

MODULE – 7 LECTURE NOTES – 5**DRAINAGE PATTERN AND CATCHMENT AREA DELINEATION****1. Introduction**

Topography of the river basin plays an important role in hydrologic modelling, by providing information on different terrain attributes which enhance the assessment and enable the simulation of complex hydrological processes. In the past, topographical maps were one of the major sources of information for derivation of the catchment characteristics in hydrological models. With the rapidly increasing availability of topographic information in digital form, like digital elevation models (DEMs), the automatic extraction of terrain attributes to represent the catchment characteristics has become very popular. Automatic algorithms used for the extraction of the catchment characteristics are benefitted by the speed, accuracy and standardization. The ability to create new, more meaningful characteristics, thereby eliminating the need to draw and digitize the attributes, is another major advantage of such algorithms.

Hydrologic models use information about the topography in the form of terrain attributes that are extracted from DEM for modeling the different hydrological process such as interception, infiltration, evaporation, runoff, groundwater recharge, water quality etc. In hydrologic studies DEMs have also been used to derive the channel network and to delineate the catchment area.

This lecture explains the algorithms used to extract the channel network and the catchment area from a raster DEM.

2. Drainage Pattern Extraction from DEM

Gridded DEM has been widely used in the hydrologic modeling to extract drainage patterns of a basin required for flow routing in the hydrologic models. The gridded DEM provides elevation information at regularly spaced grids over the area. The algorithm used must be capable of identifying the slope variation and possible direction of flow of water using the DEM.

While using the gridded DEM, inadequate elevation difference between the grids often creates difficulty in tracing the drainage pattern. Also, gridded DEM may contain depressions, which are grids surrounded by higher elevations in all directions. Such depressions may be natural or sometimes interpolation errors. These depressions also create problems in tracing the continuous flow path.

Prior to the application of the DEM in the hydrologic studies, preprocessing of the DEM is therefore carried out to correct for the depressions and flat areas.

3. Treatment of depressions and flat area

Depression or sink is defined here as a point which is lower than its eight nearest neighboring grids, as shown in Fig.1. Such points may arise due to data errors introduced in the surface generation process, or they represent real topographic features such as quarries or natural potholes.

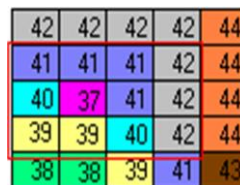


Figure 1. Example for a spurious depression in a gridded DEM

Spurious flat areas are present in a DEM when the elevation information is inadequate to represent the actual relief of the area. Fig.2 shows example of spurious flat area in a raster DEM.

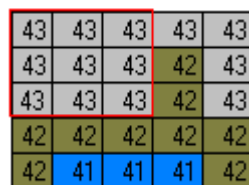


Figure 2. Example for a spurious flat area in a gridded DEM

There are many algorithms available in literature for treating depressions and flat areas in the raster DEM.

The depression filling algorithms basically identify and delineate the depression. Outlet from the depression is identified by filling the depression to the lowest value on its rim (Jenson and Domingue, 1988).

Advanced algorithms available for the depression filling make use of the overall drainage information of the watershed, either by burning the stream network (overlay the stream network and modify the elevation along channel grids) or by tracing the flow direction from the watershed outlet to the depression.

A DEM which is free of sinks is termed as a depressionless DEM.

Relief algorithms are used to identify the flow direction through flat areas in the DEM. The relief algorithm imposes relief over the flat areas to allow an unambiguous definition of flow lines across these areas.

Two implicit assumptions in the relief algorithm are the following:

- The flat areas are not truly level, but have a relief that is not detectable at the vertical resolution of the original DEM.
- The relief in the flat area is such that any flow entering or originating from that area will follow the shortest path over the flat area to a point on its perimeter where a downward slope is available.

The relief algorithm proposed by Martz and Garbrecht (1998), and the priority-first-search algorithm (PFS) proposed by Jones (2002), are some of the methods available for treating the flat areas and to trace the flow paths.

A DEM, made free of sinks and flat areas is termed as a modified DEM.

Care should be taken as these algorithms could change the natural terrain, enlarge the depression, loop the depression and/or produce an outflow point in the depression while processing a flat area which in turn could affect watershed delineation, drainage network extraction and hydrologic event simulation accuracy.

The steps for delineating watershed from a depressionless DEM are the following.

- i. Identification of the flow direction for each grid
- ii. Delineation of the flow network
- iii. Calculation of flow accumulation at each grid
- iv. Stream network delineation
- v. Delineation of the stream links

4. Determination of flow vectors

Flow vector algorithms scan each cell of the modified DEM (from the depressions and flat areas) and determine the direction of the steepest downward slope to an adjacent cell. Most common method used for identifying the flow direction is the D8 (deterministic eight-neighbors) method (Details of the D-8 algorithm are provided in Lecture 4).

Using D-8 algorithm, flow direction for each cell is estimated from elevation differences between the given cell and its eight neighboring cells.

Consider a small sample of a DEM in raster format given in Fig.3 (a). The corresponding flow direction grid and the matrix containing numerical values of the flow directions are shown in Fig. 3(b) and 3(c), respectively.

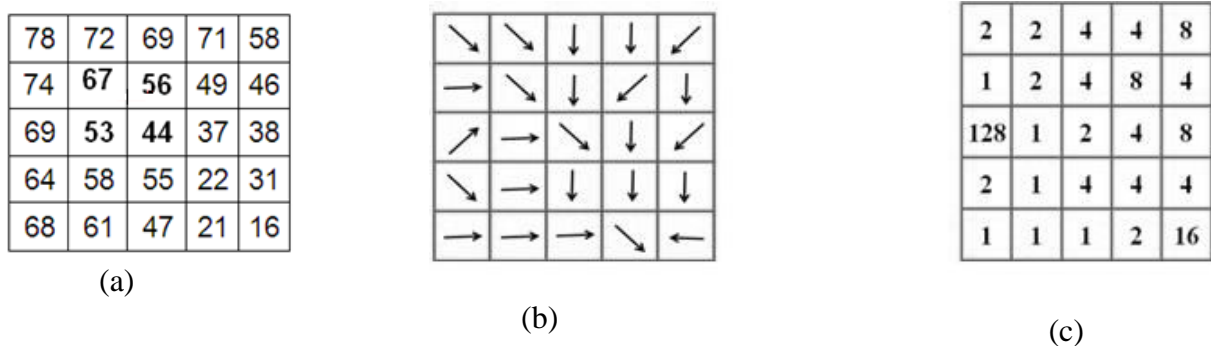


Fig.3 (a) A sample DEM (b) Flow direction grid (d) Flow direction matrix with numerical values for each direction

5. Flow network

Once flow direction grid has been obtained, flow network is created by extending the lines of steepest descent beyond each cell as shown in Fig.4

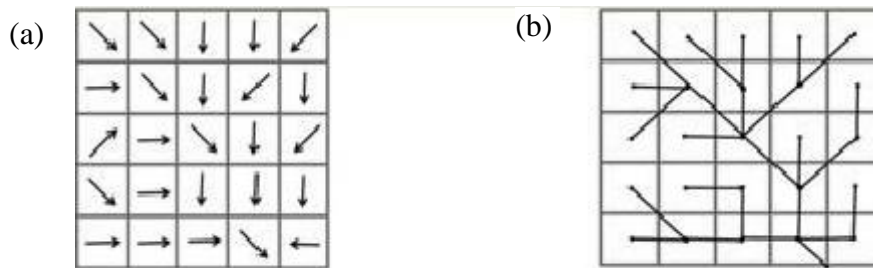


Figure 4. (a) Flow directions and (b) Flow network

6. Flow accumulation grid

Once the flow directions are identified, flow from each grid is traced to the watershed outlet. During this flow tracing, for each grid, a counter is initiated for each grid. As the flow passes through each grid, this counter is incremented by 1. Using the counter, total number of upstream grids that flow into each grid are identified and the flow accumulation grid is generated. In the flow accumulation grid, the number in each cell denotes the number of the cells that flow into that particular cell. Figure 5 (b) clearly illustrates the flow accumulation grid.

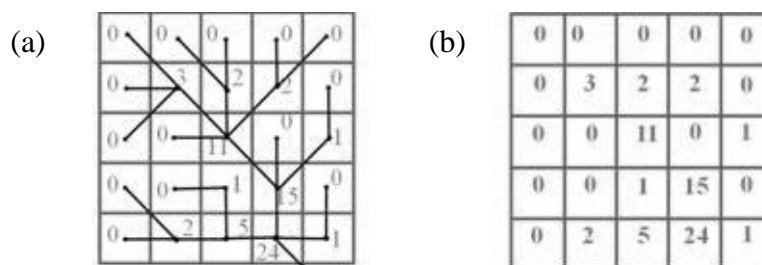


Figure 5. (a) Flow network and (b) Flow accumulation grid

7. Delineation of the stream network

Stream network is defined using the relative count of grids flowing to it, which is obtained from the flow accumulation matrix. To delineate a stream from the flow accumulation grid, it is necessary to specify a threshold flow accumulation. The threshold specifies the minimum flow accumulation at which a grid can be considered as a part of the stream. Grids which have flow accumulation greater than the threshold value are assumed to be the parts of the stream and the remaining grids are considered as overland flow grids. Fig. 6 highlights the stream grids for a threshold flow accumulation of 5 cells.

0	0	0	0	0
0	3	2	2	0
0	0	11	0	1
0	0	1	15	0
0	2	5	24	1

Figure 6. Grids that are parts of the stream network using the threshold flow accumulation of 5-cells

8. Delineation of the stream links

On specifying the threshold flow accumulation, the stream links associated with this threshold are obtained with the help of flow network grid, as highlighted in Fig.7. Knowing the stream links, the grids contributing flow to any point on the stream can be identified, which can be used to delineate the subwatersheds.

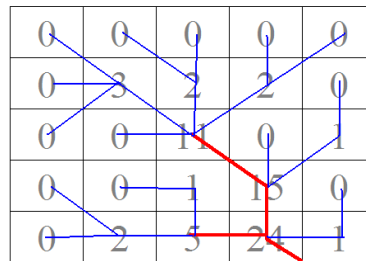


Figure 7: Stream network for a 5-cell threshold flow accumulation (shown in red color)

9. Watershed delineation from the DEM

Watershed boundaries or the location of watershed divides can be obtained based on stream channel information. Usually, watershed boundaries tend to be half way between the stream of interest and all the other neighbouring streams. If a much more precise boundary needs to be determined, the use of topographic maps are essential. These maps show elevation contours, small ephemeral streams, large water bodies etc. Pour point is the name given to the outlet of the watershed that user is interested in delineating. An estimate of watershed boundary from a topographic map requires the pour point locations. Pour points can be any point on the stream/river where the surface flow from watershed exists. The upslope catchment area at each grid of the modified gridded DEM is determined using the flow direction information. Beginning at each grid with a defined elevation value and using the flow direction vectors previously generated, the path of steepest descent is continuously followed for each grid until the edge of the DEM is reached, and the flow accumulation is derived for each grid. The flow accumulation represents the number of grids contributing flow into the grid in the watershed, and hence gives the upslope catchment area for that grid.

All the above steps to extract sub-watersheds from a raster based DEM are shown in the form of a flowchart in Fig. 8.

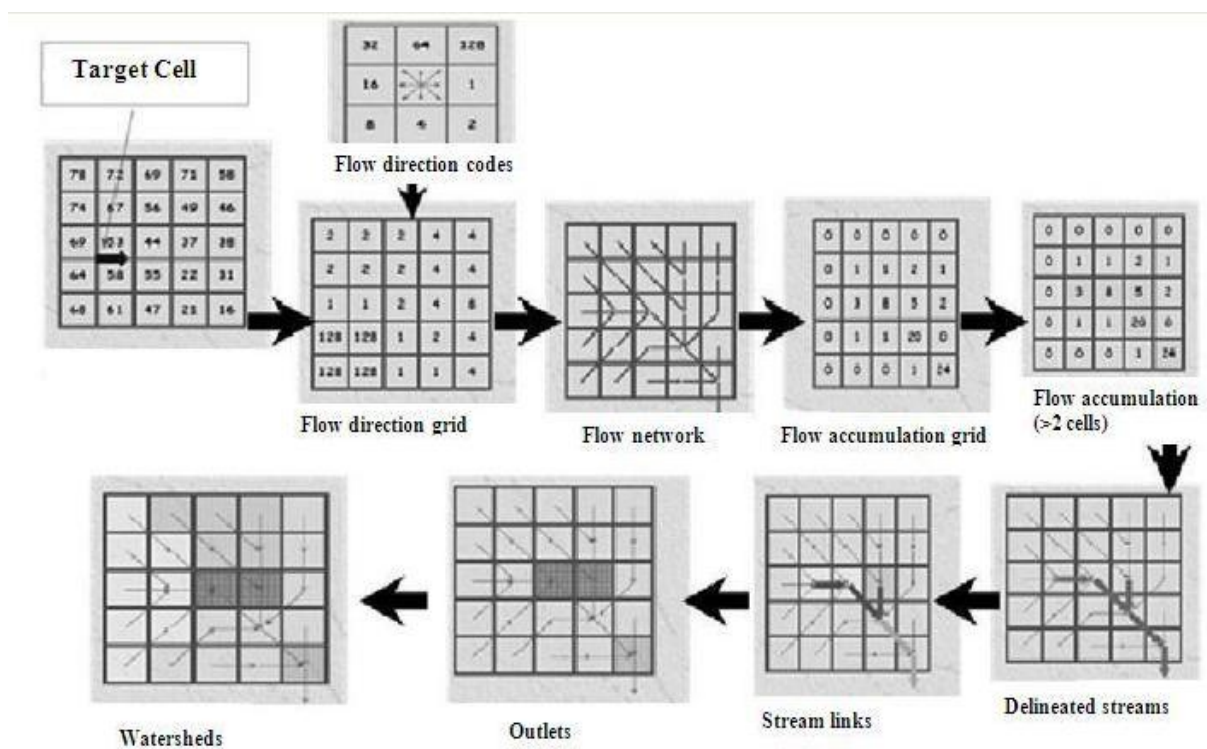


Figure 8. Steps in extracting sub-watersheds from DEM using D8 algorithm

10. Case Studies

Drainage pattern extraction from raster DEM is explained here with the help of two case studies: Krishna and Cauvery basins in India. The raster DEM used, estimated flow directions, flow accumulation grids, channel networks and the catchment areas are shown for each basin.

Raster DEMs

The SRTM DEM, from United States Geological Survey (USGS) website are downloaded in raster format for the two basins and are presented in Figure 9

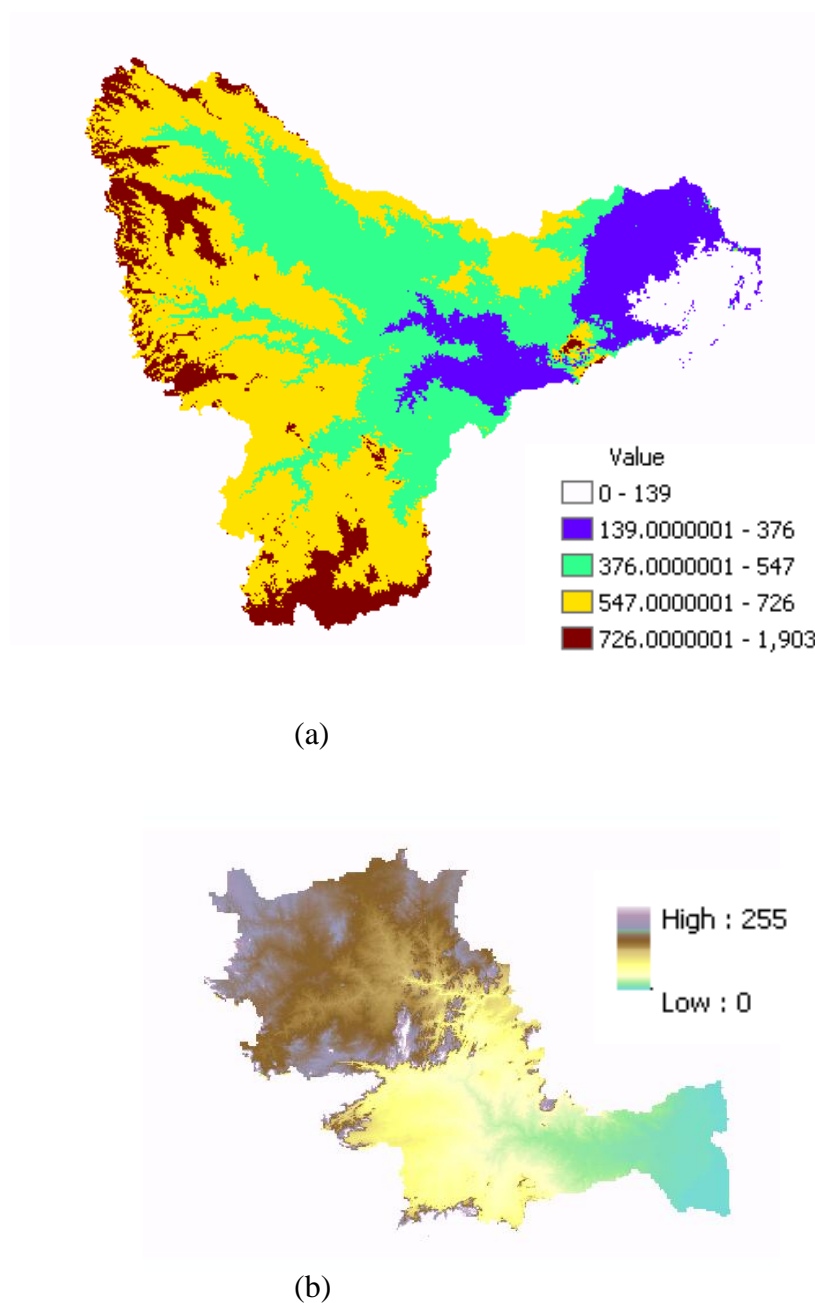


Figure 9: SRTM data for (a) Krishna basin and (b) Cauvery basin

Flow Direction

Flow direction from each cell is estimated using the D8 algorithm, embedded in the GIS framework of ArcGIS. Fig. 10 shows the flow direction images for the two case study basins.

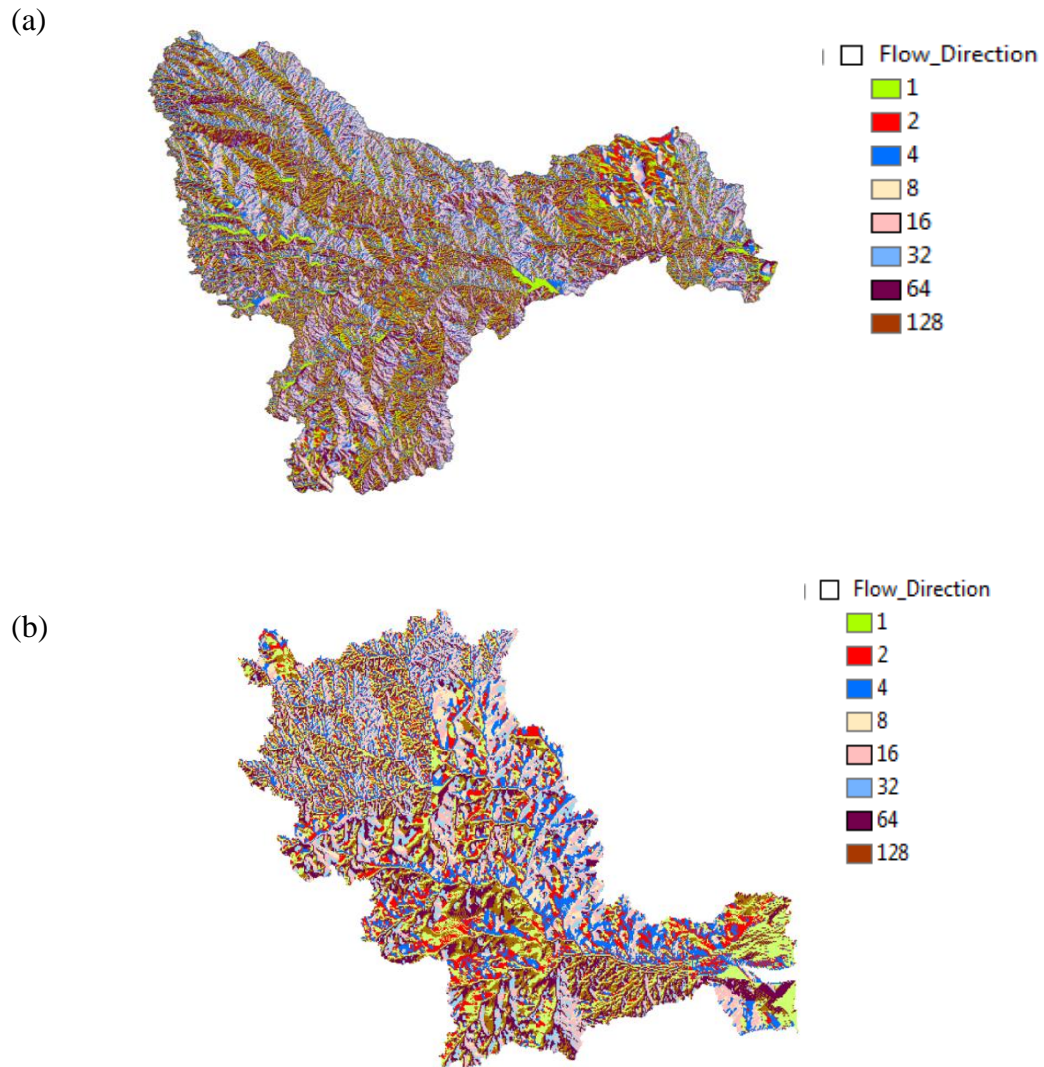


Figure 10: Flow direction image for (a) Krishna basin and (b) Cauvery basin

Flow Accumulation

Using the flow direction information, the flow is traced for each grid and the flow accumulation is derived. Here, the flow accumulation is derived using the *flow accumulation* function available in the ArcGIS Spatial Analyst. Fig. 11 shows the flow accumulation images for the two case study basins.

(a)



(b)



Figure 11: Flow accumulation image for (a) Krishna basin and (b) Cauvery basin

Stream Network

A vector dataset showing drainage network is derived based on combined information from the flow accumulation and flow direction dataset. Stream network derived for the Krishna and Cauvery basins are shown in Fig. 12.



(a)



(b)

Figure 12: Stream network of (a) Krishna basin and (b) Cauvery basin

Pour Points

In the next step, pour point locations are created. If the locations of hydrometric gauging stations are not available, pour points need to be created manually. This gives a vector dataset, created with probable outlets of drainage sub-basins in the drainage network. Fig.13 shows the location of sub basin outlet or pour points for Krishna and Cauvery basins.

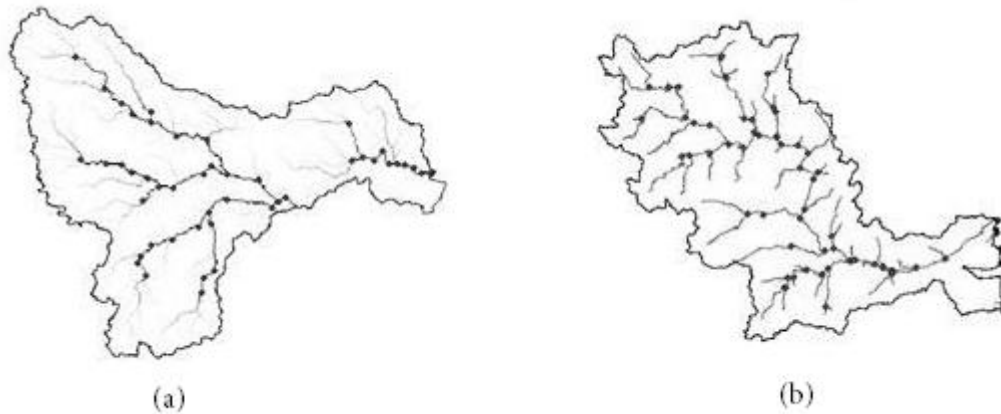


Figure 13. Sub-basin outlets or pour points in the (a) Krishna basin (b) Cauvery basin

Watershed delineation

The watersheds in the two study area are delineated using ArcGIS, as shown in Fig. 14. The sub basins delineated can be seen in different colors.

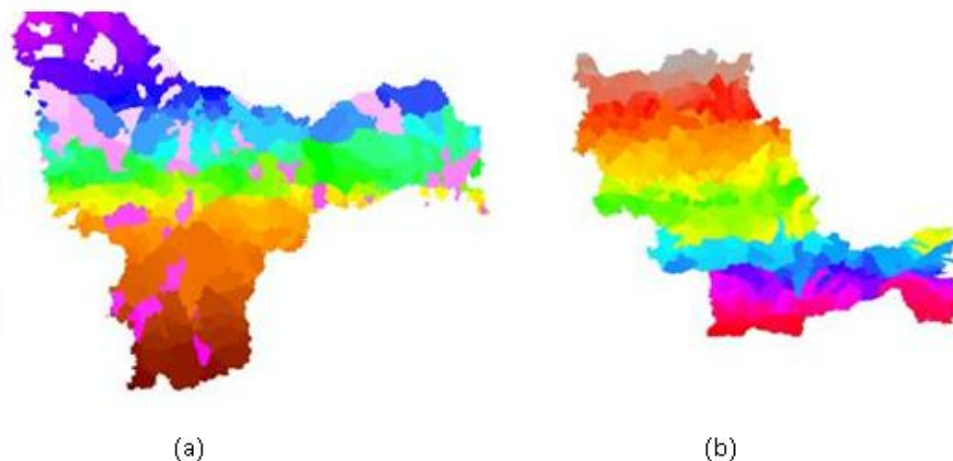


Figure 14. Watersheds delineated using ArcGIS for the (a) Krishna basin and (b) Cauvery basin

11. Accuracy of the DEM-derived information

Accuracy of the DEM-derived stream network and the catchment boundary depends on the following factors.

- The source of the elevation data, including the techniques for measuring elevation either on the ground or remotely, the locations of samples, and the density of samples.
- The horizontal resolution and vertical precision at which the elevation data is represented. If the actual topographic gradient is less than the precision of the DEM elevation data, then these areas will be represented as flat lands according to DEM data.
- The topographic complexity of the landscape being represented. For example, it may not be possible to determine if a given area of equal elevation is either a lake or a flat area, where a river possibly flows.
- The algorithms used to calculate different terrain attributes. For example, the watershed drainage structure modeled using a DEM does not fit with the actual drainage structure in flat areas

Bibliography / Further reading

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