction:

$$[dz/dy] = ((g + 2h + i) - (a + 2b + c)) / 8$$

Aspect is computed by taking the rate of change in both the x and y directions for cell e and multiplying it by:

$$aspect = 57.29578 * atan2 ([dz/dy], -[dz/dx])$$

After that, the aspect value is translated to compass direction values (0-360°) using the following formula:

```
if aspect < 0
    cell = 90.0 - aspect
else if aspect > 90.0
    cell = 360.0 - aspect + 90.0
else
    cell = 90.0 - aspect (Source Esri Arc Map 10.3)
```

3.3 Hillshed or shaded relief Algorithm:

The Hillshade tool calculates the illumination lighting values for each cell in a grid to establish the potential lighting of a surface. It accomplishes this by locating a hypothetical light source and computing the illuminance values for each cell in relation to its neighbours. When employing transparency, it can substantially improve the visibility of a surface for analysis or graphical display reasons. shadow and light are by default in grayscale shades with integers ranging from 0 to 255. (increasing from black to white).

Parameters of Hillshade

As we producing a Hillshade map for any area, the sun position in the sky is the most crucial factor to consider.

Azimuth and Altitude

The Angular direction of Sun measure in clockwise degree from north,from 0 to 360 degree is known as Azimuth. East is defined by a 90-degree azimuth. The default azimuth is 315 degrees (NE). (Fig.6a)



Fig. 6 a Hillshade's sun's default azimuth (direction) is 315° (Source Esri ArcMap 10.3)

The slope or angle of illumination above the horizon is referred to as altitude. The measurements are in degrees with a 0 to 90 (horizontal) range (overhead). By default, the angle is 45 degrees. (Fig 6b).

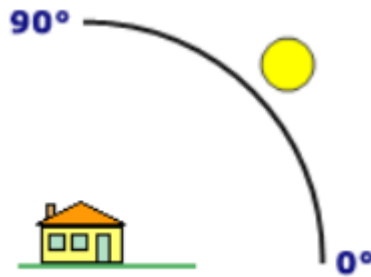


Fig.6 b Hillshade's default sun altitude is 45° (Source Esri Arc Map 10.3)

The azimuth of the hillshade below (Fig.6 c) is 315°, and the altitude is 45°.



Fig.6 c Output Result of Hillshed

How is hillshade determined?

To determine the shade value, you'll need to know the lighting source's altitude and azimuth. To get the hillshade final value for each cell in the output raster, these data will be merged with slope and aspect calculations.

Hillshade algorithm

For computing the hillshade value, use the following algorithm:

$$(1) \quad Hillshade = 255.0 * ((\cos(Zenith_rad) * \cos(Slope_rad)) + (\sin(Zenith_rad) * \sin(Slope_rad) * \cos(Azimuth_rad - Aspect_rad)))$$

The output cell value will be 0 if the hillshade value is less than 0.

Computing the illumination angle

In degrees above horizontal, the illumination source's altitude is specified. The hillshade value, on the other hand, is determined using a formula that requires the angle to be expressed in radians and the vertical deviation to be calculated. The zenith is defined as the direction straight up from a surface (directly overhead). The zenith angle is the 90-degree complement of the altitude, and it is measured from the zenith point to the illumination source's direction. The first step in computing the illumination angle is converting the altitude angle to the zenith angle. Converting the angle to radians is the next step.

Altitude changing to zenith angle:

$$(2) \text{ Zenith_deg} = 90 - \text{Altitude}$$

Radians conversion:

$$(3) \text{ Zenith_rad} = \text{Zenith} * \text{pi} / 180.0$$

Calculating the illumination direction

The illumination source's direction or azimuth is expressed in degrees. According formula of hillshade, this angle must be measured in radians. First, the azimuth angle is converted to a mathematical unit (right angle) from its geographic unit (compass direction). After that, Radians are used to convert the azimuth angle.

Measurement of azimuth angle change:

$$(4) \text{ Azimuth_math} = 360.0 - \text{Azimuth} + 90$$

If $\text{Azimuth_math} \geq 360.0$, then:

$$(5) \text{ Azimuth_math} = \text{Azimuth_math} - 360.0$$

Convert to radians:

$$(6) \text{ Azimuth_rad} = \text{Azimuth_math} * \text{pi} / 180.0$$

(Source Esri Arc Map 10.3 Help tool Box)

IV. Result and discussion

4.1 3D modeling of Slope

The greatest change in height over a given distance is known as the slope. The purpose of a slope map is to identify structural difficulties by understanding the local and regional slope variation of the terrain. On slope maps, you can see fault scarps and strata tilting. As seen in the examples below, the Slope tool is most commonly used on an elevation dataset. Slopes with a greater degree of difficulty are more difficult to navigate. The output slope raster is coloured red, while the gentle slope is coloured blue. The approach can also be used to find rapid changes in value in other types of continuous data, such population data.

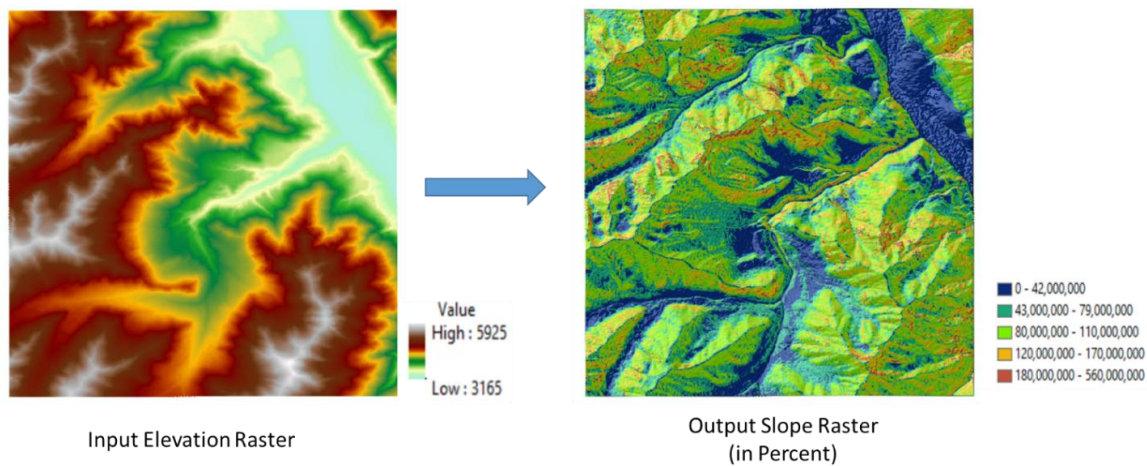


Fig.7 shows 3D modeling visualization of Slope

4.2 3D modeling application of Aspect

Aspect is measured at (0-360°) degrees clockwise after being specified as the slope surface's direction. Because flat surfaces do not face any direction, they are assigned a -1 value. The duration and severity of humidity, precipitation, wind, and sun on the land are all influenced by the aspect factor. Aspect is measured in degrees and calculated using definite differences (Wilson and Gallant, 2000). The Surface Analysis module of 3D Analyst was used to detect aspect features of the research region, same as it was used to discover slope characteristics. Four cardinal directions, four intercardinal directions, and flat lands were classified into nine groups (Figure 8). The following figure shows an elevation dataset and the output aspect raster.

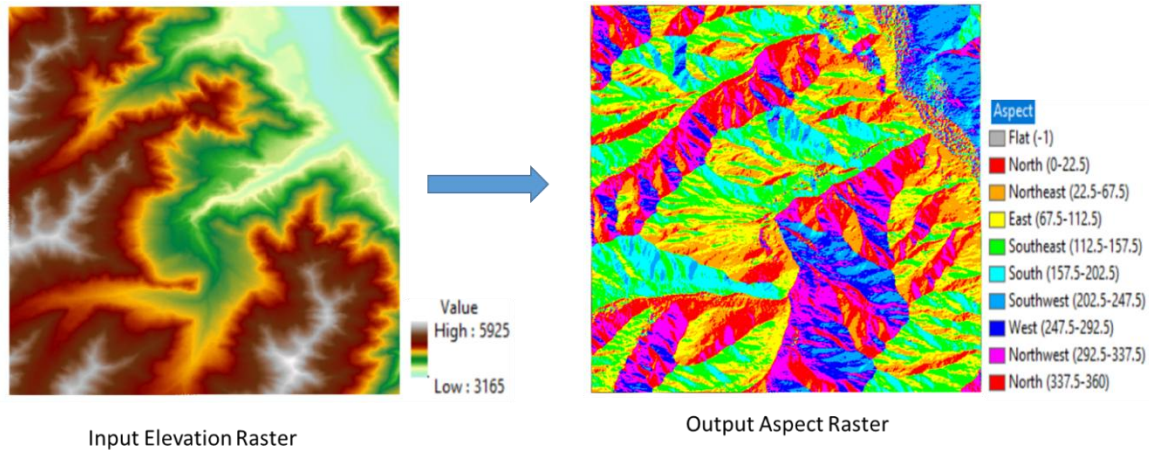


Fig.8 Showing Aspect map

Specialized agriculture: Aspect data is used to cultivate south-facing slopes in the Swiss Alps because they provide protection from cold and dry winds, which is essential for crop growth. Cattle and sheep are also herded and moved from the snow-covered summits to the valley bottom in the Swiss Alps [8].

Microclimate: The sun's beams generate microclimatic conditions on the slopes. They are, in other words, mini-climates distinct from the surrounding environment because it is warmer, drier, and better suited to the desert, a south-facing hill may be home to small types of woody trees. When compared to the opposite side, the north slopes receive less direct sunlight as a result of their orientation.

Ski slope selection: The slope direction determines how much incoming sun radiation directly strikes the slope face, affecting the overall quality of ski slopes. By influencing how much incoming solar radiation hits the slope's face directly, the slope direction influences the overall quality of ski slopes. The slope direction affects the overall quality of ski slopes by determining how much incoming solar radiation reaches the slope's face directly. Slope direction controls how much incoming solar energy directly contacts the face of the slope, making aspect maps essential for ski slope site selection.

Building constraints: Construction is prohibited on south-facing hills because they experience more frequent freeze/thaw cycles. This cycle of freezing and thawing can damage the ground beneath it, reducing overall stability. These banned building zones can be determined using aspect data.

Landslide studies: It regulates the slope's exposure to sunshine, wind direction, rainfall (degree of saturation), and discontinuity conditions, making it a crucial component in landslide investigations (Komac 2006).

4.2 3D modeling Application of Hillshed

By stacking an elevation image on top of a hillshade image and changing the transparency of the elevation image, you can quickly create a visually pleasing relief map of a terrain.

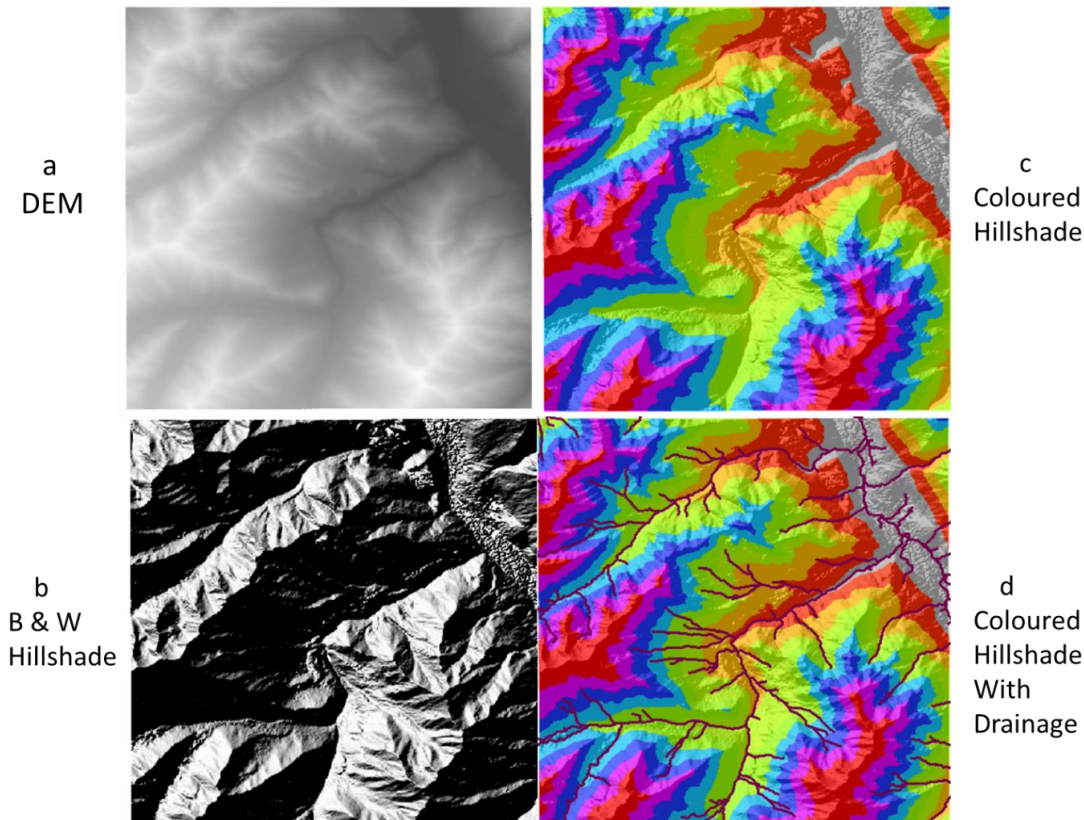


Fig.10 Showing SRTM DEM, Black and White Hillshed, Colours Hillshed & Coloured Hillshed with Drainage

Fig. 10 a represents original DEM image from that Black & White Hillshed is created (10 b), if we used Original DEM image with color pellet and 50% transparency on Hillshed map then beautiful 3D terrain is appears (10 c), then after adding Drainage network on Hillshed map it looks very easy understanding the drainage map (10 d).

V. Conclusion:

The current study shows 3D visualization techniques for slope maps, Aspect maps, and Hillshed maps, as well as their practical implementation in a real-world environment. A 3D elevation map of India is also included in this article, along with elevation information for each site. These maps can be utilized in a variety of applications, including urban planning, geology study, hazard monitoring, natural resource research, and agricultural management. The provision of 3D geographic data is a time-consuming, cost-effective, and labor-intensive process that every mapping project inherits from the Data Collection phase. Aside from this stage, the availability of tools that evolve around real or virtual world data is progressing through software development and the existence of appropriate application-oriented software. This tool should be able to perform both analysis and visualization. Under the terms of Spatial Data, the two subjects indicated above, namely data and application can create an environment for 3D GIS and, as a result, a spatially enabled society.

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