Learning Outcomes

After studying this module you shall be able to:

- Understand the role of Geographical Information System (GIS) inhydrological modeling
- Learn about utilization of GIS in Watershed analysis
- Learn about various applications of integration of GIS with hydrologicalmodeling

Introduction

Hydrology is the study of water flow, surface and subsurface along with the transport of constituents such as sediment and pollutants in the water as it flows. Hydrological modeling in itself is required for the management of water resources, flood zone prediction, groundwater zone prediction and many more. Remote sensing and GIS are being continuously utilized and are an efficient tool for the hydrological modeling. The various thematic layers, land use /land cover, soildatabase, geomorphology etc. can easily be analyzed and visualized on a GIS platform once they are geo-spatially corrected. The GIS tools helps in monitoringthe data spatially, which is an inherent requirement of the hydrological models. Thus, the integration of GIS with hydrological modeling provides an opportunity to conduct the development and planning at both high spatial and temporal periods asGIS provides representations of the spatial features of the Earth through digital elevation model etc and the surface and subsurface hydrological fluxes can then be easily represented. A spatial hydrology model helps in simulating the water flowand transport on a specified region of the earth using GIS data structures. In the current module we discuss the basic analysis that can be done in GIS using the satellite data and which forms the pre-requisite for any hydrological model on a spatial scale.

Watershed analysis

The watershed analysis helps in delineating the drainage area of the basin and can be easily automated on GIS platform. An area, which drains to a common outlet, is known as the watershed and was traditionally drawn using the topographic maps. However, today it can easily be delineated through utilization of DEM data in GIS and can spatially consider huge area to small areas. For a hydrological model to determine the hydrological fluxes in a basin domain, watershed delineation along with the stream network is important. With the advent of GIS, stream network delineation has become also extremely easy. The stream network provides an important input for modeling the river discharge. Thus, watershed analysis actually provides the details of the flow and channeling of surface water on the Earth's surface. The delineation is feasible to be restricted to select point that is a point where we have the gauge station data available or the delineation can be for the required regional area. As studied in the module, GIS surface models and terrain analysis, the slope and aspect derivation play an important role in defining the flow direction as we understand that the flow movement is from upstream to downstream. Thus, for delineating the stream direction, we first use the filled DEM, to avoid internal drainage. This is required as original DEM may have certain low elevation cells surrounded with the high elevation cells and result in unnatural depressions. Thus, the DEMs are filled by increasing the cell value to lowestoverflow point. Once we have the filled DEM, it is then utilized to obtain the slope, which helps in identifying the slope direction. The direction is based on the algorithm, D8 as discussed below -

3.1 D8 flow algorithm

D8 flow algorithm is a widely used method for evaluating the flow direction. The D8 algorithm assigns a flow direction to raster cell to one of its eight surrounding cells. This algorithm assigns the direction and allows a single flow direction towards a cellthat has the steepest slope gradient. The allowed eight directions for the pour point model or the D8 algorithm are shown in Fig. 1.

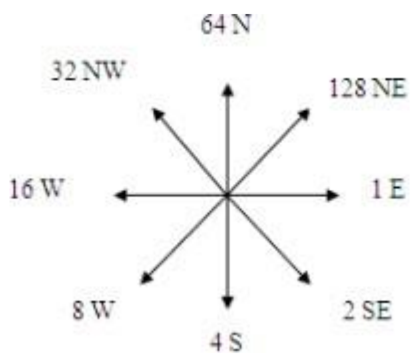


Fig 1. 8-directions for the D8 algorithm.

The directions in GIS tool are represented by the numbers shown in Fig. 1, where East direction is represented by 1 and ends at 128 in North East direction. The method is limited in the sense that it does not allow the flow to represented flowingin multiple directions as may sometime be true in real conditions especially at a lowelevation gradient surface. Fig. 2(a) represents an elevation raster and the slope calculation is shown for the pixel cell represented with value of 67. The slope calculation is shown in three directions, where the elevation value is lower than the considered pixel. The slope values for elevation values 44, 53 and 56 are found to be 16.26, 14 and 11 respectively. Thus the slope direction is South East towards the steepest slope. The Fig. 2 (c) and Fig. 2(d) represent the slope directions in two ways, one graphically and the other on the basis on numbers given to each direction for all the elevation values given in the example raster. This flow direction method is appropriate for convergent flows along the well-defined valleys but creates issues at the ridges. Thus, another model has also been developed, D-infinity, which allows the flow direction to be considered in two cells. This method creates 8 connecting triangles and the triangle with the maximum downhill slope is taken as the flow direction as shown in Fig 3. Here, the proportional water flow to each cell is given as follows

$$\text{Cell1} = \frac{\alpha_1}{\alpha_1 + \alpha_2} \text{ and Cell2 } = \frac{\alpha_2}{\alpha_1 + \alpha_2}.$$

(a)

78	72	69	71	58
74	**67**	56	49	46
69	53	44	37	38
64	58	55	22	31
68	61	47	21	16

(b)

78	72	69	71	58
74	**67**	**56**	49	46
69	**53**	**44**	37	38
64	58	55	22	31
68	61	47	21	16

$$\text{Slope}=\frac{67-56}{1}=11.00$$

78	72	69	71	58
74	**67**	**56**	49	46
69	**53**	**44**	37	38
64	58	55	22	31
68	61	47	21	16

$$\text{Slope}=\frac{67-44}{\sqrt{2}}=16.26$$

78	72	69	71	58
74	**67**	**56**	49	46
69	**53**	**44**	37	38
64	58	55	22	31
68	61	47	21	16

$$\text{Slope}=\frac{67-53}{1}=14.00$$

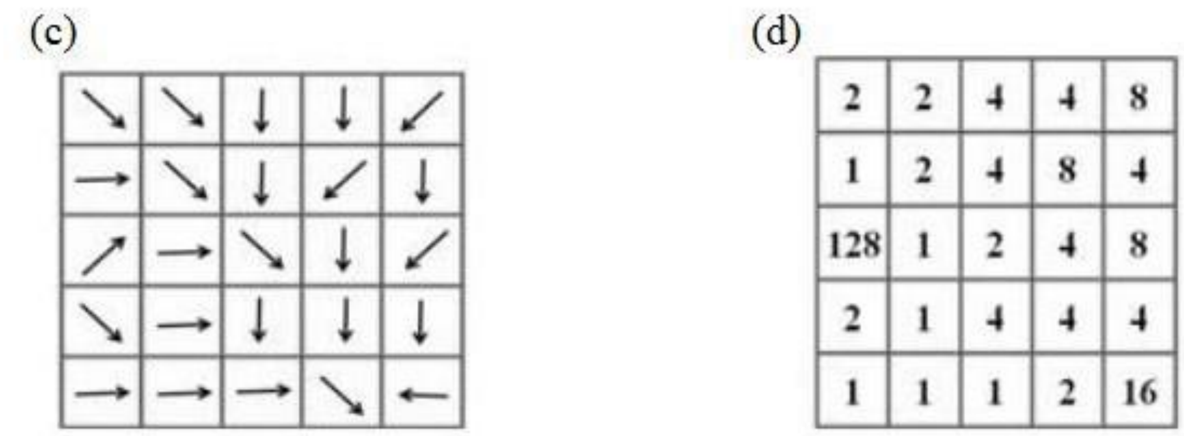


Fig 2. Flow direction based on D8 algorithm

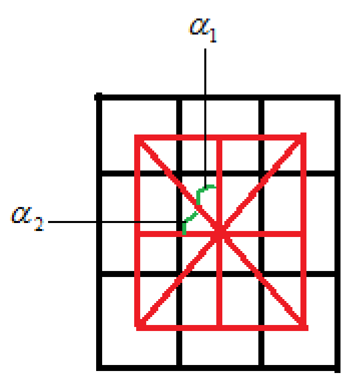


Fig 3. Flow proportion in two cells based on D-infinity method.

3.2 Flow accumulation

The flow accumulation helps in evaluating the number of upstream cells contributing to the lower or the downstream cell. The pre-requisite for obtaining the flow accumulation thematic raster is the flow direction thematic layer created with either D8 or D-infinity algorithm model. Thus, this map helps in identifying the contribution or drainage to each cell. The flow accumulation helps in generation of stream network. The cell values with a zero value represent ridges, while the cells having high values imply accumulation and may represent stream. The stream network is delineated from the flow accumulation map by providing a threshold value. A threshold value implies that the user can define a minimum number of cells that contribute water to a particular cell. For example, if set threshold to 100, then any cell in the accumulation map has a value equal or greater than 100 is considered a part of drainage network or the stream network. The threshold value determines the density of the drainage network. Higher threshold values may result in fewer streams. These streams are given numbering based on Strahler ordering as shown in Fig 4. Here each stream segment is given a number, where one is the first-order stream. Two-first stream link to form second-order stream. Once, stream numbering has been done, the final cell of the highest stream order acts as the pour point and acts as delineating point for the watershed boundary. The regional DEM can have sub-watersheds based on the select point, where we have the in situ availability of discharge data.

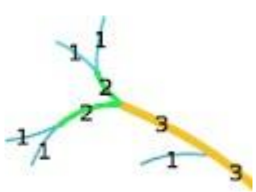
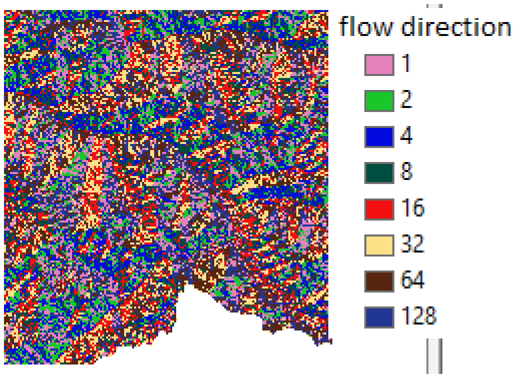
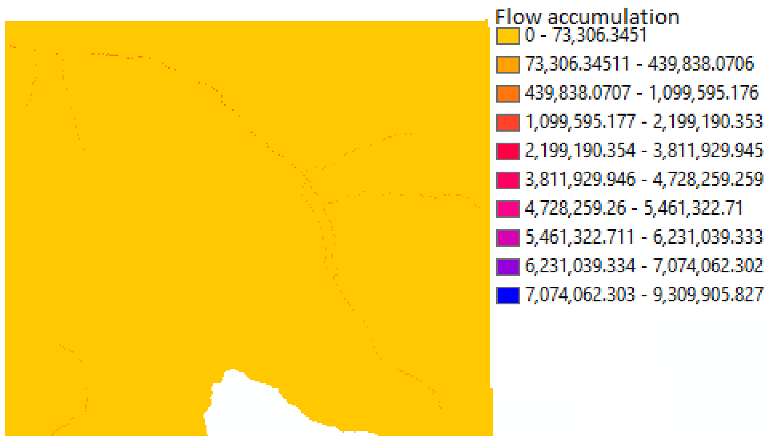
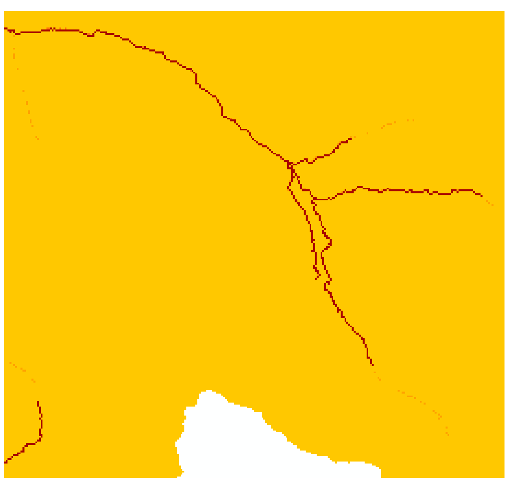


Fig 4. Stream order based on Strahler steam order method.

The Fig.5 represents the three raster generated for a region, flow direction, flow accumulation and stream map. This is then linked to provide a watershed boundary.







Stream network

3.3 Factors contributing to watershed delineation

It can be seen that the complete delineation of watershed is originally based on elevation values obtained from the DEM. Thus, a 90m DEM or even a 30m could be considered very coarse resolution for a highly heterogeneous terrain and may not provide detailed topography. Based on the regional requirement, a higher DEM resolution may be required. Secondly, the errors in DEM elevation data could provide erroneous internal drainage situations even after the Filled DEM has been utilized. Secondly, as already mentioned D8 algorithm does not allow flow distribution to multiple cells, it may create a problem in delineating the watershed in flat topography areas like the floodplains. Thus, even though watershed delineation method is highly useful, care must be taken while utilizing the tools.

3.4 Utilization of delineated watershed

The watershed as we know is the hydrological unit that is utilized in planning the resources. It allows to create a linkage with soil type and land use/land cover within the watershed. It is easily utilized for mapping the flood vulnerability zones as we get automated basin elevation, stream lengths and channel slopes. The data is easily utilized to estimate the discharge of the required stream in lieu of other satellite data like RADAR data, which provides the river stage data at high spatial and temporal scale. Even the snowmelt run-off models require the basic watershed analysis along with the snow-covered fraction areas. The physical based water balance models like Wetspa are regional scale model that utilize raster dataset and calculate the hydrological fluxes based on the water transport equations like Richard's equation. These models along with watershed delineation help in estimating the discharge and runoff which require the watershed analysis as already described. Thus, we can easily obtain the annual mean flow details at the required location based on the select point, where we also have the in situ measurements available. Hence, watershed analysis through GIS helps in providing an input to various hydrological models.

FAQs

Q1. Explain D8 algorithm

Ans: D8 flow algorithm is a widely used method for evaluating the flow direction. The D8 algorithm assigns a flow direction to raster cell to one of its eight surrounding cells. This algorithm assigns the direction and allows a single flow direction towards a cell that has the steepest slope gradient. The allowed eight directions for the pour point model or the D8 algorithm are N, S, E, W, NE,SE,SW and SW. The East direction is represented by 1 and ends at 128 in North East direction. The method is limited in the sense that it does not allow the flow to represented flowing in multiple directions as may sometime be true in real conditions especially at a low slope gradient surface. This flow direction method is appropriate for convergent flows along the well defined valleys but creates issues atthe ridges.

Q2. What are the limitations of D8 algorithm

Ans: This algorithm assigns the direction and allows a single flow direction towardsa cell that has the steepest slope gradient. The method is limited in the sense that it does not allow the flow to represented flowing in multiple directions as may sometime be true in real conditions especially at a low slope gradient surface. Thus, this flow direction method is appropriate for convergent flows along the well defined valleys but creates issues at the ridges.

Q3. What is a filled DEM?

Ans: It is seen here that a lot of information can be extracted from the DEM. However, the DEM can have some errors and the most common one is "sinks". Sinks occur when a very low elevation, relative to surrounding cells, occurs. The sinks can create an issue when one utilizes them for delineating the surface flow direction as the sinks create internal drainage effects. Thus, the sink values are modified to lowest overflow point. Once we have the filled DEM, it is then utilized to obtain the slope, which helps in identifying the steepest slope direction and creatinga flow route thematic map.

Q4. Explain flow accumulation?

Ans: The flow accumulation helps in evaluating the number of upstream cells contributing to the lower or the downstream cell. The pre-requisite for obtaining the flow accumulation thematic raster is the flow direction thematic layer created with either D8 or D-infinity algorithm model. Thus, this map helps in identifying the contribution or drainage to each cell. The flow accumulation helps in generation of stream network. The cell values with a zero value represent ridges, while the cells having high values imply accumulation and may represent stream. The stream network is delineated from the flow accumulation map by providing a threshold value. A threshold value implies that the user can define a minimum number of cells that contribute water to a particular cell. For example, if set threshold to 100, then any cell in the accumulation map has a value equal or greater than 100 is considered a part of drainage network or the stream network. The threshold value determines the density of the drainage network. Higher threshold values may result in fewer streams. These streams are given numbering based on Strahler ordering. Here each stream segment is given a number, where one is the first-order stream. Two-first stream link to form second-order stream. Once, stream numbering has been done, the final cell of the highest stream order acts as the pour point and acts as delineating point for the watershed boundary. The regional DEM can have sub-watersheds based on the select point, where we have the in situ availability of discharge data.