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Stream Order Delineation using SRTM 30 meter Resolution Digital Elevation Model (DEM) and Hydrology Tools in ArcGIS 10.3 and QGIS: Mapping of Drainage Pattern of Mandi District, Himachal Pradesh, India

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Abstract **- The paper describes step by step watershed and stream network delineation based on digital elevation models using the Hydrology tools in ArcGIS and online services for Hydrology and Hydrologic data. The 30-meter resolution SRTM image of Himachal Pradesh was downloaded from open topology website. This was further processed in QGIS and ArcGIS 10.3 software. The different hydrological processes and data management tools were used like, fill, Flow direction; flow accumulation, map algebra, stream orders, stream feature and stream dissolve in order to get the final map of Mandi drainage pattern.**
Keywords: **Stream, Delineation, ArcGIS, QGIS, Hydrology, Drainage**

I. INTRODUCTION

Mapping of drainage pattern is very important when we study watershed and stream network of any area. There are different techniques to delineate the stream order and drainage pattern used by the cartographers. This can be achieved with the help of topographic map. If the area under study is small then we can use topographic maps and digitize the AOI in order to get the desired map. This can also be done without computer by using butter paper and tracing on that, but this is very tedious job to make such map with this technique. So the another way which is available these days is with the help of GIS software which includes both open source and paid GIS software like ArcGIS, QGIS, SAGA, GRASS, Post GIS etc. These days research can download satellite images which are available for free in the internet websites like, USGS, Bhuvan, open topography etc. which can be processed in these softwares and the desired map can be generated.

Following steps has been used in order to prepare drainage pattern map of Mandi district.

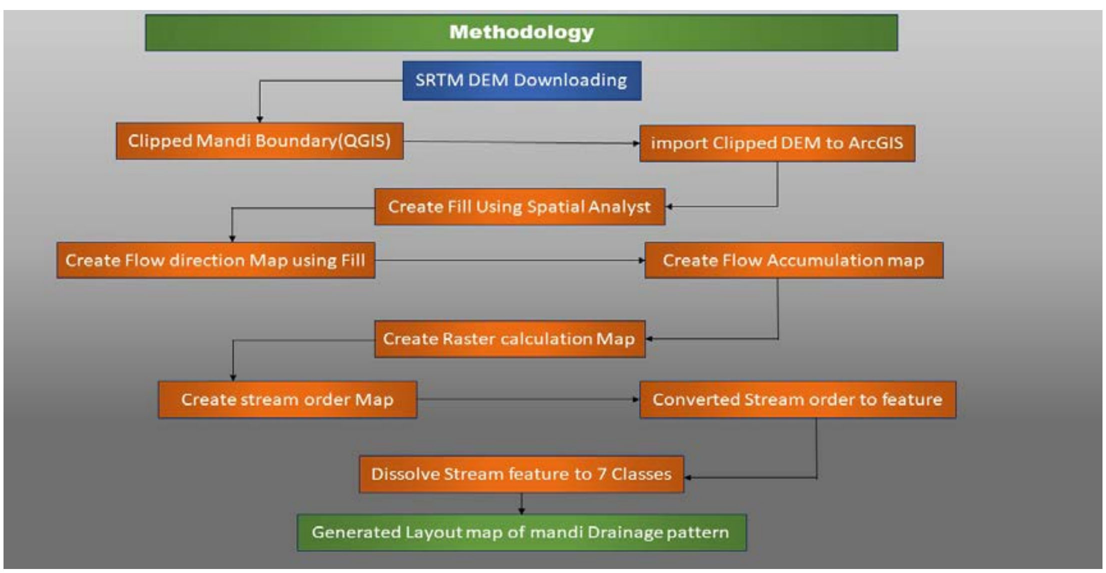

Fig. 1 Methodology

II. DOWNLOADING SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM) 30 METER RESOLUTION TIFF IMAGE

The required image was downloaded from http://opentopo.sdsc.edu/raster website by selecting the approximate AOI and then the same was downloaded free of cost.

The image thus downloaded was in tiff format which has longitudinal, latitudinal and height information in it.

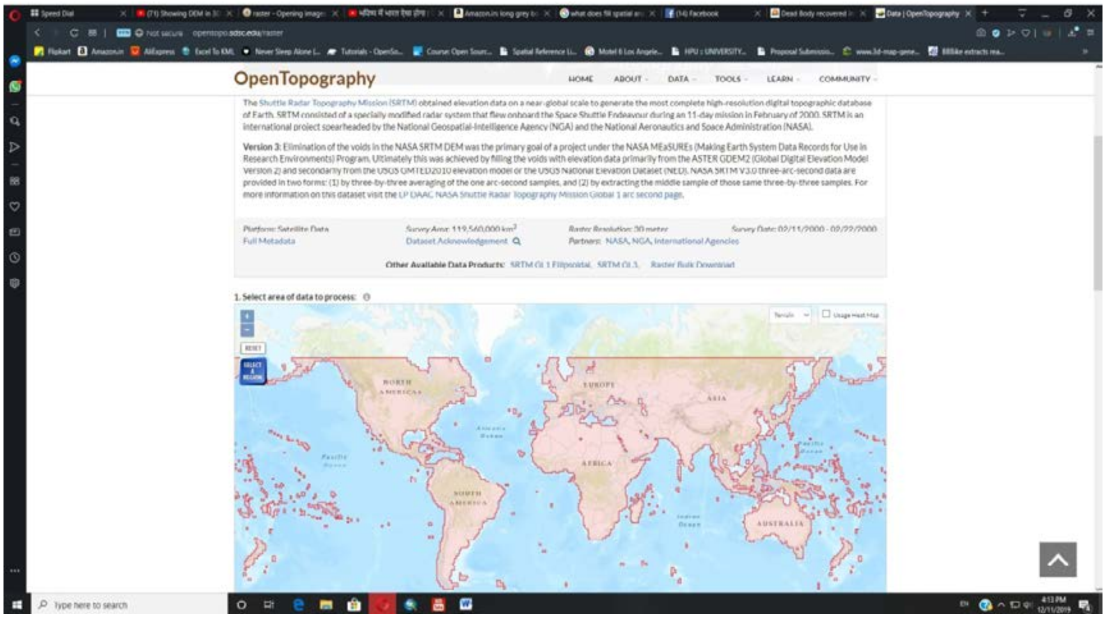

Fig. 2 Downloading SRTM Data

III. GENERATING BOUNDARY OF MANDI DISTRICT

The boundary map of Mandi district was prepared with the help of QGIS software. The base map for this purpose was procured from Mandi census report 2011 which was further georeferenced with the help of open street maps available in QGIS. After georeferencing the shape file was generated this was further processed to generate hollow outline map. In the next step, the Shuttle Radar Topography Mission (SRTM) image was opened in QGIS and the boundary map of Mandi district was draped over the image. The next step was to clip the SRTM image and boundary map so that the image of Mandi could be extracted from the image. The georeferencing in QGIS is very easy task here as we can georeference the simple jpeg image with the help of available open street map.

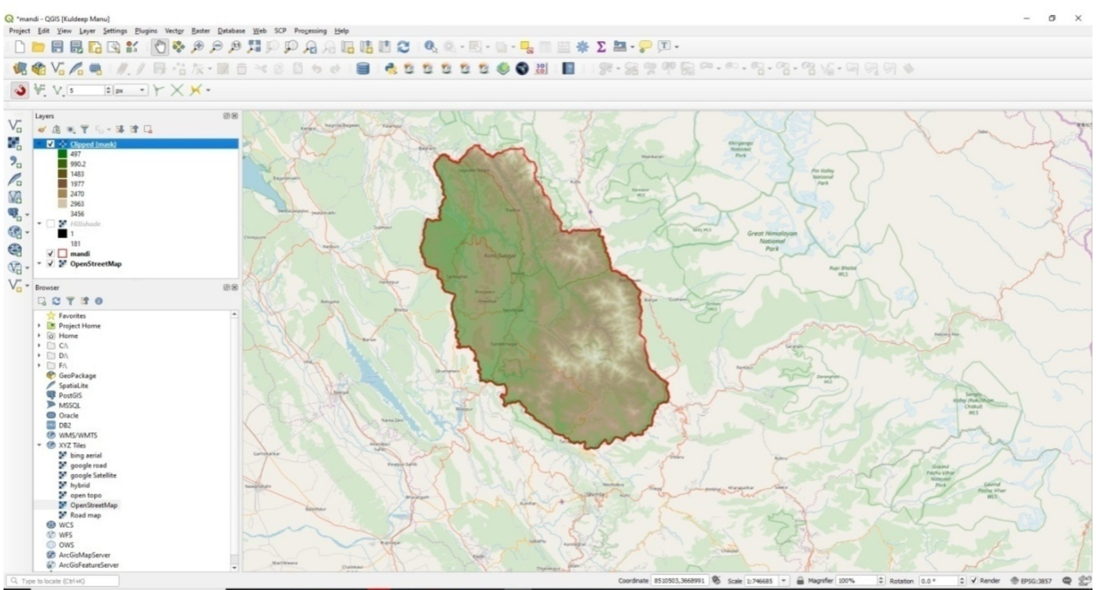

Fig. 3 Clipped Mandi DEM in QGIS

IV. USING SPATIAL ANALYST IN ArcGIS

The ArcGIS Spatial Analyst extension provides a rich set of spatial analysis and modelling tools for both raster (cell-based) and feature (vector) data. The capabilities of Spatial Analyst are broken down into categories or groups of related functionality. Knowing the categories will help you identify which particular tool to use. There are several ways to access Spatial Analyst functionality. With geoprocessing, operations in the Spatial Analyst toolbox can be performed through a Tool dialog box, Python (either at an interactive command line interface or with a script), or a Model. Traditional operations and workflows using Map Algebra can also be performed in the Python environment. There is also a Raster Calculator available for entering simple Map Algebra expressions that generate an output raster.

V. RESULTS AND DISCUSSION

A. Stream Order Delineation Using ArcGIS

In order to delineate stream order the very first step is to import the DEM data to ArcGIS software. The DEM of Mandi was imported to the software which was processed in QGIS before. After importing the required data the next step is to use the spatial analyst 'Fill'.

B. Fill

This is Hydrological tool which is used in order to the values in the raw DEM that that might be missing in that. The fill analyst calculates the missing value with the help of algorithm and taking under consideration the neighbour pixel values. The value thus obtained is assigned to the mixing value location. After processing the DEM there will not be any visual change in the resultant image but the process is very important in order to fulfil the final objectives.

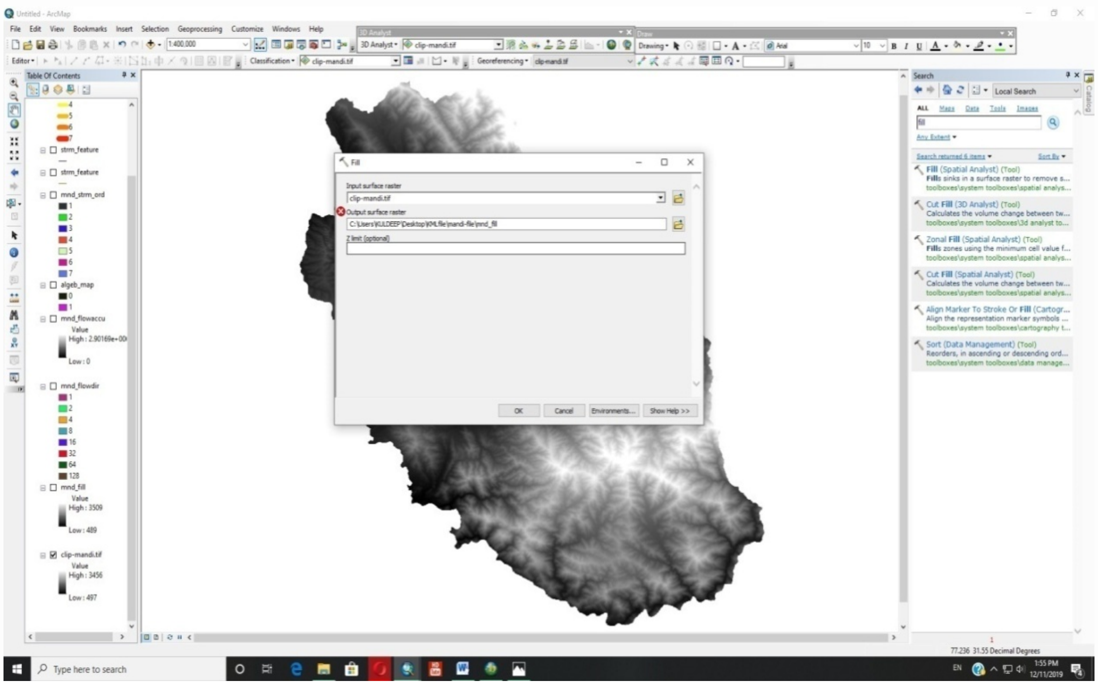

Fig. 4 Fill Calculation Map

C. Flow Direction

One of the keys to deriving hydrologic characteristics of a surface is the ability to determine the direction of flow from every cell in the raster. This is done with the Flow Direction tool. This tool takes a surface as input and outputs a raster showing the direction of flow out of each cell.

If the Output drop raster option is chosen, an output raster is created showing a ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centres of cells and is expressed in percentages. If the Force all edge cells to flow outward option is chosen, all cells at the edge of the surface raster will flow outward from the surface raster. There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight-direction (D8) flow model and follows an approach presented in Jenson and Domingue (1988).

The direction of flow is determined by the direction of steepest descent, or maximum drop, from each cell. This is calculated as follows.

*Maximum drop=change in z-value/distance*100*

The distance is calculated between cell centers. Therefore, if the cell size is 1, the distance between two orthogonal cells is 1, and the distance between two diagonal cells is 1.414 (the square root of 2). If the maximum descent to several cells is the same, the neighbourhood is enlarged until the steepest descent is found. When a direction of steepest descent is found, the output cell is coded with the value representing that direction. If all neighbours are higher than the processing cell, it will be considered noise, be filled to the lowest value of its neighbours, and have a flow direction toward this cell. However, if a one-cell sink is next to the physical edge of the raster or has at least one No Data cell as a neighbour, it is not filled due to insufficient neighbour information. To be considered a true one-cell sink, all neighbour information must be present. If two cells flow to each other, they are sinks and have an undefined flow direction. This method of deriving flow direction from a digital elevation model (DEM) is presented in Jenson and Domingue (1988). Cells that are sinks can be identified using the Sink tool. To obtain an accurate representation of flow direction across a surface, the sinks should be filled before using a flow direction raster.

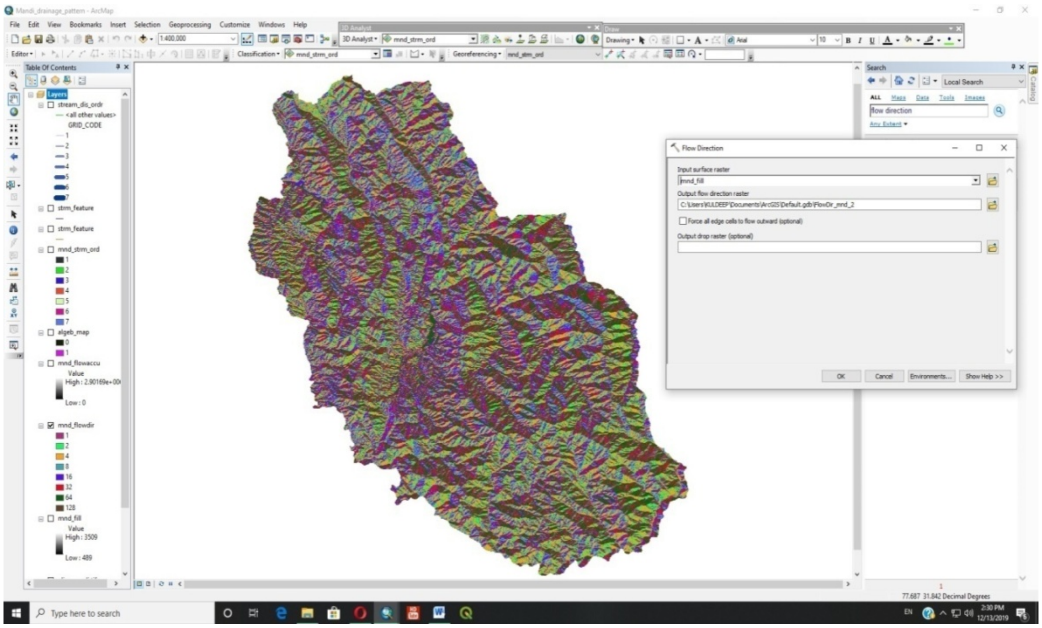

Fig. 5 Flow Direction Calculation

The resultant map generated after using this tool will be of multi-colour map which show the direction of the flow. The direction of the flow follows the slop of the DEM data.

D. Flow Accumulation

After generating the flow direction map the next step is to calculate the accumulation of flow which highlights the major drainage systems of the surface where the maximum accumulation of water occurs. After processing the image with this tool the major drainage systems of the area will be highlighted in the map in bright lines. The Flow Accumulation tool calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. If no weight raster is provided, a weight of 1 is applied to each cell, and the value of cells in the output raster is the number of cells that flow into each cell. In the graphic below, the top left image shows the direction of travel from each cell and the top right the number of cells that flow into each cell.

Cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. This is discussed in Identifying stream networks. Cells with a flow accumulation of 0 are local topographic highs and may be used to identify ridges.

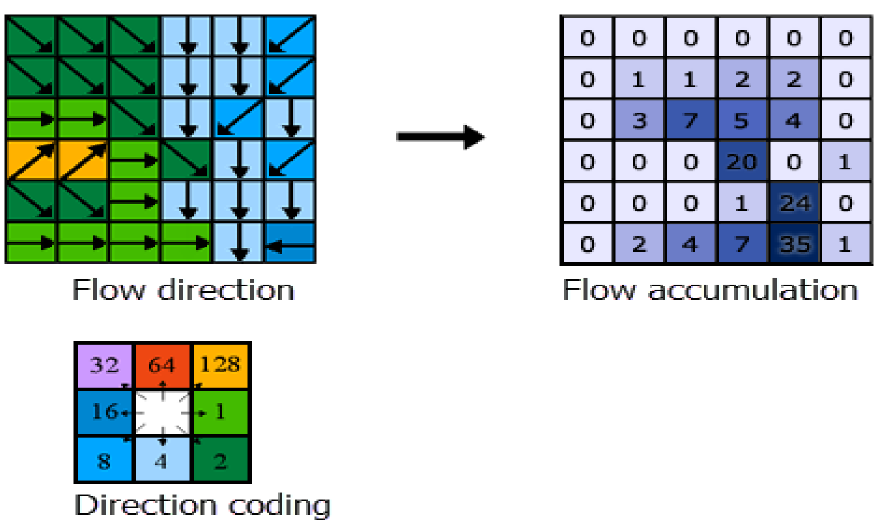

Fig. 6 Determining the accumulation of flow

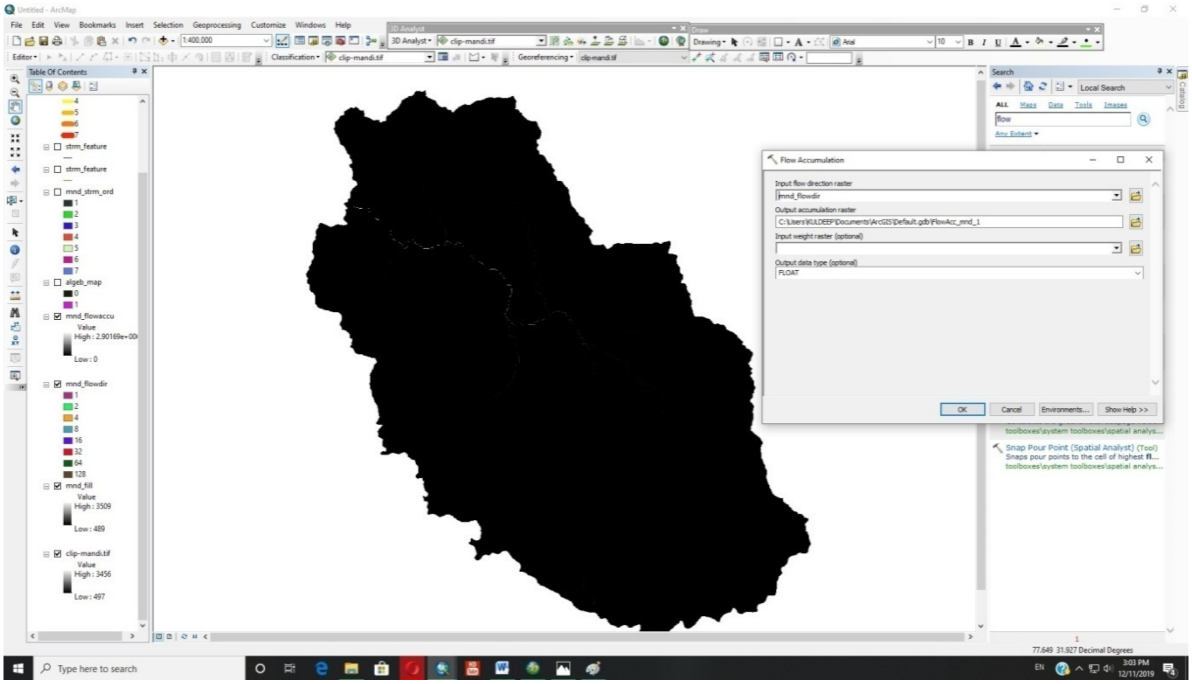

Fig. 7 Flow Accumulation Map

After calculating the flow accumulation map the next step is to reclassify the flow accumulation. For which the property of flow accumulation layer will be opened and then click the classify option in that. Then the available data is grouped into 2 classes. The break values will be classified into 0 and 100. Then the colour of the classes will be change. The resultant map thus produced is as follows.

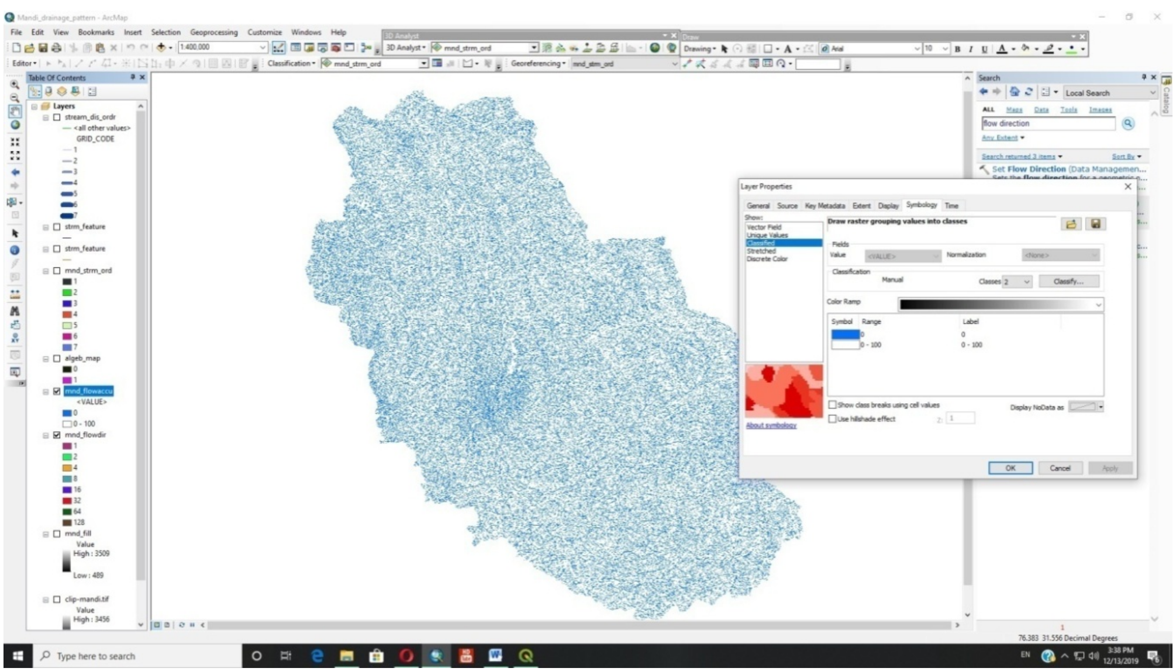

Fig. 8 Flow Accumulation Classified

E. Raster Calculator

The Raster Calculator tool allows you to create and execute a Map Algebra expression that will output a raster. Use the Layers and variables list to select the datasets and variables to use in the expression. Numerical values and mathematical operators can be added to the expression by clicking the respective buttons in the tool dialog box. A list of commonly used conditional and mathematical tools is provided, allowing you to easily add them to the expression. Full paths to data or data existing in the specified current workspace environment setting can be entered in quotes (“”). Numbers and scalars can be directly entered into an expression.

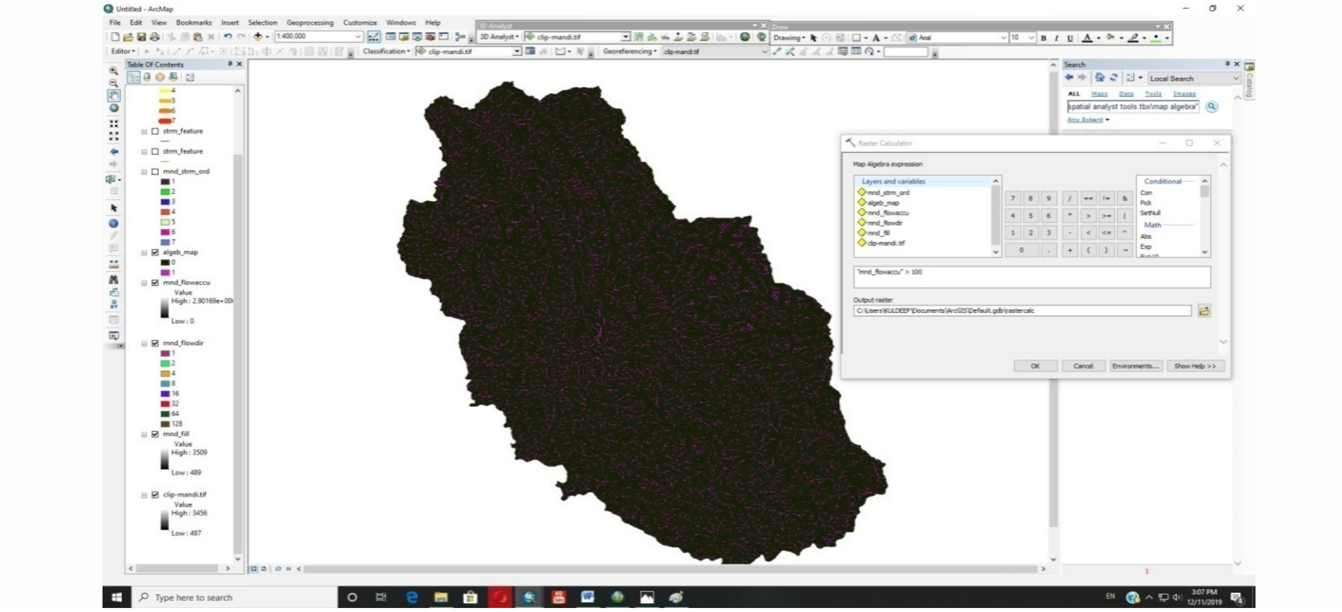

Fig. 9 Raster Calculator

This tool calculates the flow accumulating streams which are greater than 100. The resultant map as show in figure 8 highlights the stream density which is greater than 100.

F. Stream Order

After calculating the map algebra the next step is to order the stream. Stream ordering is a method of assigning a numeric order to links in a stream network. This order is a method for identifying and classifying types of streams based on their numbers of tributaries. Some characteristics of streams can be inferred by simply knowing their order. For example, first-order streams are dominated by overland flow of water; they have no upstream concentrated flow. Because of this, they are most susceptible to non-point source pollution problems and can derive more benefit from wide riparian buffers than other areas of the watershed.

The Stream Order tool has two methods you can use to assign orders. These are the methods proposed by Strahler (1957) and Shreve (1966).

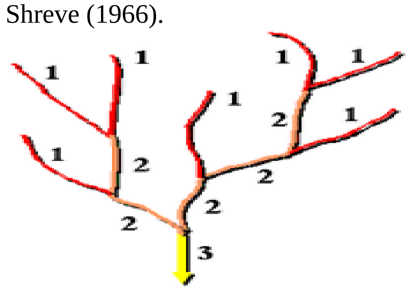

Fig. 10 Strahler stream ordering method

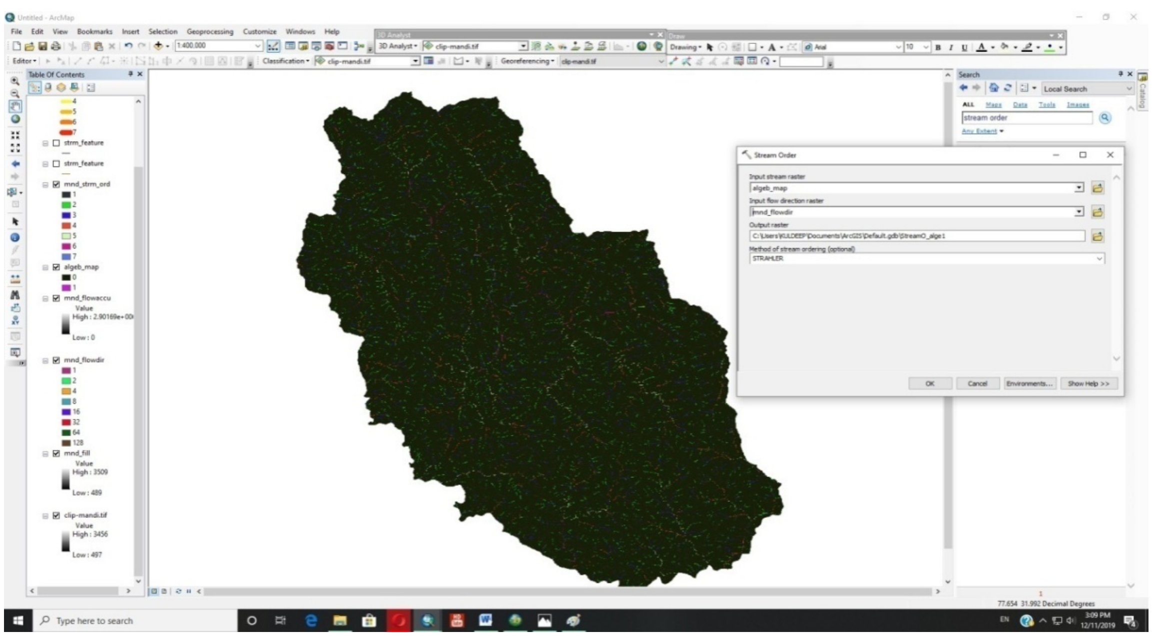

Fig. 11 Stream Order

1. Strahler Method

In the Strahler method, all links without any tributaries are assigned an order of 1 and are referred to as first order. The stream order increases when streams of the same order intersect. Therefore, the intersection of two first-order links will create a second-order link, the intersection of two second-order links will create a third-order link, and so on. The intersection of two links of different orders, however, will not result in an increase in order. For example, the intersection of a first-order and second-order link will not create a third-order link but will retain the order of the highest ordered link. The Strahler method is the most common stream ordering method. However, because this method only increases in order at intersections of the same order, it does not account for all links and can be sensitive to the addition or removal of links.

2. Shreve Method

The Shreve method accounts for all links in the network. As with the Strahler method, all exterior links are assigned an order of 1. For all interior links in the Shreve method, however, the orders are additive. For example, the intersection of two first-order links creates a second-order link, the intersection of a first-order and second-order link creates a third-order link, and the intersection of a second-order and third-order link creates a fifth-order link. Because the orders are additive, the numbers from the Shreve method are sometimes referred to as magnitudes instead of orders. The magnitude of a link in the Shreve method is the number of upstream links.

G. Stream to Feature

The algorithm used by the Stream to Feature tool is designed primarily for vectorization of stream networks or any other raster representing a raster linear network for which directionality is known. The tool is optimized to use a direction raster to aid in vectorizing intersecting and adjacent cells. It is possible for two adjacent linear features of the same value to be vectorized as two parallel lines. This is in contrast to the Raster to Polyline tool, which is generally more aggressive with collapsing the lines together. To visualize this difference, an input stream network is shown below, with the simulated Stream to Feature output compared to the Raster to Polyline output.

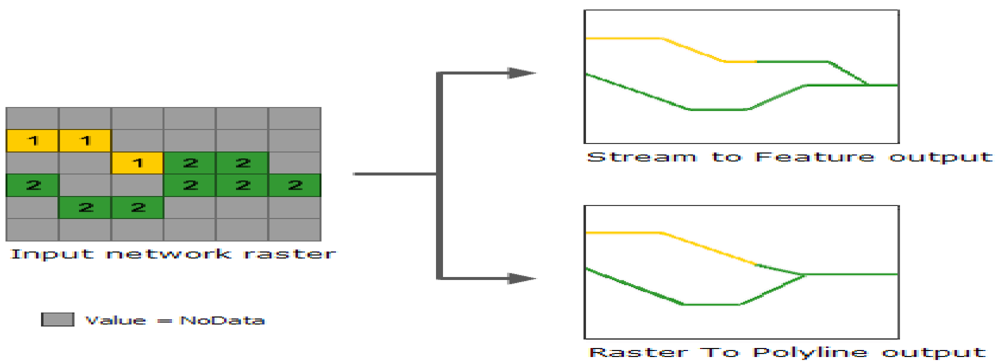

Fig. 12 Comparing vectorizing stream network raster methods

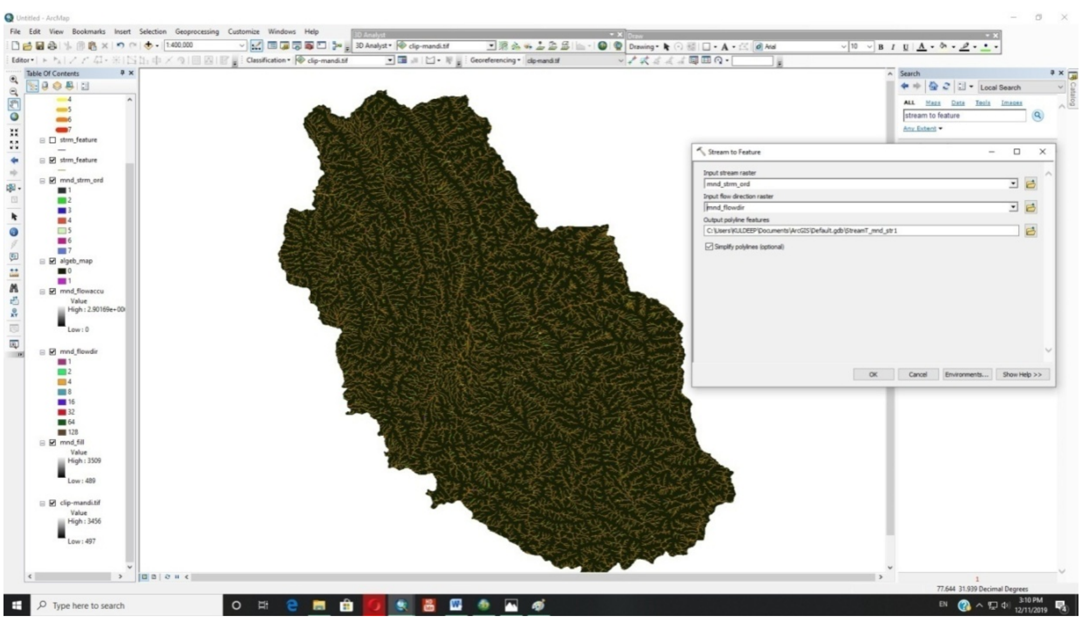

Fig. 13 Stream to Feature

H. Dissolve (Data Management)

Dissolve tool is used when you want to aggregate features based on a specified attribute or attributes. For example, you could take a feature class containing sales data collected on a county-by-county basis and use Dissolve to create a feature class containing contiguous sales regions based on the name of the salesperson in each county. Dissolve creates the sales regions by removing the boundaries between counties represented by the same salesperson.

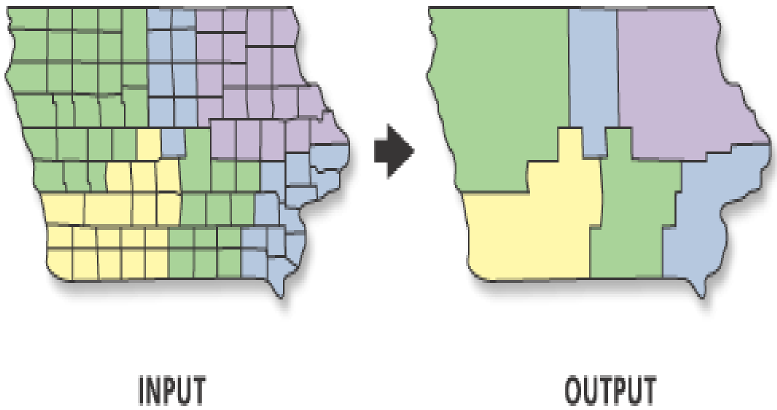

Fig. 14 Principle of Dissolve Tool

Here, after converting the streams to feature there were thousands of attributes in the attribute table which were divided into 7 classes. In order to assign the order value to them the attribute needs to be dissolved by their codes. The resultant attribute table will have only 7 attributes out of thousand attributes.

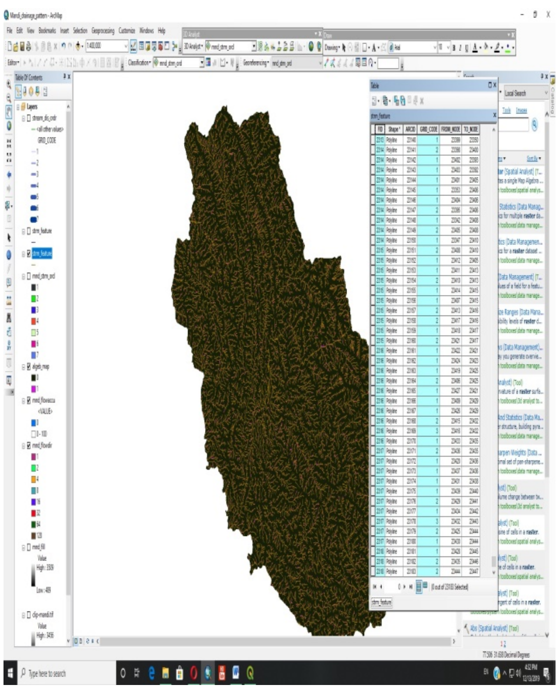

Fig. 15 Stream Order after Dissolve

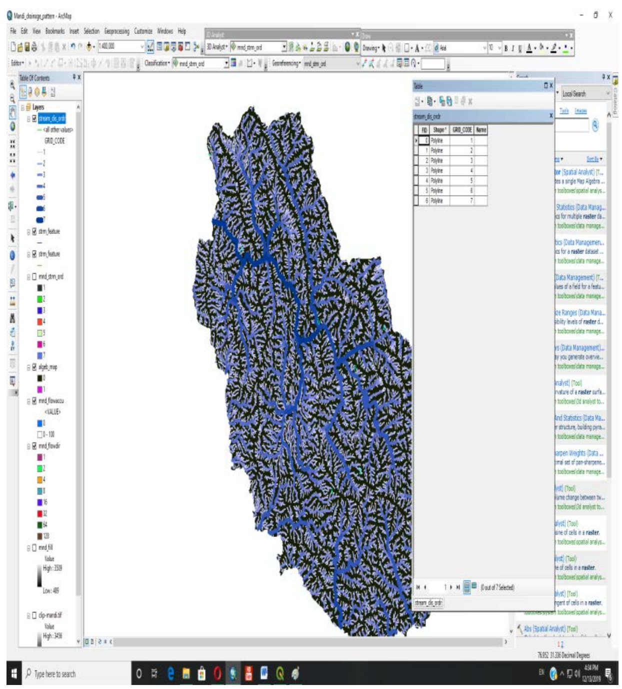

Fig. 16 Stream Order before Dissolve

After using dissolve tool the final map is generated this can be further rectified by assigning different width and colours to the streams according to their order. The highest order will be the biggest stream or river and the lowest order will be the smallest stream.

I. Drainage Map of Mandi District

Drainage map of Mandi district hence generated using all the above hydrological processed is shown in figure 15. The whole drainage system of Mandi district is divided into 7 stream orders. The highest order is 7th which is river Bias which is a major river of India. Stream order 6th is the second highest orders which are seven; these are the main tributaries of the river Bias. The next order is 5th stream order which are 27 in number. These are the main tributaries of 6th order streams. Like this there are 4th, 3rd, 2nd and first order streams in descending order.

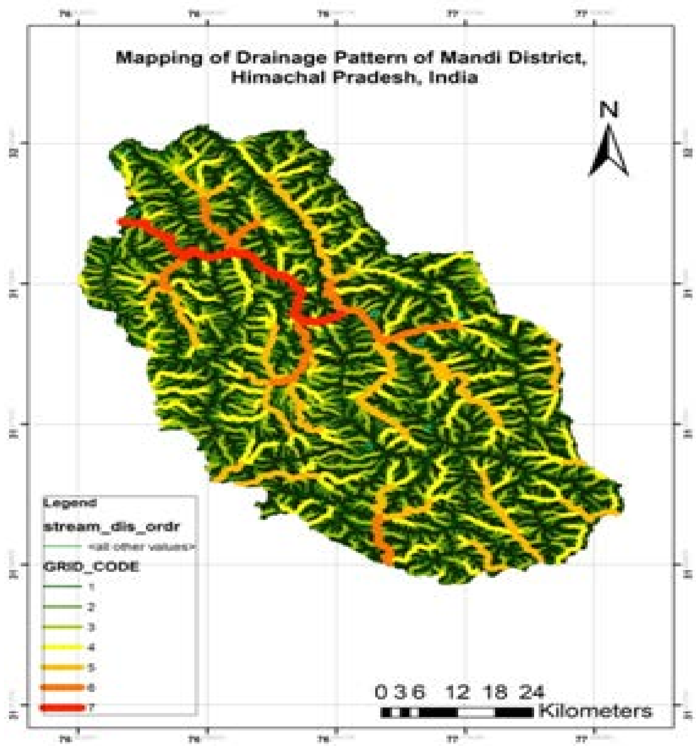

Fig. 17 Drainage Map of Mandi District, Himachal Pradesh

VI. CONCLUSION

As the main objective of this paper was to delineate the stream orders of the study area, hence the objective was achieved by processing the SRTM DEM in QGIS and ArcGIS environment. The final map is generated by following the step by step use of different spatial analyst like, fill, flow direction, flow accumulation, raster calculator, stream order and stream to feature which is further being dissolve (data management tool)to seven classes in ArcGIS. Hence, it is very easy to delineate the stream order using GIS technique with the help of ArcGIS software. If the same has to be done with the help of traditional cartographic technique then it would take weeks to generate such a map.

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