

MODULE – 7 LECTURE NOTES – 4

ESTIMATION OF ATTRIBUTES FROM RASTER DEM

1. Introduction

Terrain attributes derived from the DEM are broadly classified as primary attributes and secondary attributes. Primary attributes are those derived directly from the DEM, whereas secondary attributes are derived using one or more of the primary attributes. Some of the primary attributes, which are important in the hydrologic analysis, derived from the DEM include slope, aspect, flow-path length, and upslope contributing area. Topographic wetness index is an example of the secondary attribute derived from the DEM. Topographic wetness index represents the extent of the zone of saturation as a function of the upslope contributing area, soil transmissivity and slope.

Gridded DEM represents the surface as a matrix of regularly spaced grids carrying the elevation information. Most of the terrain analysis algorithms using the gridded DEM assume uniform spacing of grids throughout the DEM. Topographic attributes are derived based on the changes in the surface elevation with respect to the distance.

This lecture covers brief explanation of various topographic indices that can be derived from the raster DEM.

2. Calculation of slope from the DEM

Slope is defined as the rate of change of elevation, expressed as gradient (in percentage) or in degrees.

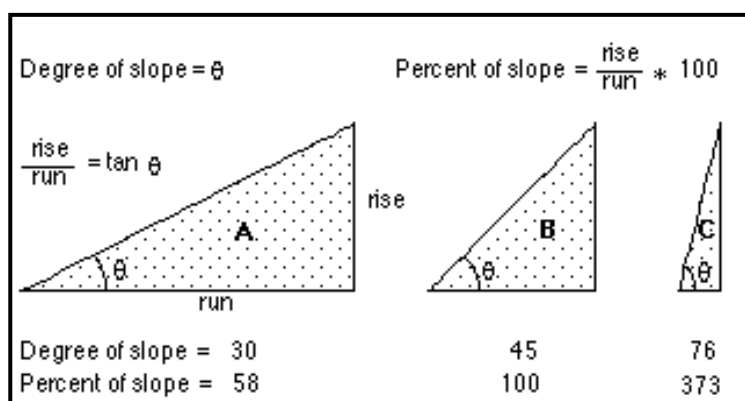


Figure 1. Estimation of slope

Using the finite difference approach, slope in any direction is expressed as the first derivative of the elevation in that direction.

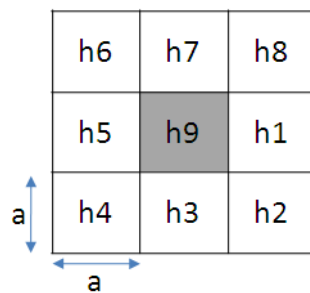
$$\text{Slope in the x direction } S_x = \frac{\partial h_x}{\partial x}$$

$$\text{Slope in the y direction } S_y = \frac{\partial h_y}{\partial y}$$

In general, slope of any point is given as follows

$$S = \sqrt{\left(\frac{\partial h_x}{\partial x}\right)^2 + \left(\frac{\partial h_y}{\partial y}\right)^2}$$

Consider the example grids given below, in which the elevation are marked as h1, h2...h9.



Using the finite difference formulation, slope of the central grid (grid 9) can be calculated as follows.

$$S_9 = \sqrt{\left(\frac{h1 - h5}{2a}\right)^2 + \left(\frac{h3 - h7}{2a}\right)^2}$$

In this approach, only the four directions are considered. However, the slope estimated using the above equation generally gives reasonably accurate values of the slope.

On the other hand, deterministic eight-neighborhood (D8) algorithm estimates the slope by calculating the rate of change of elevation in the steepest down slope direction among the 8 nearest neighbors, as shown below.

$$S_{9,D8algorithm} = \text{Max} \left[\frac{h9-h1}{L}, \frac{h9-h2}{L}, \dots, \frac{h9-h8}{L} \right]$$

where L is equal to a for cardinal neighbors and $\sqrt{2} a$ for diagonal neighbors.

This approach is generally preferred when the channel slope is required.

When gridded DEMs are used for the analysis, each of the grids is compared with its nearest 8 neighbors and the slope is derived for each grid. The local slope calculated from a gridded DEM decreases with increase in the DEM grid size. This is because, as the grid size increases, the grids represent larger areas. In the slope calculation, since the spatial averages of the elevation for such larger areas are used, it tends to result in smoother or less steep surface (Wolock and Price 1994).

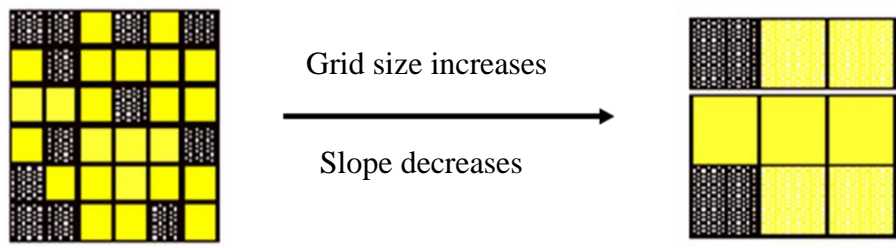


Figure.2 DEM grid size and slope relationship

Selection of DEM grid size is therefore important to get appropriate slope map, particularly in fields like erosion studies, where the processes are largely related to the slope.

3. Calculation of aspect from the DEM

Aspect is the orientation of the line of steepest descent, normally measured clockwise from the north, and is expressed in degrees.

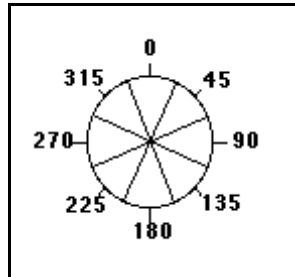


Figure 3. Aspect directions

4. Determination of flow direction

In watershed analysis using raster based DEM, water from each cell is assumed to flow or drain into one of its eight neighboring cells which are towards left, right, up, down, and the four diagonal directions. The flow vector algorithm scans each cell of the DEM, and determines the direction of the steepest downward slope to an adjacent cell.

The most common method used for identifying the flow direction is the D8 (deterministic eight-neighbors) method. The method was first proposed by O'Callaghan and Mark (1984). In this method, a flow vector indicating the steepest slope is assigned to one of the eight neighboring cells.

A detailed description of the D8 algorithm for drainage pattern extraction is provided in the following sub-section.

4.1. D8 Algorithm

In this method, the flow direction for each cell is estimated from elevation differences between the given cell and its eight neighboring cells, and hence the name D8 algorithm. Most GIS implementations use the D8 algorithm to determine flow path.

In D-8 algorithm, water from each cell is assumed to flow or drain into one of its eight neighboring cells which are towards left, right, up, down, and the four diagonal directions.

The flow is assumed to follow the direction towards the cell having the steepest slope. If the steepest downward slope is encountered at more than one adjacent cell, flow direction is assigned arbitrarily towards the first of these cells encountered in a row by row scan of the adjacent cells. Where an adjacent cell is undefined (i.e. has a missing elevation value or lies outside the DEM grid), the downward slope to that cell is assumed to be steeper than that to any other adjacent cell with a defined elevation value.

Once the flow direction is identified, numerical values are assigned to the direction. The general flow direction code or the eight-direction pour point model, followed for each direction from the center cell is shown in the figure below. Each of the 8 flow directions are assigned numeric values (Fig.4), using the 2^x series, where $x = 0, 1, 2 \dots$ etc.

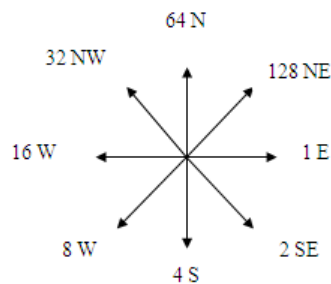


Figure 4. The eight direction pour point model

From Fig.4, it can be inferred that the flow direction is coded as 1 if the direction of steepest drop is to the right of the current processing cell, and 128 if the steepest drop is towards top-right of the current cell.

Consider a small part of a gridded DEM as shown in Fig. 5. Assume the cell size as 1 unit in dimension. Consider the grid with elevation 67. There are 3 adjacent grids having elevation less than 67 (with elevation 56, 53 and 44), and these three are considered as the possible flow directions. In the flow vector algorithm, the direction of steepest slope among these three directions is identified.

Slope is calculated along the three directions as shown in Fig. 5 (b). Slope is the maximum towards the bottom right cell, and hence water would follow that direction. As a result, according to the eight direction pour point model, the center cell (with elevation 67) is allotted a flow direction value of 2.

The same procedure is repeated for all the grids in a DEM. The resulting flow directions and the corresponding flow direction values are shown in Fig. 5 (c) and (d), respectively.

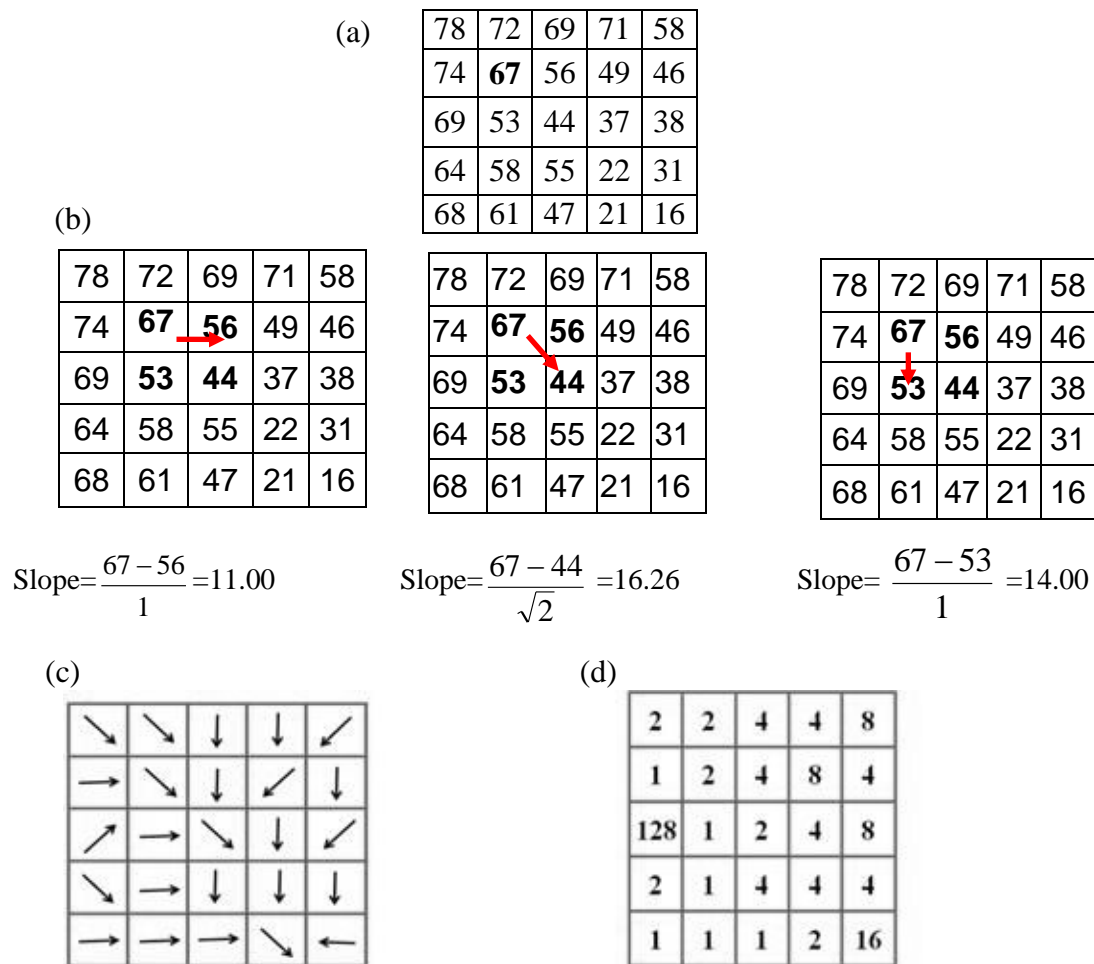


Fig.5 (a) A sample DEM (b) Estimation of the steepest down slope direction (c) Flow direction (d) Flow direction matrix with numerical values for each direction

Disadvantages of eight direction pour point method are the following:

- It limits the direction of flow between two adjacent nodes to only eight possibilities
- There is discrepancy between the lengths of the drainages as calculated by the method
- The method fails to capture parallel flow lines

Use of two outflow paths (Tarboton, 1997), partitioning of the flow into all down slope (Quinn et al., 1991), use of a stochastic approach to determine the gradient (Fairfield and Leymarie, 1991) were some of the improvements made on the D-8 algorithms latter.