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Watershed delineation using SRTM DEM for Bangalore South Region

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Abstract: *In this paper, we generated 150 sub-watersheds for Bangalore south region using 30m SRTM DEM. Initially, the outlet points are extracted using raster elevation data. The flow direction is derived using a modified D8 algorithm. The stream network is extracted by integrating both the outlets and flow direction using a position matching method. The stream order is derived using Strahler's algorithm. The sub-watersheds for selected mouth points are constructed by considering the stream links. The flow direction accuracy is found to be 95.45% which is compared against the standard D8 algorithm. The overall accuracy of the stream order for the proposed method is found to be 91.83% and is compared with the accuracy of SWAT and Archydro tool.*
Keywords*-flow direction,outlet points,stream order, stream links, watershed.*

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I. INTRODUCTION

Watershed is an area of land where water flows downhill (perpendicular to contour lines) and feeds to reservoirs (streams, rivers or lakes). The watershed delineation is an essential parameter for hydrological modeling like flood predication, estimating the runoff and also helpful in assessing the disaster risk. Watershed has five major components: watershed boundary, Sub-basin, drainage divides, outlets and stream network. The smaller watersheds within a large watershed are called sub-watersheds/ sub-basin. The boundary which divides watersheds is termed as drainage divide. The point from which water flows from watershed to the next watershed (catchment area) is called an outlet point or snap pour point. Fig.1 describes the watershed and its components. Conventionally, area-based and point-based methods are used to delineate the watershed. In area-based, the watershed is generated by dividing the desired area into several sub-watersheds. In point-based, the watershed is generated concerning the desired outlet point (mouth point), the point may be reservoirs like lake, river or dam.

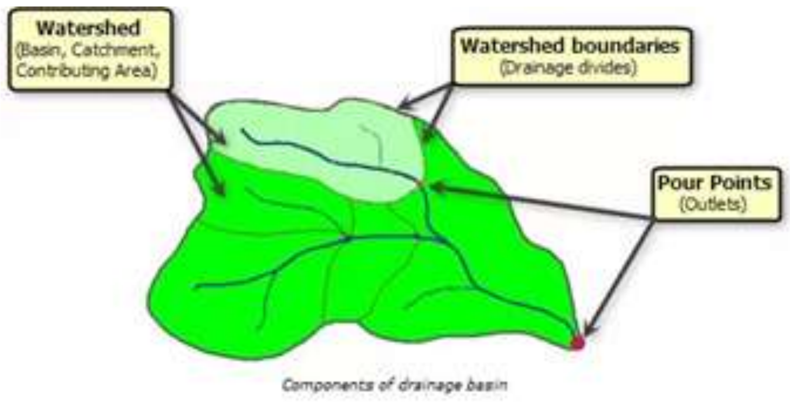

Fig 1: Watershed and its components

Previously, the watersheds and stream networks were extracted using the topographic maps and contour maps of the desired area with a manual drawing by the experts. These methods are time-consuming and are discouraged. With the evolution of the Digital Elevation Model (DEM), delineation of watershed and stream network becomes easy and reduced data complexity as it overcomes the limitations of a conventional method. It also enables the user to manipulate the data as per the requirements. The First Left (FL) and Last Right (LR) methods turn out to be more complex and accuracy was found to be 50 %, as it scans each row from top left to bottom right.

In the proposed method, the SRTM DEM of 30m resolution is used to delineate the watersheds of Bangalore south zone. We combined the local morphological based algorithm and flow directional based algorithm to effectively delineate the watershed.

Initially, the outlet points are extracted by considering terrain elevation information. The flow direction is derived using a modified D8 algorithm. The stream raster is constructed using a position matching method by considering both outlets and flow direction then,the stream raster is converted into stream vector. The stream order for each outlet is extracted using Strahler's algorithm. Sub watersheds are generated using snap pour points of stream orders four to six.

The main contributions of the proposed method are:

1. Delineated watershed based on flow direction and stream order.
2. Proposed flow direction model achieves better accuracy than D8 algorithm and SWAT.

Rest of the paper is organized as follows:Section 2 is a brief related work. Section 3 illustrates the study area and methodology of the proposed work, Section 4 contains experiments and results. Section 5 concludes the proposed work.

II. RELATED WORK:

Dinesh Sathyamoorthy [1] extracted watershed from GTOPO30 global Digital elevation model using mathematical morphology. The DEM is smoothened using reconstruction operation. The pits are extracted using 3×3 kernel erosion operation then the skeletonization is performed to get the boundary of the watershed. The proposed method works well to extract the deeper pits and is applicable for a flat surface.

G.P. Obi Reddy et al [2] performed a comparative evaluation of six different watershed thresholds on STERGDEM and Cartosat-1 DEM to extract the drainage networks of various geographic sizes. Many initiation points of stream network for smaller area and threshold was found in cartosat-1 DEM. As the threshold increase, the difference between extracted drainage parameters reduces in both the DEM.

The automatic watershed of oltet river of Romania was delineated from SRTM-DEM of 90m resolution. The ArcGIS and Quantum GIS (Wroclaw) was used for the study. The Q-GIS doesn't require any pre-processing, it internally removes all sink and pit. ArcGIS externally needs pre-processing. Based on flow direction and flow accumulation watershed was generated for oltet river [3].

The outlet points are efficiently mapped to the stream network based on the Advanced Outlet Repositioning Approach (AORA). The outlets are extracted randomly, then these outlets are moved to the nearest river stream based on the flow path. AORA performs better and watershed generated for 993 outlets and produces less outlet shifting error. Overall watershed is generated with seven different basins [4].

The drainage pattern, flow direction, and mainstream are extracted from DEM using stream guiding algorithm [5]. This overcomes the drawbacks of the stream burning algorithm. The Location of Main Stream (LMS) is determined first followed by outlets in the non-LMS area. Finally, the flow direction in the undetermined area is extracted. The main outline of the proposed work is to find the flow direction of all the outlets. The stream guiding algorithm effectively extracted all the river streams and follows the steepest decent rule.

The watershed for Sabarmati River, India was generated by Litan Kumar Ray et al [6]. The watershed generated from three GIS tools: Archydrology, Archydro, and ArcSWAT were compared and found that ArcSWAT produces the least error. The three different DEMs: SRTM of 90m, Cartosat-1 of 20m and ASTER V2 of 30m were used to validate the performance of GIS tools. ASTER V2 of 30m in ArcSWAT was found better in delineating watershed for Sabarmati River. The disjoint and missing river streams were found for Archydro and other DEM data.

The filling is a pre-processing step in any drainage network extraction. GuiyunZhoua [7] proposed a novel method to fill the depressions in sub-watersheds. The DEM was down-sampled into four groups and again the resolution was reduced to half of its previous DEM. The priority flood algorithm was used to fill the depressions. The parallel processing was performed to reduce the time complexity.

Jing Zhang [8] extracted the hydraulic information from DEM using Archydro. Initially, the DEM pre-processing was performed for the Hillsborough River watershed. The streamflow was defined and an accumulated grid was generated. Based on the accumulated grid, the stream network and watershed boundaries were generated. Overall, the study found that the automatic generation of a watershed using Archydro was efficient and feasible for the data used.

III. Methodology

The SRTM DEM of 30m resolution is used in the proposed method to generate the watershed for Bangalore South region. The obtained four different DEM files are merged using ArcMap and the desired DEM is extracted using shapefile of the study area by performing 'Clip'operation. The data is pre-processed using 'fill' operation to remove the depressions, it doesn't change the natural properties of the terrain. The system architecture of the proposed method is shown in Fig 2.

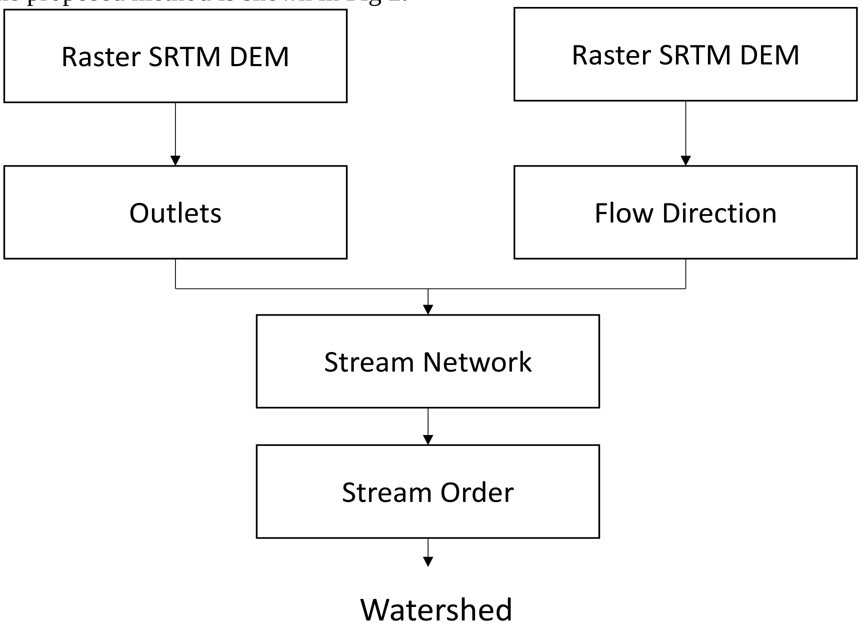

Fig 2: Proposed System Architecture

2.1 Outlet extraction

In Fig 3, let the elevation at point A is 100m and elevation at point B is 90m, the relative height between A and B is 10m and the terrain structure is upslope from A to B. At point C the earth's elevation is 200m and relative height from B to C is -110m, so the terrain is downhill. Similarly, the relative height from point C to point D is 150m and terrain is found to be upslope from point C to point D. The terrain structure from point D to Point E is found to be upslope.

The water hits on surface B flows towards point C. Water hits on surface E flow towards Point D and finally reaches to point C. Overall water collects at point C. The Point C is called outlet. Water discharges to the next catchment area through outlet C. Algorithm 1 describes the procedure to extract all possible outlets of the given study area.

Algorithm 1

- Step 1: Find the most positive number - max.
- Step 2: Check the previous values for positive numbers. If found, add them to max.
- Step 3: Check all the values until a positive number is found.
- Step 4: If negative numbers are found during step 3, add them and check if it neutralizes max. If so, max becomes an outlet and its neighboring points form micro watershed. If not, repeat step 3 until it is neutralized.

Initially, we determined the most positive number and assigned to a variable. If the maximum positive number found than the current value in the variable, then perform addition. The process continues until a positive number is found. If a negative number is found then neutralize the number by adding the variable, then avariable representing a point itself found to be an outlet. Otherwise, the process continues until it neutralizes the variable.

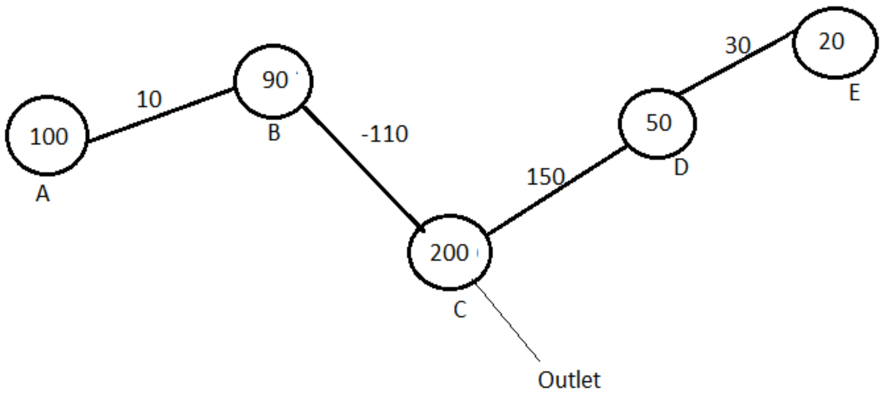

Fig 3: Outlet extraction.

2.2 Flow direction

The DEM which is free from sink/pit is used to determine the direction of water flow from one cellto another through outlet. The flow direction for each center pixel in 3×3 matrix block is calculated by comparing the elevation data of center pixel with its eight neighboring cells. The color coding is adopted to determine the direction of flow.

The eight neighboring pixels indicated eight different directions (North, South, East, West, North East, East South, South West, and West North). Eight different colors are assigned to each neighboring pixels to analyze the direction of flow from center pixel. Fig.4 shows the process of generating flow direction. The steepest slope method and lowest height method are followed to produce the flow direction map.

2.2.1 Steepest slope method

In the steepest slope method, we generate the direction of water flow by determining the steepness value. For each 3by 3 block, the relative height between the center cell/center pixel (CP) and its eight neighbor pixels is calculated. If, for an instance, the relative height is positive value (CP has greater value than its neighbors) then, the relative height value is divided by 1.4 (distance), for corner neighbor.The relative height is divided by unity (distance) for horizontal neighboring cells. This process determines the steepness value between the CP and its neighbors. The (position of the) neighbor with the largest 'steepness' value is the output flow direction for the current central pixel.

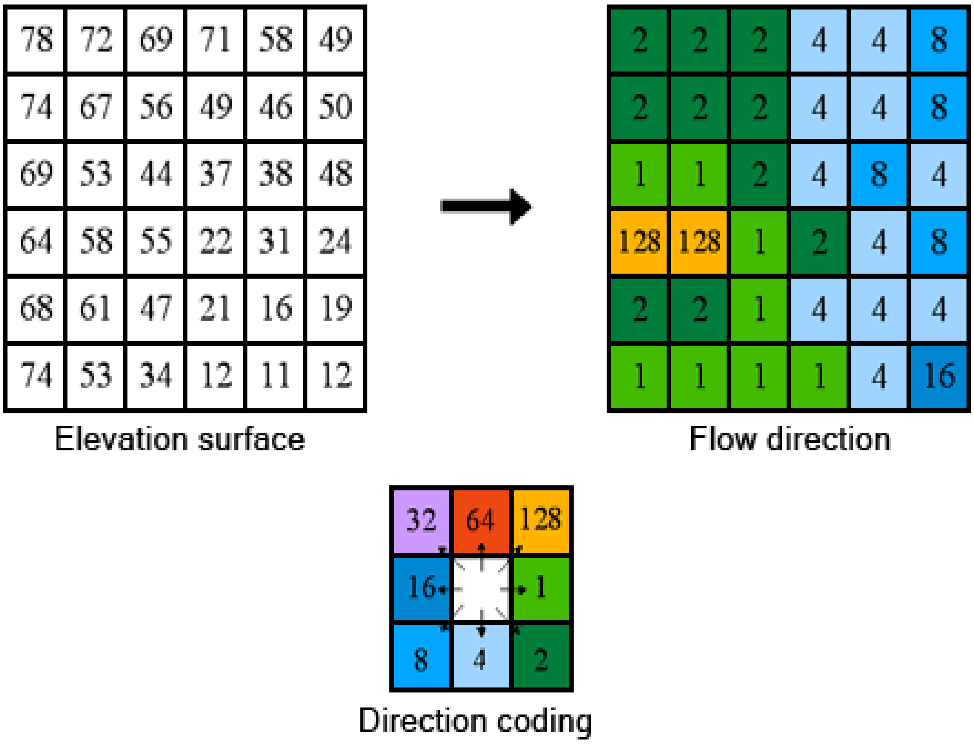

Fig 4: Flow direction

3.2.2. Lowest height method

In the lowest height method, the direction of water flow is generated by considering the relative height, which is determined by calculating the height difference concerning its surrounding eight pixels.For each 3x3 input blocks, the relative height between the current CP and its neighboring cells is calculated. The current CP takes a path which is having largest relative height value among its neighboring cells.

2.2.2 Additional factors that are considered while generating flow direction:

- Return undefined value in the output when,

a) The pixels falls on the edges/margins/corners.
b) The CP itself has undefined value.

- If all neighboring pixels of a central pixel has a larger value than the central pixel itself, then there is a sink or pit in the data hence, remove sink and pit using fill operation
- Ignore the neighboring pixels during operation, when it has undefined values.
- If three consecutive rows or consecutive columns have same value, then the middle position of those three pixel is considered.
- If two consecutive rows or consecutive columns have same relative height value, then any of these two position is considered arbitrarily.

2.3 Stream Raster

The stream links represent the spatial distribution and geographical factors of a watershed. The stream links are extracted using outlets and flow direction. The correlation and decoding method between outlet matrix and flow direction matrix results stream raster. Finally, stream raster is converted into stream vector. Algorithm 2 defines the procedure to extract the stream links.

Algorithm 2:

```
pos=1;
initialize a[i,j] = var;
position mapping;
if p(O(i,j))=p(F(i,j))
a[i,j)=flow_dir(code);
```

```
else if
Pos++;
a[i,j]= outlet;
stream_node=outlet;
else
returnflow_dir(code);
end if
end if
```

3.4 Steam Order

Stream order is a numerical numbering assigned to each stream link. The stream order describes the characteristics of a stream link. One order stream indicates an independent river stream (smallest tributaries), it has no upstream concentrated flow. Three order streams are headwater streams, four to six orders are medium flow streams. Seventh order or larger order constitutes larger tributaries. There are two methods to generate stream orders: Strahler’s method and Shreve’s method. In the proposed work, Strahler’s method is adopted, which is shown in Fig 5.

Fig 5: Strahler’s method

The first-order streams (independent streams) joins together forms a second-order stream. The second-order streams join together forms third order streams. When second-order stream joins with third-order stream it results in highest order stream (third-order stream). When two different stream orders join together it results in the highest order stream link. When same order streams joins together it forms next higher magnitude stream order. The higher-order streams have large size streams and this stream ordering helps to identify the type of reservoir.

3.5 Watershed delineation

Watershed is the boundary, which separates basins, rivers, sea, etc. In the proposed method watershed is delineated by constructing boundary from the root node (selected mouth point) touching all the endpoints of the stream network. Selecting the mouth point automatically identifies its corresponding stream network and its endpoints, thus generates watershed for the selected mouth point.

IV. Implementation And Results

The SRTM DEM of 30m resolution of Bangalore south and Bangalore east is used for the study. The DEM data is pre-processed using fill operation. The pre-processed DEM data is shown in Fig 6. Possible 50326835 outlet points are extracted. The Flow direction using modified D8 algorithm with direction coding in different colors are shown in Fig 7.

The stream network generated using both outlets and flow direction is shown in Fig 8. The stream order generated using Strahler's algorithm is shown in Fig 9. The stream orders are indicated in different colors. The 150 sub-watersheds for fourth, fifth and sixth order outlets are generated and is shown in Fig 10.

The accuracy of the derived flow direction is calculated using correctly codded cells and the total number of cells. It is the ratio of correctly codded cells to the total number of cells in the DEM.

Overall Accuracy (OA) = $\frac{\text{correctly coded cells}}{\text{total number of cells}} \times 100$

The accuracy of the derived watershed for 150 different outlet points are calculated using the drainage map. The extracted stream order was compared against the drainage map and accuracy was calculated.

Stream order accuracy= $\frac{\text{Correctly extracted stream links}}{\text{total stream links in drainage map}} \times 100$

The accuracy of the flow direction is compared against D8 algorithm and overall accuracy of the stream order is compared against SWAT (Soil and Water Assessment Tool) and ArcHydro Tools which is tabulated in Table 1 and Table 2.

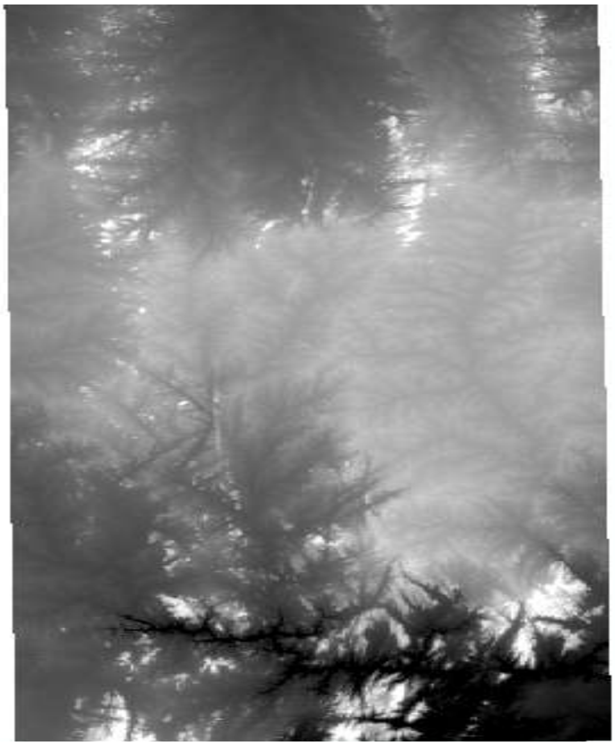

Fig 6: Input SRTM DEM

Table 1: Flow Direction Accuracy of the D8 algorithm and the proposed method

	D-8 algorithm	**Proposed method**
Flow direction accuracy	94.40	95.45

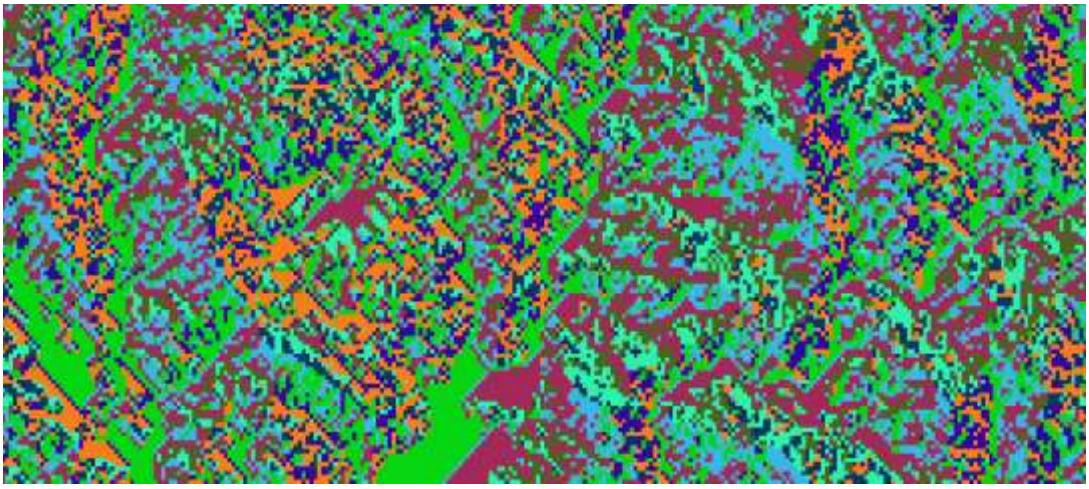

Fig 7: Flow direction

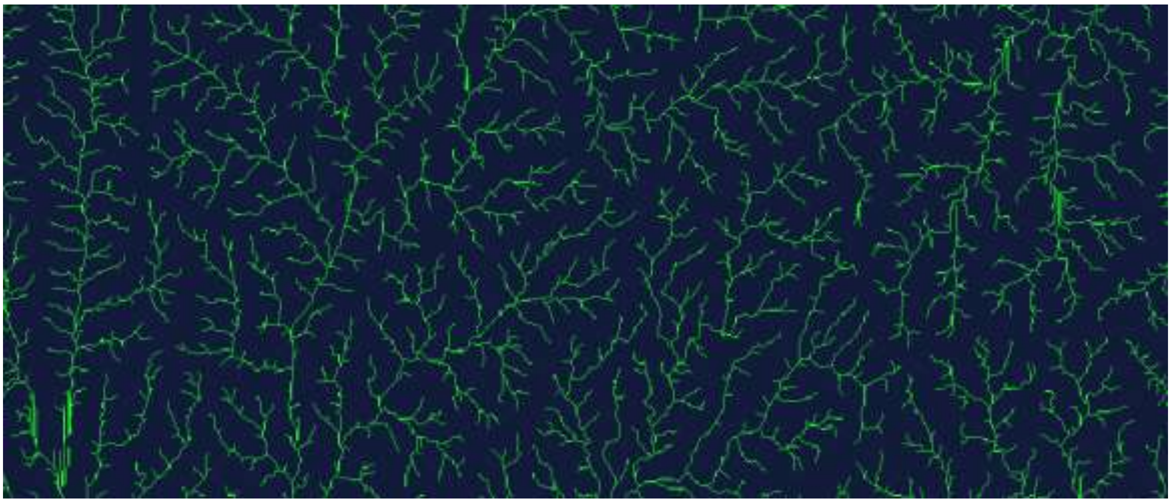

Fig 8: Vector Stream Network

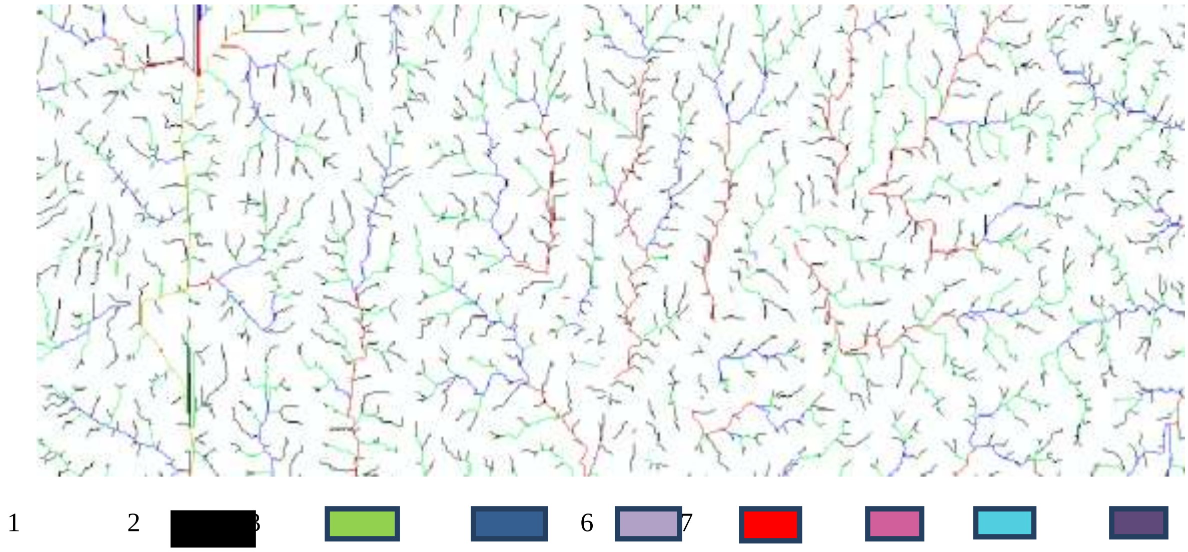

Fig 9: Stream order

Table 2: Stream order Accuracy of the SWAT, ArcHydro and proposed method

	SWAT	**ArcHydro**	**Proposed method**
Stream order accuracy	90.11	91.05	91.83

Fig 10: Watershed

V. Conclusions

In the proposed method, we have delineated watershed and sub-watersheds for Bangalore south region. The acquired SRTM DEM files are merged and desired DEM is clipped using shapefile of the study area in ArcMap. The extracted DEM is pre-processed to remove sink/pit. All possible outlets are extracted by analyzing raster terrain elevation information. The flow direction is generated by calculating steepness value and lowest height and by employing additional rules. The direction color coding is adopted to identify the flow of direction in output raster from one cell to another. Then by using both outlets and flow direction, stream links are extracted. Strahler's algorithm is used to find the stream order which is used to identify the size of the stream and thereby it greatly helps to identify the type of reservoir. Finally, 150 sub-watersheds for fourth, fifth and sixth order outlets are delineated by constructing boundary for the selected outlet point (pour point) covering all the endpoints of its stream links.

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