TECHNICAL REPORT

RUNOFF ESTIMATION IN A CATCHMENT USING GIS AND WEB BASED TOOLS: A CASE STUDY

NATIONAL INSTITUTE OF HYDROLOGY

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Technical Report

RUNOFF ESTIMATION IN A CATCHMENT USING GIS AND WEB BASED TOOLS: A CASE STUDY

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PREFACE

As a result of advanced technologies in geospatial and remote sensing analyses and also due to the spread of internet technologies, web based applications in hydrological sciences are also on the increase. The study presented is an attempt to demonstrate how these tools can be utilised in the estimation of runoff from a catchment. Here effective usage of application of web-based tools like shared hydrometeorological data, satellite imageries, GIS applications, modeling software and other required information are demonstrated. For the demonstration study a sub-basin of River Godavari (the Manjira sub-basin) was selected.

With the popularity of internet technologies and advancements in world wide web applications, there are manifold possibilities to facilitate for scientific research, especially in the area of earthsciences/ water resources investigations. It may be of benefit to many to utilize such opportunities provided by internet applications to carry out at least preliminary investigations, if not advanced studies, in the area of hydrological studies. The methodology adopted therefore was essentially to demonstrate how the freely available information/ tools in the internet/ web can be utilized for hydrological applications such as runoff estimation from watershed. It is well known that hydrometeorological data, satellite imageries, GIS applications, modeling software and other required information are shared in the internet by various organizations on public domain for use anyone. Such information or tools can be utilized effectively for hydrological studies. In addition to Geographic information systems (GIS) have been used for various analyses of spatially distributed data. The ArcGIS program which is also used for the study employed many web applications like GoogleEarth and other public domains where data is shared freely to estimate runoff from a catchment. In general, the methodology involved the application of ArcGIS for GIS based analysis, Curve Number Method for rainfall-runoff estimation, Toposheets – Survey of India, Geological Maps- GSI, Rainfall data – IMD/ State Depts., SRTM data – USGS, Imageries – GLCF (global land cover facility), Land cover data – ESDI (earth science data interface), Google earth image/ google map – Google Inc.

Presented report of the demonstration study carried out by Dr. Mathew K Jose, Scientist D (Principal Investigator) along with Dr. B. Venkatesh of HRRC NIH contains technical details of the methodology used, analyses tools, and resources utilized. The attempt presented here is expected to provide some insight on the usage of web based technologies for hydrological applications.

R D Singh
(DIRECTOR)

ABSTRACT

The study presented is an attempt to demonstrate how these tools can be utilised in the estimation of runoff from a catchment. Here effective usage of application of web-based tools like shared hydrometeorological data, satellite imageries, GIS applications, modeling software and other required information are demonstrated. For the demonstration study a sub-basin of River Godavari (the Manjira sub-basin) was selected. The study area is the river basin of Manjira river, a tributary of R Godavari. Hydrologic analyses are conducted using different kinds of data required and various tools available on the web as open sources to estimate the runoff from watersheds of the R Manjira sub basin. Digital Elevation Models (DEM) of all the catchments in the study area of Manjira River sub-basin were prepared. Also, watershed prioritization and classification of landuse carried out. Web applications Google Earth, GoogleMap, Landsat images etc. have been utilized. The runoff estimation procedure follows the flowchart of: DEM preparation in Arc GIS, Flow Direction maps, Flow accumulation, stream definition, catchment grid delineation, watershed delineation, flow length calculation, land cover/ land use map preparation, Curve number computation, and finally runoff depth calculation.

With the popularity of internet technologies and advancements in world wide web applications, there are manifold possibilities to facilitate for scientific research, especially in the area of earthsciences/ water resources investigations. It may be of benefit to many to utilize such opportunities provided by internet applications to carry out at least preliminary investigations, if not advanced studies, in the area of hydrological studies. The methodology adopted therefore was essentially to demonstrate how the freely available information/ tools in the internet/ web can be utilized for hydrological applications such as runoff estimation from watershed. It is well known that hydrometeorological data, satellite imageries, GIS applications, modeling software and other required information are shared in the internet by various organizations on public domain for use anyone. Such information or tools can be utilized effectively for hydrological studies. In addition to Geographic information systems (GIS) have been used for various analyses of spatially distributed data. The ArcGIS program which is also used for the study employed many web applications like GoogleEarth and other public domains where data is shared freely to estimate runoff from a catchment. In general, the methodology involved the application of ArcGIS for GIS based analysis, Curve Number Method for rainfall-runoff estimation, Toposheets – Survey of India, Geological Maps- GSI, Rainfall data – IMD/ State Depts., SRTM data – USGS, Imageries – GLCF (global land cover facility), Land cover data – ESDI (earth science data interface), Google earth image/ google map – Google Inc. To demonstrate the estimation of runoff as detailed in the mothodology, the Soil Conservation Service (SCS) curve number method from the web is used. In the Curve Number Method, the runoff volume is related to land use, land treatment, hydrological conditions, hydrological soil group, and antecedent soil moisture condition in the drainage basin. All these parameters could be derived using various GIS tools.

Here using Curve number method along with remote sensing and GIS applications, prediction of the runoff depth had been carried out. Remote sensing and GIS applications were employed for the preparation of the catchment area, stream order, land use/land cover, and identifying various type of land uses. The curve number (CN) for each type of land use/ land cover had been approximated and these CN numbes used for the calculation of runoff depth for particular catchment. The required rainfall data was collected from various sources.

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I. Introduction

As we know that water is one of the most important natural resources on earth, it is everywhere. Water is in the ground and in the air that we breathe. All animals, plants and humans need water to survive. Water has formed our earth since its beginning. It also prevents the earth from becoming too hot or too cold. Water never disappears. We use the same water over and over again.

Water in our daily lives

Water has been important for people for thousands of years. Without water there would be no life on earth. We use water in our houses for cooking, bathing and washing the dishes. Water is used to grow food. In many dry areas farmers must bring water to the fields through canals and expensive irrigation systems . Industries and factories also use water. Fruits and vegetables must be cleaned before they can be processed and sold in supermarkets. Water is used for cooling in many areas, for example in steel production. Many countries around the world use water to produce energy. Powerstations burn coal which turns water into steam**.** Countries with many mountains and rivers use the power of water to produce electricity. Water is important for our free time. People enjoy themselves at seasideresorts or on cruise trips . Transportation was at first carriedout on waterways . Ancient civilizations traded goods across the Mediterranean Sea . Today oil, coal, wheat and other products are transported on waterways.

World water supply

The amount of water we have on earth is always the same . However, clean water, is getting rarer because of pollution.

Most of the world's water, about 97% is in the oceans. 1.4 billion cubic kilometers is saltwater. Only 3% is the freshwater in lakes, rivers and glaciers.

Much of the world has enough fresh water but there are regions that are too dry and don't get enough rain. Developingcountries often do not have enough water for their growing populations . Other areas do not have enough water because people waste it.

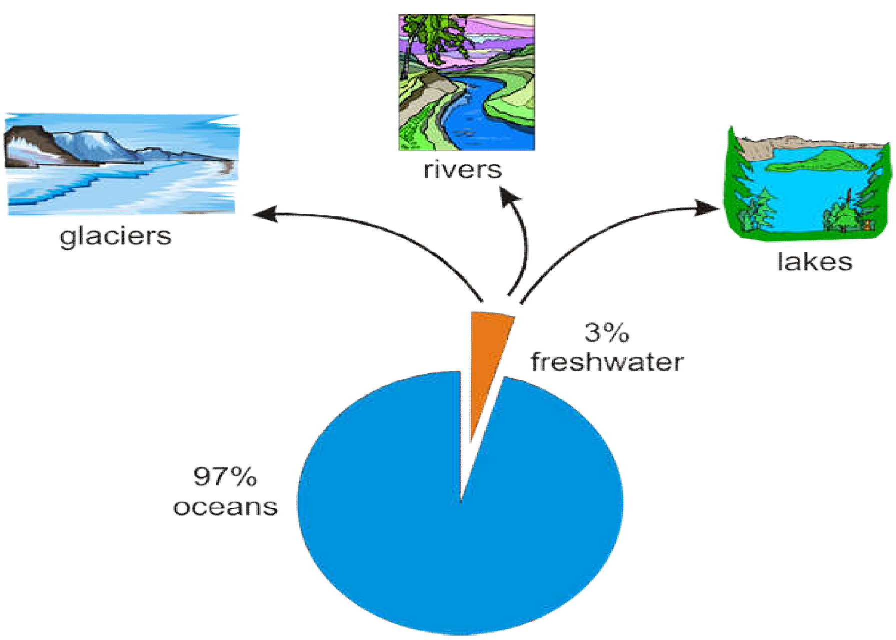

Figure 1: Water Estimates

Water cycle

Water moves in a steady cycle. It never goes away or disappears but it changes from solid to liquid to gas.

When the sun heats up water it becomes a gas and evaporates. As it rises it cools down and clouds form. Clouds have many very small droplets of water in them. When they get too heavy they fall down to the ground as rain or snow.

Although some of this precipitation rises directly into the atmosphere again most of it gets into the ground and remains in aquifers. Snow and ice remain on glaciers and ice caps until it gets warmer. Then it starts melting and the liquid follows into lakes and rivers.

Water has shaped the surface of the earth for many years. It causes erosion , makes mountains smoother , rivers carve themselves into valleys and makes them wider . Ocean waves form coastlines .

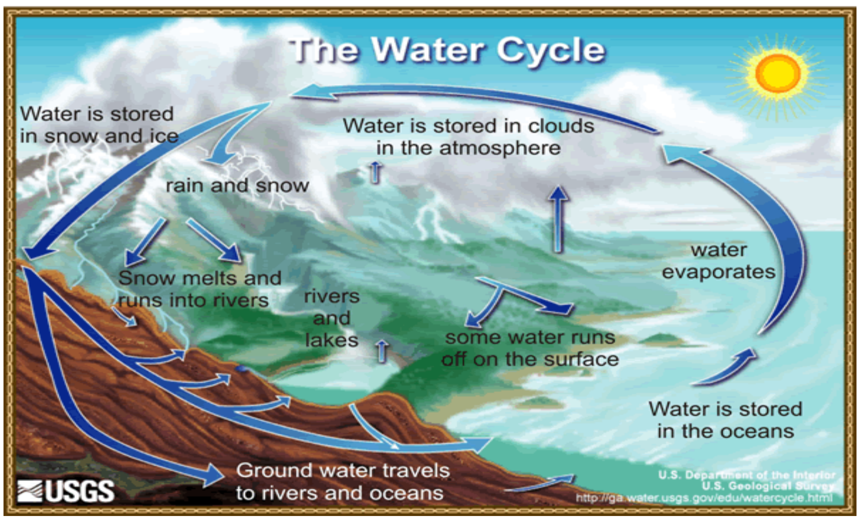

Figure 2: Water Cycle

Water resources engineering is a branch of civil engineering which deals with the quantitative study of the hydrologic cycle – the distribution and circulation of water linking the earth's atmosphere, land and oceans. Applications include the management of the urban water supply, the design of urban storm-sewer systems, and flood forecasting. It also includes Hydraulic engineering which consists of the application of fluid mechanics to water flowing in an isolated environment (pipe, pump) or in an open channel (river, lake, ocean).Applications of hydraulic engineering include the design of hydraulic structures, such as sewage conduits, dams and breakwaters, the management of waterways, such as erosion protection and flood protection, and environmental management (such as prediction of the mixing and transport of pollutants in surface water). Hydroelectric-power development, water supply, irrigation and navigation are some familiar applications of water resources engineering involving the utilization of water for beneficial purposes.

II. OBJECTIVE

I. To create watershed boundaries from raster digital elevation model datasets
II. Preparation of Land Use/Land Cover Map.
III. Find the volume of Runoff using SCS-CN Method.

III. Flow Chart

Water Shed Delineation

Figure 3: Flow Chart of Water Shed Delineation

Land Use/Land Cover Map preparation

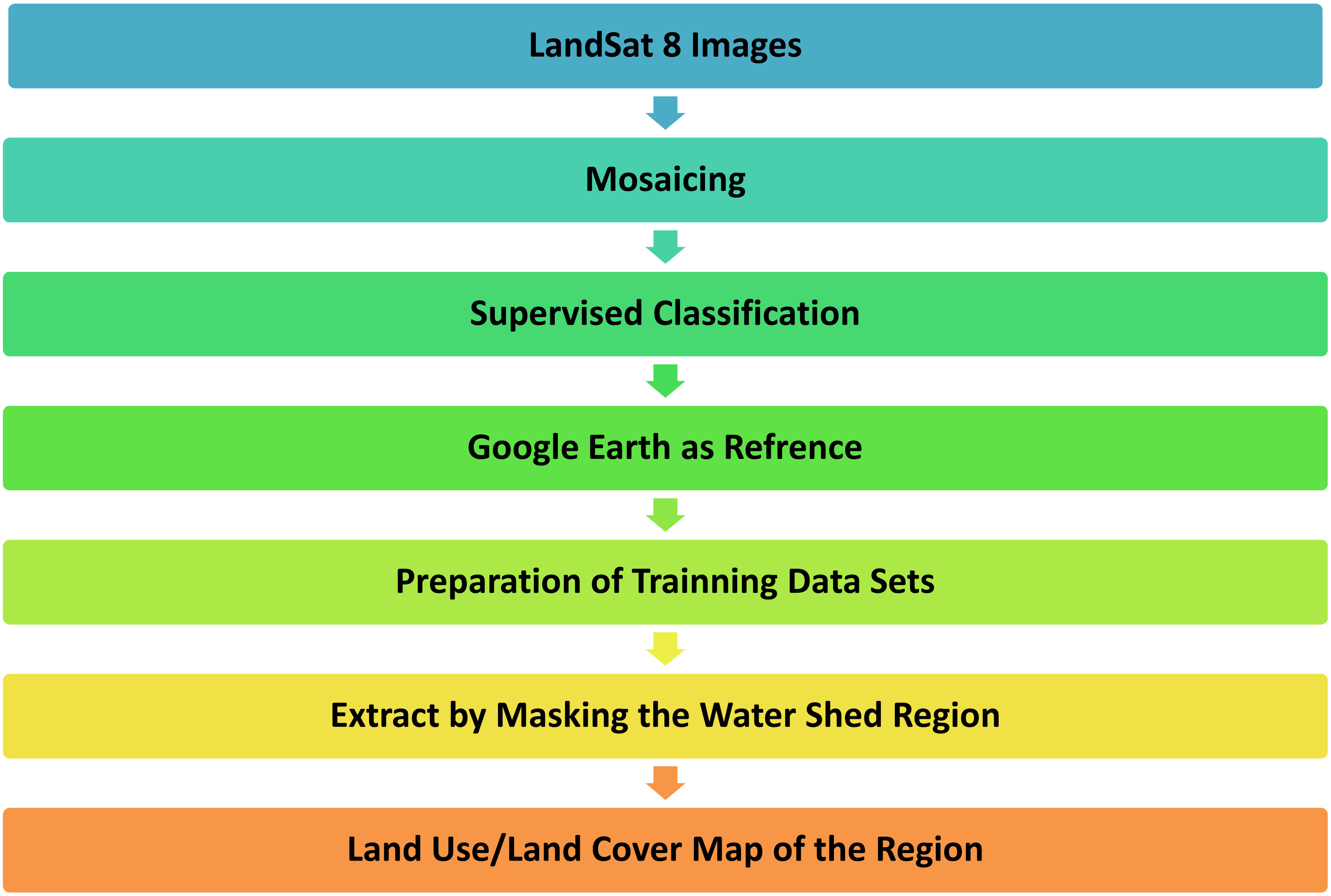

Figure 4: Flow Chart of LU/LC Map Preparation

Discharge calculations and assumptions

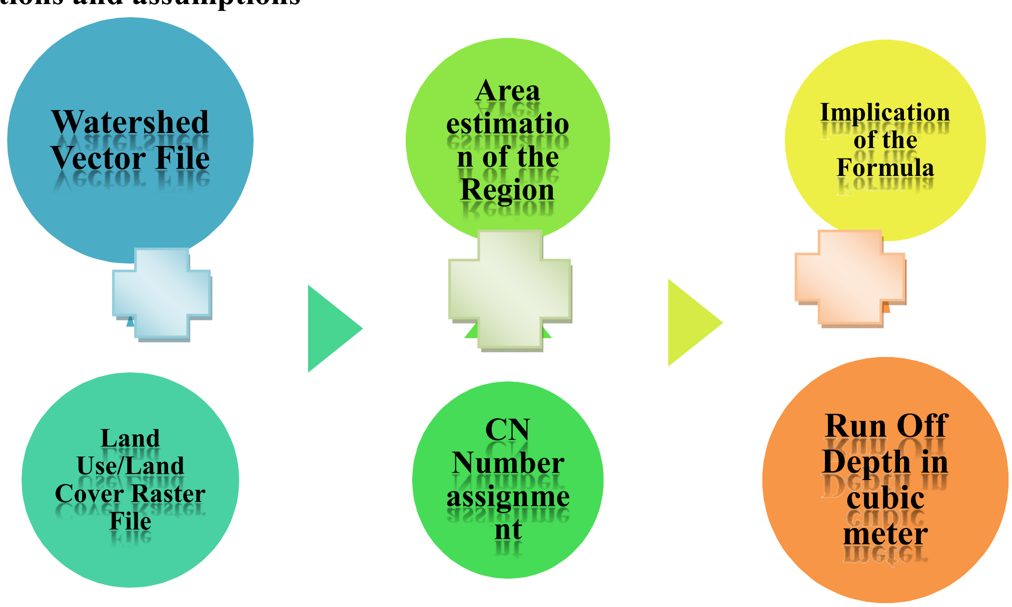

Figure 5: Flow Chart of Discharge Calculation

IV. Methodology

1. Determination of watershed
2. Preparation of Land use land cover map
3. Discharge calculations and assumptions

A. Watershed delineation

1. Start ArcGIS and create a new map document named as Watershed Delineation

1. Creating a depressionless DEM using the mosaic raster called as fill.

2. Flow direction raster formulated from the depression less DEM prepared earlier.

3. Flow accumulation raster evaluated from the flow direction using arc tools hydrology tools

4. Watershed pour points identification is done using pour point tool.

5. Delineating watersheds using the pour points stream order derived from flow accumulation raster.

3. Automatically delineating watersheds ("Basins").

4. Calculating flow length using flow length tool from arc tool box.

5. Raster to vector conversion (stream network as line shape)

6. Watershed visualization

Note:

Start ArcGIS and open a new map document

1. Download the data set, unzip it and save the files to your working directory.

2. If you create a directory that has spaces anywhere in the pathname, expect things not to work properly.

3. Open ArcMap.

4. Enable the Spatial Analyst Extension.

5. Add the layer Dem to the data frame.

6. Set some environment properties (Geoprocessing > Environments)

Creating a depressionless DEM

It is important to start with an elevation grid that has no depressions.

1. Open the ArcToolbox toolset Spatial Analyst Tools > Hydrology. This is where the surface hydrology tools are located.

2. Open the Fill tool. The input surface is the Dem grid. Output is C:\temp\hydro\Fill_dem1 (the default name). Grid filling may take a few minutes.

3. After a few minutes, a new layer, fill_dem1, will be added to the data frame. This is identical to the Dem raster, but any areas of internal drainage are filled in. Note the difference in the lowest elevation value in the legend; sink cells in the original data set have been filled in.

4. Delete the Dem layer from the data frame, since you will be working on the filled grid from this point on. It is important to have a depressionless DEM for all subsequent hydrological analyses. Areas of internal drainage can cause problems later in the watershed delineation process.

Flow direction

Using the ARCHYDRO Tool we commence the following operations

1. Open the Flow Direction tool. The input surface is the filled Dem grid. The output raster should be set to C:\temp\hydro\FlowDir_fill1 (the default).

OK.

2. Turn off display of the Fill_dem1 layer. Add the layer streams to the data frame You should start to see some patterns. Note that the numbers refer to coded direction of flow.

Direction of flow must be known for each cell, because it is direction of flow that determines the ultimate destination of water flowing across the surface.

Flow accumulation

1. Open the Flow Accumulation tool.

1. Set the input flow direction raster to the output of the last task (FlowDir_fill1).

2. Set the output raster to C:\temp\hydro\FlowAcc_flow1 (default name). Then

OK.

2. Turn off the Flow Direction layer. The flow accumulation layer has a value for each cell; that value represents the number of cells upstream from that cell. Cells with higher values will tend to be located in drainage channels rather than on hillsides or ridges.

3. Alter the legend for this layer. It will be easier to visualize high-flow pathways by altering how cells are displayed. Change the symbology method to classified.

You should also see that the DEM-generated drainage network looks somewhat like the vector streams, although if you look at details you will see where the data sets do not line up. You will need to zoom in before you can see the details of the flow network. Flow accumulations are important because they allow us to locate cells with high cumulative flow. Pour points must be located in cells of high cumulative flow, or the resultant watersheds will be very small.

Stream Definition

Add the input as Flow accumulation raster.

Define the number of cells input to the accumulation zones for the thresholding of the streams

Stream Segmentation

Add the Flow Direction raster and Steam Definition layer as input to the tool.

This tool gives the order to the stream creating a stream order layer.

Catchment Grid Delineation

Add Flow Direction and Stream order layer as input to the following tool.

It provides us with the automatic catchment area segmentation of the individual stream with the distance parameter from the outlet point to the input points.

Catchment Polygon processing

Add Catchment grid as input to the tool and the following tool creates a separate poly gon to the separate feature of catchment grid.

Hence we have a series of catchment of the region of interest.

Drainage Line Processing

Add Stream order layer and flow direction layer as input to the tool.

Output of the drainage line is created along the catchment area consisting the data of the stream order of the river.

Adjoint Catchment Area

It is the technical property of the drainage which can be interpreted as a watershed of the region if the systematical attachment between the stream, catchment and the flow direction towards the flow accumulation zones, hence this tool collects the adjoining features of the stream and the catchment and grouping these features into a single attribute value.

Batch Point generation

It is the creation of a point shape file for the determination of the pour points of the catchment delineation starting from the drainage point of highest and final accumulation.

Batch Watershed Delineation

Using this batch point and along with it stream line data and the catchment data and finally the adjoining data of the terrain is used as input for the various parameters to be formulated for the delineation of the watershed of the area of interest.

Calculating flow length

Flow length shows the distance water will need to travel across the grid.

1. Open the Flow Length tool.

1. The input raster is the flow direction grid created earlier (flowdir_fill1).

2. Use defaults for the other controls. Ok.

2. Alter the color ramp so you can see the differences between low flow length and high flow length areas. In this color ramp, the red cells are at the upper reaches of streams in the forest, and the blue cells are farther downstream.

This shows the flow length to the ultimate pour point for each cell.

Watershed visualization

The last step for this lesson will be to visualize the watersheds created earlier with other data.

1. Create a new data frame.

2. Add a copy of the grid layer fill_dem1 from the other data frame.

3. Create a hillshade grid from fill_dem1.

4. Add the pour_points point feature layer.

5. Add the stream network you created above.

6. Add a copy of the watershed1.shp polygon feature layer. 7. Alter its legend so that is is not filled and displayed with a red outline.

7. Alter the drawing order and legends so that features are discernible.

B. Land Use/Land Cover

Land use and land cover (LULC) refers to the physical characteristics of earth surface, captured in the distribution of vegetation, water, soil and other physical features of the land, including those created solely by human activities(Louisa and Antonio, 2001).

The study area Sub-Basin of Manjira River falls in path/row 144/47, 145/47, 144/48 & 145/48 of LandSat 8 data of 7th April, 2014 was used for Land Density/type classification and google earth was used as a reference imagery for this study based on ground truth data. The study area was extracted using boundary layer provided by Andhra Pradesh Admin Data shape files. Each image was enhanced using linear contrast stretching and histogram equalization to improve the image quality and to identify ground control points (GCP). The datasets were brought into Universal Transverse Mercator (UTM) projection and WGS 84 datum. In the present work, Supervised Classification was used because this has been most frequent method for remotely sensed data classification. In supervised classification samples of known identity were used to classify pixels of unknown identity. Training sites in the image are generated to represent the typical spectral information of the land cover classes, like dense forest, open forest, barren land and agricultural land etc (Reddy and Roy, 2008). In supervised classification the pixel categorization process is done by specifying to the computer algorithm, numerical descriptors of the various land cover types present in the scene. To this representative sample site of known cover types called training areas are used to compile the key that describes the spectral attributes for each feature type of interest. There are various algorithms for classification, which include minimum distance to mean classifier, parallelepiped classifier and maximum likelihood classifier. In the minimum distance to means classifier the mean value for the training dataset is calculated and this is used for classification of other unclassified pixels. The pixels are classified to the particular class from which it is at a minimum distance. This is mathematically simple and computationally efficient but is intensive to different degrees of variance in the spectral response data.

Table 1. Attribute data of supervised classification of change detection images

	LISS-III 2010		LAND SAT 2000	
FEATURE NAME	AREA OCCUPIED IN (Sq.Km)	% OF AREA OCCUPIED	AREA OCCUPIED IN (Sq.Km)	% OF AREA OCCUPIED
AGRICULTURE FIELDS	317.354	37.75	364.297	43.32
AQUACULTURE TANKS	215.757	25.66	277.668	33.02
DRAINS	4.234	0.27	4.234	0.27
FALLOW LAND	57.113	6.79	19.587	2.31
MANGROVES	13.868	1.64	13.868	1.64
MUD FLATS	37.918	4.51	46.006	5.47
PLANTATION MIXED WITH CROP	106.025	12.61	45.132	5.47
RIVERS	36.414	4.3	36.414	4.3
SETTLEMENTS	56.869	6.76	35.346	4.2
TOTAL	845.552	100.00	845.552	100.00

Supervised Training

Supervised training is closely controlled by the analyst. In this process, you select pixels that represent patterns or land cover features that you recognize, or that you can identify with help from other sources, such as aerial photos, ground truth data, or maps. Knowledge of the data, and of the classes desired, is required before classification. By identifying patterns, you can instruct the computer system to identify pixels with similar characteristics. If the classification is accurate, the resulting classes represent the categories within the data that you originally identified.

Selecting Training Samples

It is important that training samples be representative of the class that you are trying to identify. This does not necessarily mean that they must contain a large number of pixels or be dispersed across a wide region of the data. The selection of training samples depends largely upon your knowledge of the data, of the study area, and of the classes that you want to extract. ERDAS IMAGINE enables you to identify training samples using one or more of the following methods:

• using a vector layer

• defining a polygon in the image

• identifying a training sample of contiguous pixels with similar spectral characteristics

• identifying a training sample of contiguous pixels within a certain area, with or without similar spectral characteristics

• using a class from a thematic raster layer from an image file of the same area (i.e., the result of an unsupervised classification)

User-defined Polygon: Using your pattern recognition skills (with or without supplemental ground truth information), you can identify samples by examining a displayed image of the data and drawing a polygon around the training site(s) of interest. For example, if it is known that oak trees reflect certain frequencies of green and infrared light according to ground truth data, you may be able to base your sample selections on the data (taking atmospheric conditions, sun angle, time, date, and other variations into account). The area within the polygon(s) would be used to create a signature.

C. Run off estimation using SCS-CN Method

Using the LU/LC map we identify the soil groups and types of the area of interest. Correspondingly Curve number of the soil type was identified using the Curve Number table provided by the engineering Hydrology text.

In methodology a brief description of the assignment of the curve number for the soil groups is mentioned.

Then flowingly the run off volume was calculated using the curve number formula.

V. ANALYSIS

Fill

 A sink is a cell with an undefined drainage direction; no cells surrounding it are lower. The pour point is the boundary cell with the lowest elevation for the contributing area of a sink. If the sink were filled with water, this is the point where water would pour out.

 The z-limit specifies the maximum depth of a sink that will be filled. The z-limit is not the maximum depth to which a sink will be filled.

- All sinks that are less than the z-limit lower than their lowest adjacent neighbor will be filled to the height of their pour points.

- Due to the iterative nature of Fill, it can be CPU and disk intensive. It can require up to four times the disk space of the input raster.

- The number of sinks found with the z-limit will determine the length of processing time. The more sinks, the longer the processing time.

- The Sink tool can be used to find the number of sinks and help identify their depth. Knowing the depth of the sinks can help in determining an appropriate z-limit for Fill.

- Fill can also be used to remove peaks. A peak is a cell where no adjacent cells are higher. To remove peaks, the input surface raster must be inverted. This can be performed with the Minus tool. Specify the highest value of the input surface raster as the input raster or constant value 1, and input surface raster as Input raster or constant value 2. Perform a Fill. Invert the results to obtain a surface that has original surface raster values with the peaks removed. The z-limit can be applied to this process as well. If nothing is specified for z-limit, then all peaks will be removed. If it is specified, where the difference in z-value between a peak and its highest adjacent neighbor is greater than the z-limit, that peak will not be removed.

Figure 6: DEM Fill

Flow Direction

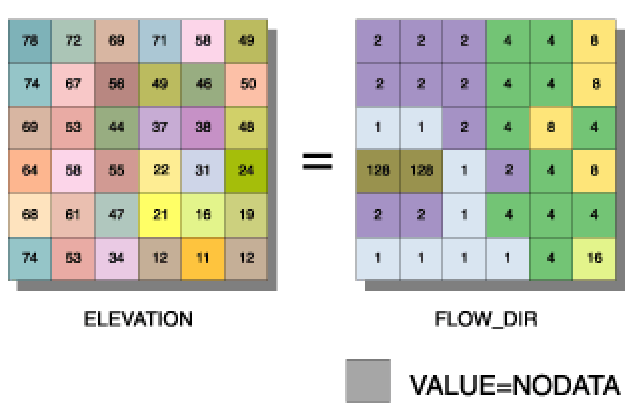

Figure 7: Flow Direction Working

- The output of the Flow Direction tool is an integer raster whose values range from 1 to 255. The values for each direction from the center are:

32	64	128
16		1
8	4	2

Figure 8: Flow Direction Values

For example, if the direction of steepest drop was to the left of the current processing cell, its flow direction would be coded as 16.

- If a cell is lower than its eight neighbors, that cell is given the value of its lowest neighbor, and flow is defined toward this cell. If multiple neighbors have the lowest value, the cell is still given this value, but flow is defined with one of the two methods explained below. This is used to filter out one-cell sinks, which are considered noise.

- If a cell has the same change in z-value in multiple directions and that cell is part of a sink, the flow direction is referred to as undefined. In such cases, the value for that cell in the output flow direction raster will be the sum of those directions. For example, if the change in z-value is the same both to the right (flow direction = 1) and down (flow direction = 4), the flow direction for that cell is 1 + 4 = 5. Cells with undefined flow direction can be flagged as sinks using the Sink function.

- If a cell has the same change in z-value in multiple directions and is not part of a sink, the flow direction is assigned with a lookup table defining the most likely direction. See Greenlee (1987).

- The {out_drop_raster} is calculated as the difference in z-value divided by the path length between the cell centers, expressed in percentages. For adjacent cells, this is analogous to the percent slope between cells. Across a flat area, the distance becomes the distance to the nearest cell of lower elevation. The result is a map of percent rise in the path of steepest descent from each cell.

When calculating the {out_drop_raster} in flat areas, the distance to diagonally adjacent cells (1.414 * cell size) is approximated by 1.5 * cell size to increase the processing speed by using integer calculations.

- When using the NORMAL option, a cell at the edge of the surface raster will flow toward the inner cell with the steepest drop in z-value. If the drop is less than or equal to zero, the cell will flow out of the surface raster

he direction of flow is determined by the direction of steepest descent from each cell.
This is calculated as: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.

If the descent to all adjacent cells is the same, the neighborhood is enlarged until a steepest descent is found.

If all neighbors are higher than the processing cell, it will be considered noise, filled to the lowest value of its neighbors, 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 NoData cell as a neighbor, then it is not filled due to insufficient neighbor information. To be considered a true one-cell sink, all neighbor information must be present.

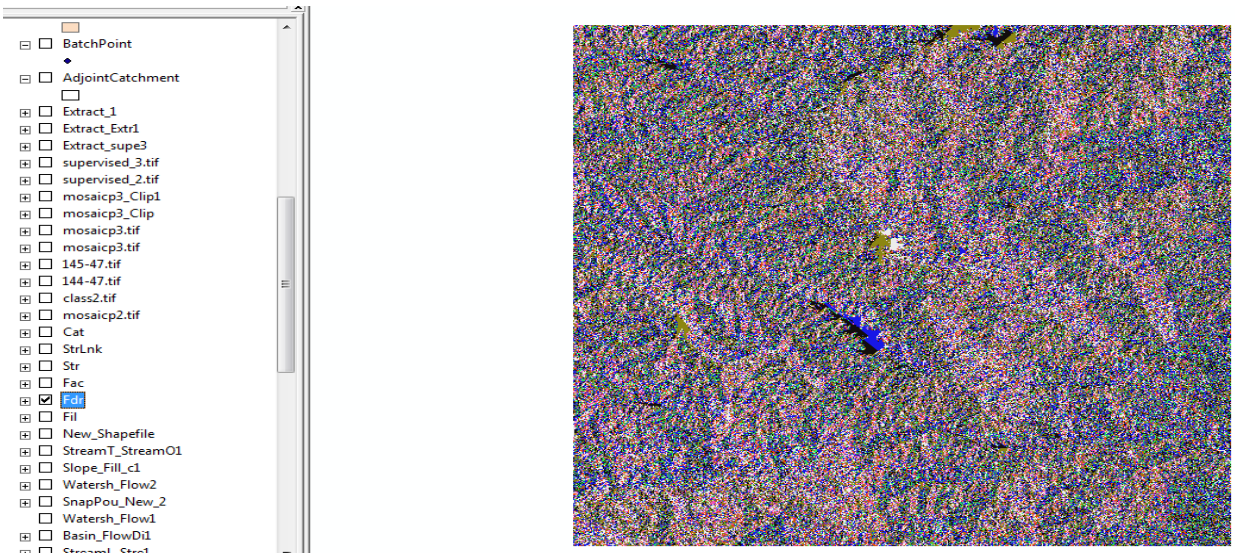

Figure 9: Flow Direction of the Area of Interest

Flow Accumulation

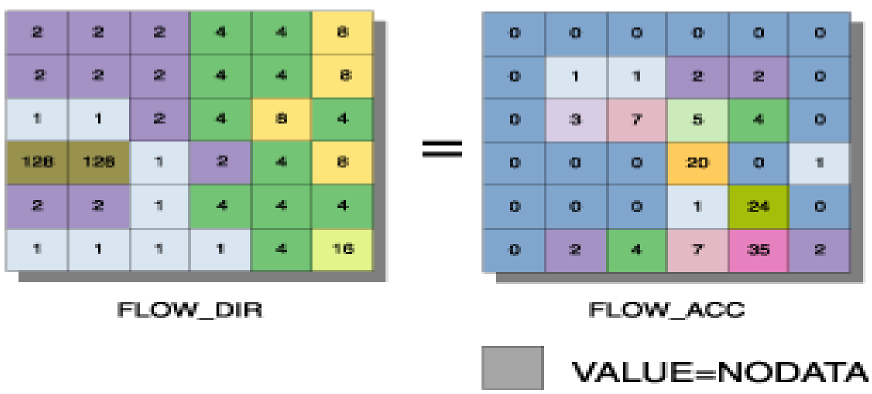

Figure 10: Flow Accumulation Working

- The result of Flow Accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each downslope cell.

- Cells of undefined flow direction will only receive flow; they will not contribute to any downstream flow. A cell is considered to have an undefined flow direction if its value in the <in_flow_direction_raster> is anything other than 1, 2, 4, 8, 16, 32, 64, or 128.

- The accumulated flow is based on the number of cells flowing into each cell in the output raster. The current processing cell is not considered in this accumulation.

- Output cells with a high flow accumulation are areas of concentrated flow and can be used to identify stream channels.

 Output cells with a flow accumulation of zero are local topographic highs and can be used to identify ridges.

 If the <in_flow_direction_raster> is not created with the FlowDirection command, there is a chance that the defined flow could loop. If the flow direction does loop, Flow Accumulation will go into an infinite loop and never finish.

A sample usage of the Flow Accumulation tool with the {in_weight_raster} might be to determine how much rain has fallen within a given watershed. In such a case, the {in_weight_raster} may be a continuous raster representing average rainfall during a given storm. The output of Flow Accumulation would then represent the amount of rain that would flow through each cell, assuming that all rain became runoff and there was no interception, evapotranspiration, or loss to groundwater. This could also be viewed as the amount of rain that fell on the surface, upslope from each cell.

The results of Flow Accumulation can be used to create a stream network by applying a threshold value to select cells with a high accumulated flow. For example, the procedure to create a raster where the value one represents the stream network on a background of NoData could use one of the following:

- Perform a Con operation in which the input conditional raster is "Flowacc", the input true raster a constant "1", and the expression "> 100".
- Alternatively, perform a Set Null in which the input conditional raster is "Flowacc", the input true raster a constant "1", and the expression "< 100".

In both examples, all cells that have more than 100 cells flowing into them are assigned one; all other cells are assigned NoData. For future processing, it is important that the stream network, a set of raster linear features, be represented as values on a background of NoData.

The resulting stream network can be used as input to the Stream Order, Stream Line, and Stream Link tools.

Figure 11: Flow Accumulation of the DEM

Stream Order

 The input stream raster linear network should be represented as values greater than or equal to one on a background of NoData.

- The results of the Flow Accumulation function can be used to create a raster stream network by applying a threshold value to select cells with a high accumulated flow. For example, cells that have more than 100 cells flowing into them are used to define the stream network. Use the Con or Set Null functions to create a stream network raster where flow accumulation values of 100 or greater go to one, and the remainder are put to the background (NoData). The resulting stream network can be used in Stream Link and Stream to Feature. An analytical method for determining an appropriate threshold value for stream network delineation is presented in Tarboton et al. (1991).

- The output of Stream Order will be of higher quality if the input stream raster and input flow direction raster are derived from the same surface. If the stream raster is derived from a rasterized streams dataset, the output may not be usable because, on a cell-by-cell basis, the direction will not correspond with the location of stream cells.

- In the STRAHLER order method, all links with no tributaries are assigned an order of one and are referred to as first order. When two first-order links intersect, the downslope link is assigned an order of two. When two second-order links intersect, the downslope link is assigned an order of three, and so on. When two links of the same order intersect, the order will increase. This is the most common method of ordering.

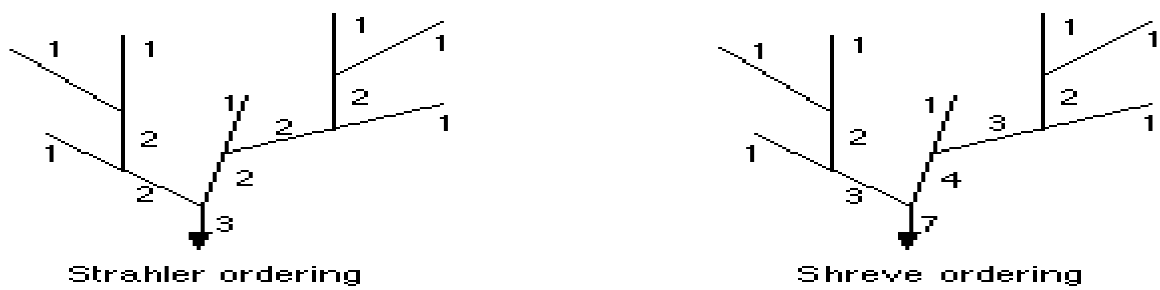

Figure 12: Stream Order Methods of Calculation

- The output from the Stream Order tool is an integer raster.
- References include: Tarboton, D. G., R. L. Bras, and I. Rodriguez-Iturbe. 1991. On the Extraction of Channel Networks from Digital Elevation Data. 'Hydrological Processes'. 5: 81-100.

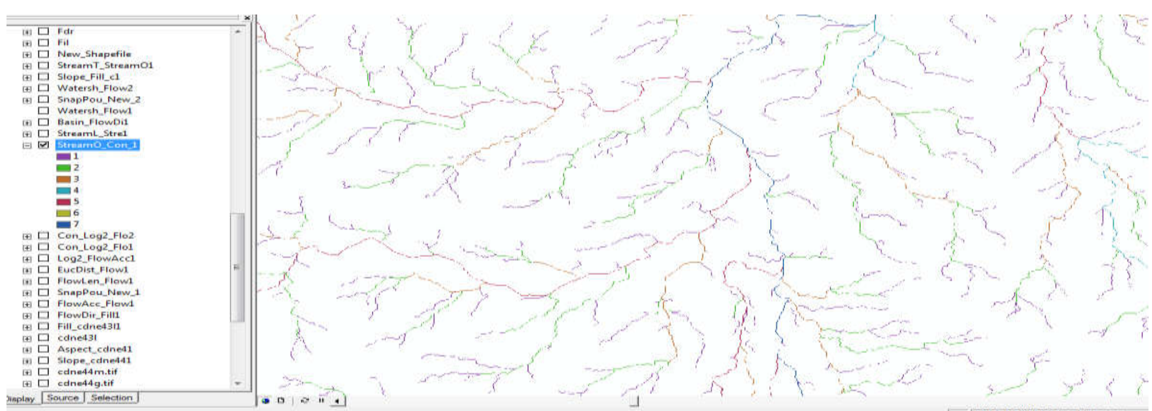

Figure 13: Stream Order

Snap Pour Point

- The Snap Pour Point tool is used to ensure the selection of points of high accumulated flow when delineating drainage basins using the Watershed tool. Snap Pour Point will search within a snap distance around the specified pour points for the cell of highest accumulated flow and move the pour point to that location.

- If the input raster or feature pour point data is a point feature class, it will be converted to a raster internally for processing.

- The output is an integer raster when the original pour point locations have been snapped to locations of higher accumulated flow.

Stream Link

- The input stream raster can be created by thresholding the results of the Flow Accumulation function. Refer to the Flow Accumulation topic for an example.
- The stream raster linear network should be represented as values greater than or equal to one on a background of NoData.
- The output of the Stream Link tool is an integer raster.

Links are the sections of a stream channel connecting two successive junctions, a junction and the outlet, or a junction and the drainage divide.

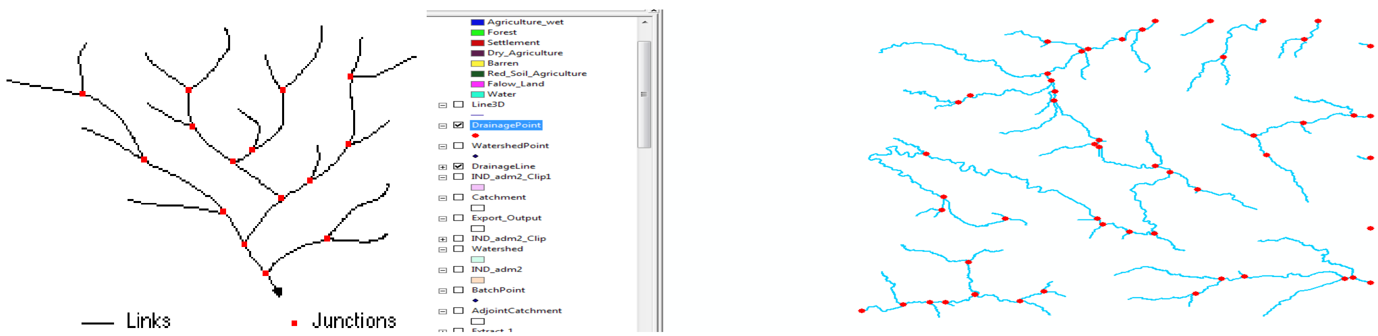

Figure 14: Stream Linking Depiction of the Region

Stream Shape

- The<net_grid> can be created by thresholding the results of FlowAccumulation.

- The raster linear network should be represented as valid values on a background of NoData. There should be contiguous features with the same value, such as the result of the StreamOrder or StreamLink function. StreamShape should not be used on a raster in which there are few adjacent cells of the same value.

- The arcs of the output shapefile will point downstream.

- Learn more about how to specify the input raster dataset in the Map Algebra expression of Raster Calculator.

Stream Shape is a vectorised program designed primarily for vectorization of stream networks or any other raster representing a raster linear network for which directionality is known.
StreamShape is optimized to use a direction raster to aid in vectorizing intersecting and adjacent cells. Using StreamShape, it is possible for two adjacent linear features of the same value to be vectorized as two parallel lines.

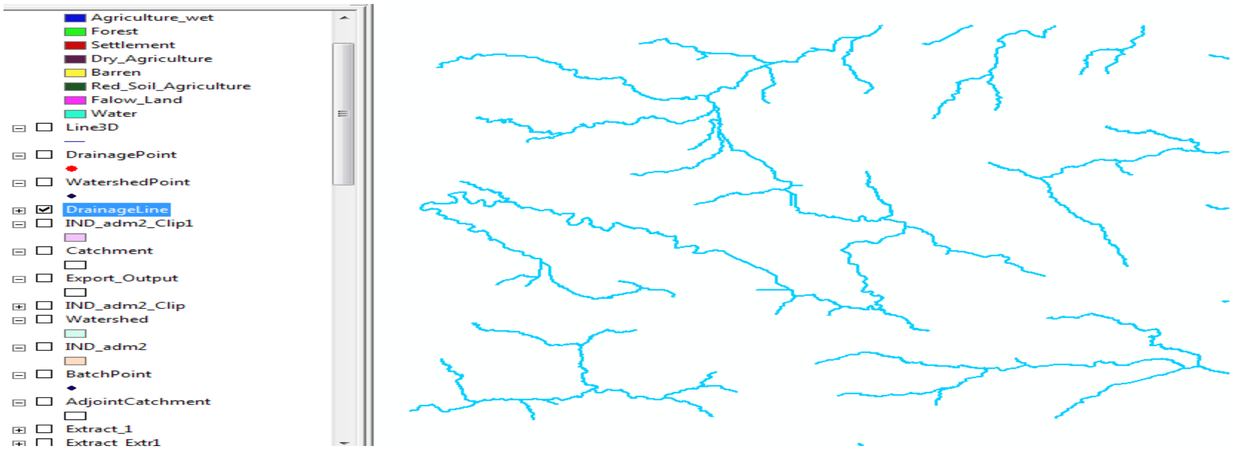

Figure 15: Drainage area of the Catchment

Stream To Feature

- The input stream raster linear network should be represented as values greater than or equal to one on a background of NoData.

- The results of the Flow Accumulation function can be used to create a raster stream network by applying a threshold value to select cells with a high accumulated flow. For example, cells that have more than 100 cells flowing into them are used to define the stream network. Use the Con or Set Null function to create a stream network raster where flow accumulation values of 100 or greater go to one, and the remainder are put to the background (NoData). The resulting stream network can be used in Stream Link and Stream to Feature.

- There should be contiguous features with the same value, such as the results of the Stream Order or Stream Link function. Stream to Feature should not be used on a raster in which there are few adjacent cells of the same value.

- The arcs of the output shapefile will point downstream.

Watershed

- The value of each watershed will be taken from the value of the source in the input raster or feature pour point data. When the pour point is a raster dataset, the cell values will be used. When the pour point is a point feature dataset, the values will come from the specified field.

- Better results will be obtained if the Snap Pour Point tool is used beforehand to help locate the pour points to cells of high accumulated flow.

A watershed is an area that drains water and other substances to a common outlet as concentrated drainage. Other common terms for a watershed are basin, catchment, or contributing area. This area is normally defined as the total area flowing to a given outlet or pour point. These areas are the output of the Watershed tool. The boundary between two watersheds is referred to as a watershed boundary or drainage divide.

An outlet, or pour point, is the point at which water flows out of an area. This is the lowest point along the boundary of the watershed. The cells in the source raster are used as pour points above which the contributing area is determined. Source cells may be features, such as dams or stream gauges, for which you want to determine characteristics of the contributing area.

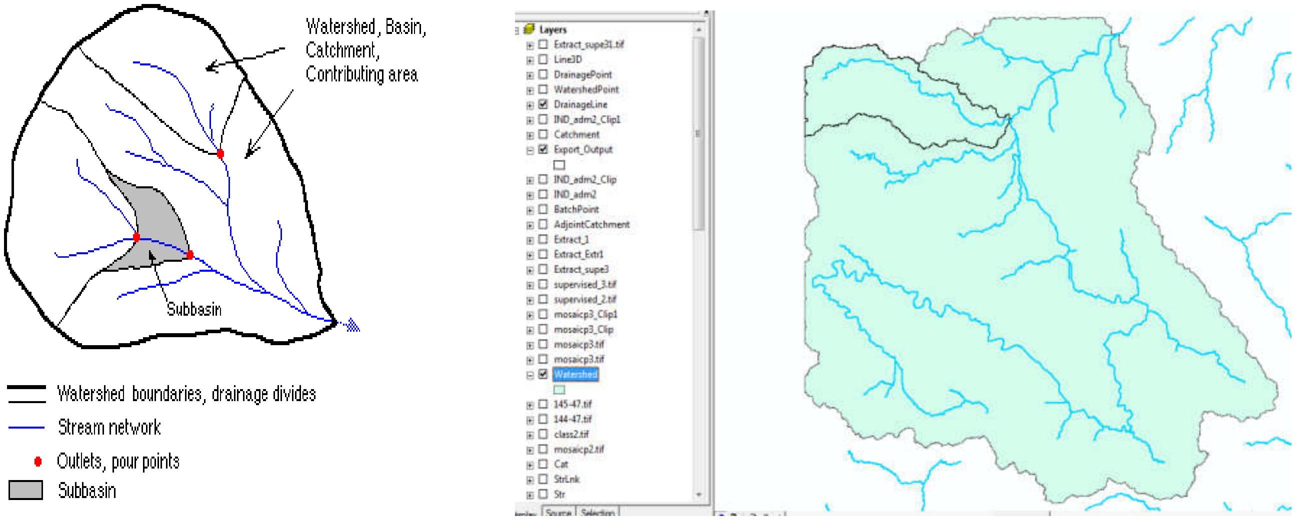

Figure 16: Watershed of the Area

Digital Elevation Model

The most common digital data of the shape of the earth's surface is cell-based digital elevation models (DEMs). This data is used as input to quantify the characteristics of the land surface.

A DEM is a raster representation of a continuous surface, usually referencing the surface of the earth. The accuracy of this data is determined primarily by the resolution (the distance between sample points). Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM.

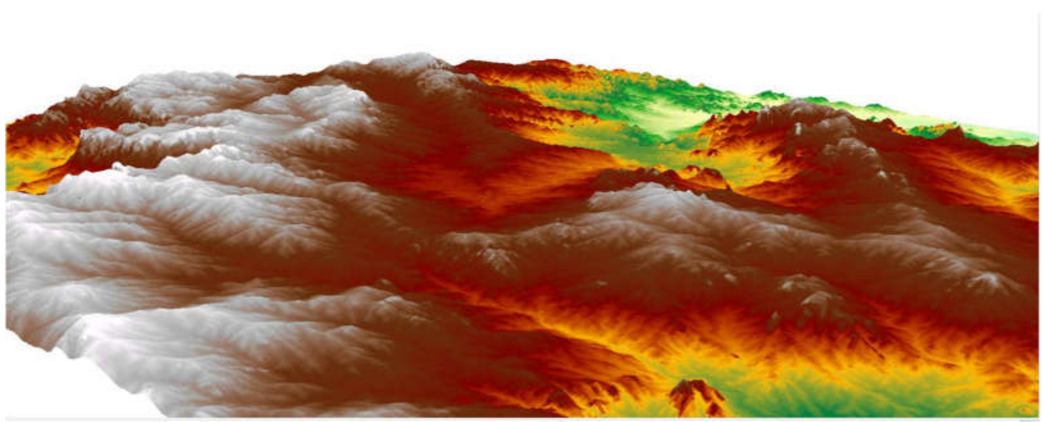

Figure 17: Digital Elevation Model of the Watershed Region

Errors in DEMs are usually classified as either sinks or peaks. A sink is an area surrounded by higher elevation values and is also referred to as a depression or pit. This is an area of internal drainage. Some of these may be natural, particularly in glacial or karst areas (Mark, 1988), although many sinks are imperfections in the DEM. Likewise, a spike or peak is an area surrounded by cells of lower value. These are more commonly natural features and are less detrimental to the calculation of flow direction.

Errors such as these, especially sinks, should be removed before attempting to derive any surface

information. Sinks, being areas of internal drainage, prevent downslope flow routing of water.
The number of sinks in a given DEM is normally higher for coarser resolution DEMs. Another common cause of sinks results from storing the elevation data as an integer number. This can be particularly troublesome in areas of low vertical relief. It is not uncommon to find 1 percent of the cells in a 30-meter-resolution DEM to be sinks. This can increase as much as 5 percent for a 3 arc–second DEM.
DEMs may also contain noticeable horizontal striping, a result of systematic sampling errors when creating the DEM. Again, this is most noticeable on integer data in flat areas.

The hydrologic analysis functions described here are designed to model the convergence of flow across a natural terrain surface. There is an assumption that the surface contains sufficient vertical relief that a flow path can be determined. The functions assume that water can flow in from many cells but out through only one cell.

Curve Number (Soil Conservation Service Curve Number (SCS-CN))
The Soil Conservation Service (SCS) curve number (CN) method is one of the most popular methods for computing the runoff volume from a rainstorm. It is popular because it is simple, easy to understand and apply, and stable, and accounts for most of the runoff producing watershed characteristics, such as soil type, land use, hydrologic condition, and antecedent moisture condition. The SCS-CN method was originally developed for its use on small agricultural watersheds and has since been extended and applied to rural, forest and urban watersheds. Since the inception of the method, it has been applied to a wide range of environments. The SCS-CN method was first published in 1956 in Section-4 of the National Engineering Handbook of Soil Conservation Service (now called the Natural Resources Conservation Service), U. S. Department of Agriculture. To describe these curves mathematically, SCS assumed that the ratio of actual retention to potential maximum retention was equal to the ratio of actual runoff to potential maximum runoff, the latter being rainfall minus initial abstraction. In mathematical form, this empirical relationship is

$$\frac{F}{S} = \frac{Q}{P - I_a}$$

where
F = actual retention (mm)
S = potential maximum retention (mm)
Q = accumulated runoff depth (mm)
P = accumulated rainfall depth (mm)
I, = initial abstraction (mm)

$$F = P - I_a - Q$$

Combining above Equations

$$Q = \frac{(P - I_a)^2}{P - I_a + S}$$

To eliminate the need to estimate the two variables I, and **S** in the above Equation, a regression analysis was made on the basis of recorded rainfall and runoff data from small drainage basins. The data showed a large amount of scatter (Soil Conservation Service 1972). The following average relationship was found

$$\mathbf{I_a = \lambda\, s}$$

On the basis of extensive measurement in small catchment's SCS have adopted, **λ=0.2** as a standard.

This modifies the equation to

$$Q = \frac{(P-0.2\,S)^2}{P+0.8\,S} \quad \text{for } P > 0.2\,S$$

$$Q = 0 \qquad \text{for } P < 0.2S$$

It allows the runoff depth to be estimated from rainfall depth, given the value of the potential maximum retention **S.** This potential maximum retention mainly represents infiltration occurring after runoff has started. This infiltration is controlled by the rate of infiltration at the soil surface, or by the rate of transmission in the soil profile, or by the water-storage capacity of the profile, whichever is the limiting factor.The potential maximum retention **S** has been converted to the Curve Number CN in order to make the operations of interpolating, averaging, and weighting more nearly linear. This relationship is

$$CN = \frac{25400}{254 + S}$$

Asthe potential maximum retention **S** can theoretically vary between zero and infinity, the above equation shows that the Curve Number CN can range from one hundred to zero.
For paved areas, for example, **S** will be zero and CN will be 100; all rainfall will become runoff. For highly permeable, flat-lying soils, **S** will go to infinity and CN will' be zero; all rainfall will infiltrate and there will be no runoff. In drainage basins, the reality will be somewhere in between.

Factors Determining the Curve Number Value

The Curve Number is a dimensionless parameter indicating the runoff response characteristic of a drainage basin. In the Curve Number Method, this parameter is related to land use, land treatment, hydrological condition, hydrological soil group, and antecedent soil moisture condition in the drainage basin.

Land Use or Cover

Land use represents the surface conditions in a drainage basin and is related to the degree of cover. In the SCS method, the following categories are distinguished:

Fallow is the agricultural land use with the highest potential for runoff becausethe land is kept bare;

Row crops are field crops planted in rows far enough apart that most of the soilsurface is directly exposed to rainfall

Small grain is planted in rows close enough that the soil surface is not directlyexposed to rainfall

Close-seeded legumes or rotational meadow are either planted in close rows orbroadcasted. This kind of cover usually protects the soil throughout the year;

Pasture range is native grassland used for grazing, whereas meadow is grasslandprotected from grazing and generally mown for hay;

Woodlands are usually small isolated groves of trees being raised for farm use.

Treatment or Practice in relation to Hydrological Condition
Land treatment applies mainly to agricultural land uses; it includes mechanical practices such as contouring or terracing, and management practices such as rotation of crops, grazing control, or burning. Rotations are planned sequences of crops (row crops, small grain, and close-seeded legumes or rotational meadow). Hydrologically, rotations range from poor to good.
Poor rotations are generally one-crop land uses (monoculture) or combinations of row crops, small grains, and fallow. Good rotations generally contain close-seeded legumes or grass.
For grazing control and burning (pasture range and woodlands), the hydrological condition is classified as poor, fair, or good.
Pasture range is classified as poor when heavily grazed and less than half the area is covered; as fair when not heavily grazed and between one-half to three-quarters of the area is covered; and as good when lightly grazed and more than three-quarters of the area is covered.
Woodlands are classified as poor when heavily grazed or regularly burned; as fair when grazed but not burned; and as good when protected from grazing.

Hydrological Soil Group
Soil properties greatly influence the amount of runoff. In the SCS method, these properties are represented by a hydrological parameter: the minimum rate of infiltration obtained for a bare soil after prolonged wetting. The influence of both the soil's surface condition (infiltration rate) and its horizon (transmission rate) are
thereby included. This parameter, which indicates a soil's runoff potential, is the qualitative basis of the classification of all soils into four groups.
The Hydrological Soil Groups, as defined by the SCS soil scientists, are:

Group A: Soils having high infiltration rates even when thoroughly wetted and a high rate of water transmission. Examples are deep, well to excessively drained sands or gravels.

Group B: Soils having moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. Examples are moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Soils having low infiltration rates when thoroughly wetted and a low rate of water transmission. Examples are soils with a layer that impedes the downward movement of water or soils of moderately fine to fine texture.

Group D: Soils having very low infiltration rates when thoroughly wetted and a very low rate of water transmission. Examples are clay soils with a high swelling potential, soils with a permanently high water table, soils with a clay pan or clay layer at or near the surface, or shallow soils over nearly impervious material.

Antecedent Moisture Condition

The soil moisture condition in the drainage basin before runoff occurs is another important factor influencing the final CN value. In the Curve Number Method, the soil moisture condition is classified in three Antecedent Moisture Condition **(AMC)**
Classes:
AMC **I:** The soils in the drainage basin are practically dry (i.e. the soil moisture content is at wilting point).

AMC **II:** Average condition.
AMC III: The soils in the drainage basins are practically saturated from antecedent rainfalls (Le. the soil moisture content is at field capacity).

Table

AMC group	Total 5-day antecedent rainfall (mm): Dormant season	Growing season
I	Less than 13	Less than 36
II	13 to 28	36 to 53
III	More than 28	More than 53

VI. Result

Thecatchment of streams were computed from the DEM and the Land use/Land cover(LU/LC) map was prepared from the Land sat data. After preparation of catchment of streams and the LU/LC map, the watershed of interest was taken along with its land use/land cover map.

The area of the watershed was computed and also the areas with different soil, cover and hydrologic condition within the watershed was found out.

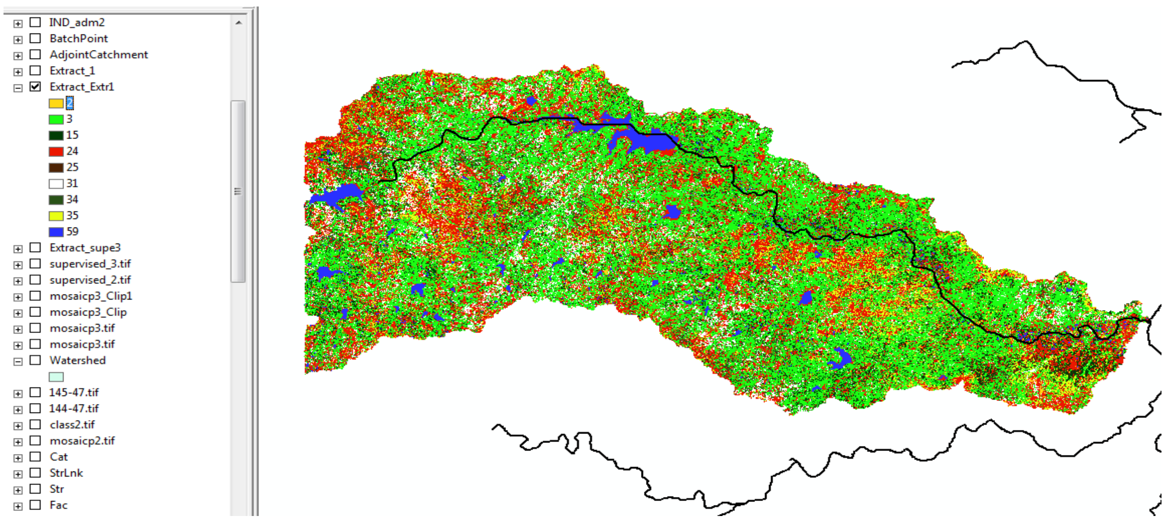

Figure 18: Watershed of the Study area

Total area of watershed=1711.953918 Km^2
Areas within the watershed

Wet agriculture - 56.765701 Km^2

Dry agriculture –72.726303 Km^2

Barren –99.708298 Km^2

Sand –125.8686 Km^2

Urban –765.27362 Km^2

Forest –16.5348 Km^2

Fallow Land –127.4454 Km^2

The Curve number corresponding to different soil, cover and hydrologic conditions were assumed accordingly with reference to the Curve number table.

Curve Number of different land use and land cover within the watershed.

Wet agriculture - 83

Dry agriculture – 75

Barren – 72

Sand – 96

Urban – 90

Forest – 65

Fallow Land – 86

Equivalent Curve Number $= \frac{\sum (CN_1 \times a_1 + CN_2 \times a_2 + ... + CN_n a_n)}{\sum a},$

= 78

Using this curve number the Maximum potential retention is computed (S)

$$S = \frac{25,400}{\text{CN}} - 254.$$

S = 71.64mm

Runoff Depth

$$Q = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \text{ for } P > 0.2\ S$$

VII. Computation of Runoff

The data used for calculation are for the year 2004

Attributes of Extract_Extr1

Rowid	VALUE *	COUNT	CLASS_NAME	CN_NAME	AREA
0	2	16118	water	no	15
1	3	850304	settlement	1/8_Acreorlessoccupied,Grp-	765
2	15	139854	sand	DesertUrban,Grp-C	126
3	24	481250	redsoilagri	SR+CR,Poor,Grp-C	433
4	25	18372	forest	Wood_grass,fair,Grp-C	17
5	31	141606	falloland	bareSoil,Grp-B	127
6	34	80807	dryagri	SR+CR,Poor,Grp-B	73
7	35	110787	barren	DesertShrubs,fair,grp-B	100
8	59	63073	agriwet	SR+CR,Poor,Grp-C	57

Record: 0 Show: All Selected Records (0 out of 9

April:-

Month	April
Rainfall in mm	27.75351
Runoff in mm	2.118889

May:-

Month	May
Rainfall in mm	45.01239
Runoff in mm	9.201441

June:-

Month	June
Rainfall in mm	51.65703
Runoff in mm	12.78764

July:-

Month	July
Rainfall in mm	87.61277
Runoff in mm	37.05824

August:-

Month	August
Rainfall in mm	121.827
Runoff in mm	64.50885

September:-

Month	September
Rainfall in mm	180.6322
Runoff in mm	116.2335

October:-

Month	October
Rainfall in mm	15.51547
Runoff in mm	0.019362

Observed Runoff at the gauging stations:-

The runoff are total runoff for a month

April:-2.196669 mm

May:-2.736459 mm

June:-0 mm

July:-144.7235 mm

August:-44.30635 mm

September:-201.7041 mm

October:-57.41443 mm

VIII. Conclusion

In the above work carried out, it is shown that how Remote sensing and GIS is applicable in water resources domain. Here the using Curve number method along with RS and GIS is used for prediction of the runoff depth. In this the RS and GIS technique was used for the preparation of the catchment, catchment area, stream order, Land use/land cover etc. The LU/LC map is prepared for identifying the various type of land uses like agriculture, forest, barren land, Urbanization etc. Now the curve number(CN) for each type of Land use/land cover has been approximately predicted. These CN number is used for the calculation of runoff depth for a particular catchment. The rainfall data is obtained from the Indian meteorological department (IMD) through National Institute of Hydrology(NIH) where our Summer internship was commenced.

These rainfall data of latitude 18.5 and longitude 77.5 was extracted from the raw data which was summed totaled for a month's April, May, June, July, August, September, October of the year 2004. These months were taken as monsoon occurs in this months. This total rainfall obtained for each month was used for computation of runoff of the respective month using CN number method.

Observed runoff data of a particular gauzing station within the catchment for the same time period is obtained from NIH. The data was daily discharge data in meter cube per second, which was converted in equivalent depth and was compared with the discharge computed using SCS-CN or CN method.

The runoff observed and the runoff calculated show deviation due to many factors :-

- The gauging station not at the outlet. The station was at a distance I/4th from the outlet.

- The data used for computation and observation may not be proper.
- The improper assumption of the Curve Number.
- Unaware soil type in that catchment.
- Due to time required by the rainfall water to reach the gauging station.
- Not proper computation of LU/LC.
- Due to large watershed considered.

This method however can be tried for a small watershed as the time required for the water would be almost immediate. The preparation of land use and land cover would also be better as the area is small. The soil data of the catchment should be known for the proper prediction of the Curve Number. There should also be a gauging station at the outlet for the proper measurement of the runoff to verify the results.

IX. References

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- http://www.slideshare.net/search/slideshow?lang=%2A%2A&page=2&q=geostatistics&searchfrom=header&sort=relevance
- http://glovis.usgs.gov/
- http://earthexplorer.usgs.gov/