From Table 3-3 K equal 2.517 at 25 and 3.179 at 50 Year Return Period. The sample size of the record was 16. However k from 20 sample was chosen which is the nearest value in the records.

Table 3-4 The probability event rainfall Comparison of P.P.F, Gumbel, PMP.

Return Period	P.P.F	Gumbel	PMP
25yr	105 mm	104 mm	103 mm
50yr	125 mm	124 mm	122.5mm

A comparison between results of the probability of rain each of 25 and 50 years yielded results that are comparable for three methods.

Using maximum value for the yearly rainfall depth 125 mm who for 50 years gave an estimated value of (125 x0.6 mm) as given by (Chow, 1988) who stated that the daily maximum rainfall will be equal to 0.6 x maximum annual rainfall .

This value is used in the simulation process.

3.5.2 Estimation of runoff

The runoff is considered as a function of rainfall and influenced by many factors that are often difficult to identify. To estimate the direct runoff for Wadi Hadramout catchment, resulting from precipitation in the catchment involves SCS approach which is calculated using simple empirical formulas, various tables available and the average curve number of the catchment.

3.5.2.1 Excess of rainfall

The following method may be used to get the excess of rainfall.

3.5.2.1.1 Soil Conservation Service (Curve Number Method)

The SCS curve number is an index based on specified land cover/soil combinations (Soil Conservation Service, US Department of Agriculture, 1956 It was originally developed based on empirical studies done by the US Soil Conservation Society (now the National Resources Conservation Society) in an effort to determine more accurately how water behaved in small, agricultural watersheds (Soil Conservation Service, US Department of Agriculture, 1956), (Mishra, 2004).

The Soil Conservation Service (SCS) method was developed as a transform method for calculating runoff by determining abstractions from rainfall. An abstraction is the water lost by either infiltration or surface storage (Chow, 1988).
The basis of the curve number method is the empirical relationship between the retention (rainfall not converted into runoff) and runoff properties of the watershed and the rainfall. (National Engineering Handbook, 2007).

3.5.2.1.2 Infiltration Formula by Curve Number Method

Infiltration capacity of the soil surface, which is defined as the maximum rate at which rain can be absorbed by soil.

When the rain falls at a rate greater than the infiltration capacity of the ground, an excess of precipitation will occur. No overland flow (runoff or precipitation excess) will occur if the rainfall intensity is lower than the infiltration capacity.

The infiltration rate implicit equation for constant rainfall rate, an equation which was derived by differentiation of the basic curve number equation (Elena, 2001)

$$f = \left(\frac{S}{P + 0.8S}\right)^2 i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq 3.4}$$

Where: f = infiltration rate,

i = rainfall rate.

3.5.2.1.3 Loss Method

Loss of rainfall is considered as an important factor of a major direct impact on runoff in the Catchment. Using precipitation loss method to estimate the relationship between Rainfall, Excess Rainfall after rain and loss of rain which caused by the several factors as follows:

1- Interception caused by various changes which represent multiple land uses and agricultural cover on the surface.

2 - The infiltration of water through the soil into the ground.

3 - Evaporation

4 - Evapotranspiration

The processes of Evaporation and Transpiration can be ignored in the simulation due to its very small effect, and therefore come the processes of interception and infiltration rate.

These factors are the main factors to estimate the loss of rainfall.

The curve number method provides relationships between initial abstractions, Ia, and Curve Numbers (CN) based on experiments carried out in experimental Catchment.

Also, a relationship for excess rainfall has been established as

$$Q = \frac{(\mathrm{P} - 0.2\mathrm{S})^2}{P + 0.8S} p > 0.2S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \quad Eq\ 3.5$$

$$Q = \frac{(\mathrm{P} - \mathrm{Ia})^2}{(P + \mathrm{Ia}) + \mathrm{s}} p > \ Ia \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Eq\ \ 3.6$$

$$s = \frac{1}{0.0394}\left(\frac{1000}{\text{CN}} - 10\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 3.7$$

Where

Q = Rainfall excess

P = potential maximum runoff that is equal to the total precipitation

S = Potential Maximum Retention

I_a = Initial Abstraction

CN = Runoff Curve Number

Notes that the I_a can be determined as a percentage from initial abstraction.

Recent research has indicated that the factor of 0.2 is probably adequate for large storms in rural areas, but it likely an overestimate for small to medium storms and is probably too high for urban areas (David, 2006).

Initial loss that is calculated from the following relation is commonly assumed:

$$\text{Ia} = 0.2s \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq 3.8}$$

3.5.2.1.4 Transform Method

Amount of excess rainfall can be transformed into a runoff directly from the application of Unit Hydrograph Method. Thus, it is an important element in Hydrological Modeling as it consists of direct runoff and excess rainfall.

In this research, the Method of SCS Unit Hydrograph was used to complete the process of simulation.

Time to peak

T_P is the elapsed time from the beginning of the effective (runoff-producing) rainfall to the peak discharge, expressed as

$$T_P = \frac{\mathrm{Tr}}{2} + T_L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 3.9$$

Where T_r is the excess rainfall duration (hr),T_L is the lag time (hr) is the elapsed time from the centroid of effective rainfall to the peak discharge (David, 2006).

Lag Time is calculated by SCS lag formula as following:

$$T_{lag} = \frac{\mathrm{L}^{0.8}\left(\frac{1000}{\mathrm{CN}}\right) - 10^{0.7}}{1900 \times \sqrt{\mathrm{Y}}} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 3.10$$

Where: L is the catchment length in m

CN is the curve number

Y is the Catchment slope in percent (Chow V. T., 1959).

Peak discharge

The peak discharge (m^3/s) for the catchment is determined from

$$Qp = \frac{\mathrm{CA}}{\mathrm{T_P}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 3.11$$

Where C = 2.08, A Is the drainage area in square kilometers

Tp Time of peak in hour. (Dilip K. , 2011).

3.6 Models Used In Applied Models

A description of the softwares used in this research as the following:

3.6.1 Geographic information system (GIS)

Geographic information system GIS is a manual or automated system, which can store, retrieve, manipulate, and display environmental data in a spatial format.

It has the capabilities to use different set of operation for working with spatially referenced geo-data (Wan N. , 2012).

(GIS) has been defined as "information about features and phenomena located in the vicinity of the surface of the Earth", including human activities that occur on it (Goodchild, 2000).

It uses several manual data elements like mapping, aerial and ground photograph.

GIS is continuous process of data, pre-processing, data management, manipulation and analysis and product generation. (Congalton R., and Green K., 1992).

These enabling techniques which depend on the spatial capabilities of GIS produce where the benefits are nearly impossible to be obtained using the spreadsheets or other non-graphic methods of data organization. (Alaghmand, 2008).

3.6.2 Watershed Modeling System (WMS)

Watershed Modeling System (WMS), developed by Environmental Modeling Systems, Inc. at Brigham Young University, is a comprehensive graphical modeling environment for all phases of watershed hydrology and hydraulics.

WMS includes powerful tools to automate modeling processes such as automated basin delineation, geometric parameter calculations, GIS overlay computations including curve numbers (CN), rainfall depth, roughness coefficients, etc., and cross-section extraction from terrain data.

WMS provides an interface for a variety of hydrologic and hydraulic models within a GIS-based processing framework. (Edsel, 2011).

The functions of WMS are as following:

1. Automatically compute area, slope, mean elevation, maximum flow distance etc.
2. Automatically cut cross sections.
3. Compute hydrologic basin data such as time of concentration, curve number, and infiltration parameters.

4. Manipulate stream networks to represent man-made features or proposed changes to the watershed.
5. Create flood depth maps.

3.6.3 Hydrologic Engineering Center's – Hydrologic Modeling System (HEC-HMS)

HEC-HMS Model was chosen to study the availability of different methods to simulate the main hydrological processes that occur during a flood event without the presence of any complications during the hydrological processes which may have significant effects during the floods. It is possible to make a simulation scenario to determine the effects associated with the occurrence of flooding in the catchment. HEC – HMS is very suitable for use in the catchment area in the following cases:

1. Has a basic component to study the complex interaction between the atmospheres, land geology, vegetation, soil (Pilgrim, 1993).
2. A schematic representation of Wadi Hadramout basin network.
3. Sufficient capacity to analyze catchment, determine of the effect of rainfall and its representation in the hydrograph.
4. Provides several options in loss method modeling
5. Ability to analyze sub-catchments despite differences in spatial parameters.

6. Hydrological parameters storage and handling.

7. Easy to modify data and add different options such as routing.

8. Easy integration and import data from WMS.

9. Hydraulically build a model to get useful results in the simulation of runoff, velocity, flow rate and other results (Chen, 2005).

10. Capability to simulate the flood storage available in catchment depending on a variety of initial water levels.

11. Combining a basin model, meteorologic model, and control specifications formed a simulation run (Kunal, 2009).

The basic components of the HEC-HMS are the basin model, meteorologic model, control specifications. The basin model includes several methods to transforming excess precipitation into surface runoff; unit hydrograph methods include the Clark, Snyder, and SCS technique. An implementation of the kinematic wave method is also included, and methods are available to simulate infiltration losses, the Muskingum-cung method (Jos, 2009).

The meteorologic model performed meteorologic data analysis and included precipitation and evapotranspiration. The control specification specified the time span of the simulation. Control specifications include a starting date and time, ending date and time, and a time interval .The maximum possible time interval value is one day, and the minimum possible time interval value is one minute (Chi, 2011).

3.6.3.1 Hydraulic Routing

The routing component represents flood-wave movement through a catchment reach. The input consists of an inflow hydrograph and parameters defining the routing characteristics of the reach.
The output consists of an outflow hydrograph at the reservoir outlet or downstream end of the reach (Maidment, 1993).

According to (Chow, 1988), the hydraulic method of routing is distinguished from the hydrologic routing method in that the hydraulic method uses differential equations for unsteady flow for the solution, while hydrologic routing does not utilize these equations.

3.6.3.1.1 Muskingum-cung Flow Routing

In the absence of observed flow data, the Muskingum-Cung method may be used for parameter estimation. This concept is also applied when measured flow data are available, but with significant degree of uncertainty (Mesfin, 2005).

Hydrologic routing was performed using the Muskingum-Cung Standard method.

The Muskingum-Cung standard method is based on the continuity equation and the diffusion form of the equation. Routing coefficients are automatically computed by the program from specified parameters. Standard cross-sections can be circular or prismatic. Required input includes channel shape, length, energy slope, bottom width or diameter, channel side slope, and Manning's n roughness coefficient (Eileen, 2007) The development of the wedge due to a flood wave which causes inflow to exceed outflow and creates a wedge of storage can be calculated by the following equations (Chow, 1988).

$$S = k[XI + (1 - X)O\,] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots..Eq\ 3.12$$

Where

S is storage, I is Inflow, O is outflow. K and X values are determined using characteristics of the channel, where K is essentially a proportionality constant and X is a weighting factor that ranges from $0 \leq X \leq 0.5$.

The X parameter must range from 0 to 0.5 and defines the shape of the wedge storage. An X value close to 0 would represent almost a linear reservoir, which means there is no backwater; whereas an X value closer to 0.5 would represent a full wedge. The Muskingum method considers a linear relationship between inflow and outflow.

3.6.3.1.2 SCS Synthetic Unit Hydrograph (UH)

The HEC-HMS used the unit hydrograph method. By definition the unit hydrograph (UH) can be treated as a function that converts the rainfall to the observed runoff on a given watershed. This transfer function is often termed as response function in hydrology.
A watershed determination of model parameters from the observed rainfall-runoff data is one of the objectives of UH analysis.

Similar analysis can be done on the watersheds except that the model parameters are obtained from the physical characteristics of the watershed (area, perimeter, etc.).

Runoff hydrograph usually consists of a fairly regular lower portion that change slowly throughout the year and a rapidly fluctuating component that represents the immediate response to rainfall.

The lower, slowly changing portion of runoff is termed base flow. The rapidly fluctuating component is called direct runoff. This distinction is made because the unit hydrograph is essentially a tool for determining the direct runoff response to rainfall.

1. The unit hydrograph is the direct runoff hydrograph produced by a storm of given duration such that the total volume of excess rainfall is 1 mm. The total volume of direct runoff is also 1 mm.

2. The ordinates of UH indicate the direct runoff flow produced by the watershed for every millimeter of excess rainfall; therefore, the units are m^3/sec.

3. A volume of 1 mm is the amount of water in a 1-mm layer uniformly distributed over the entire watershed area. This volume is equal to the area under the UH.

4. Storms of different durations produce different UHs even if the excess rainfall volume is always 1 mm.

5. Longer storms will likely produce smaller peaks and longer duration in the UH.

6. The duration associated with the UH that of originating storm and not the base duration of the UH. (Krishna, 2003).

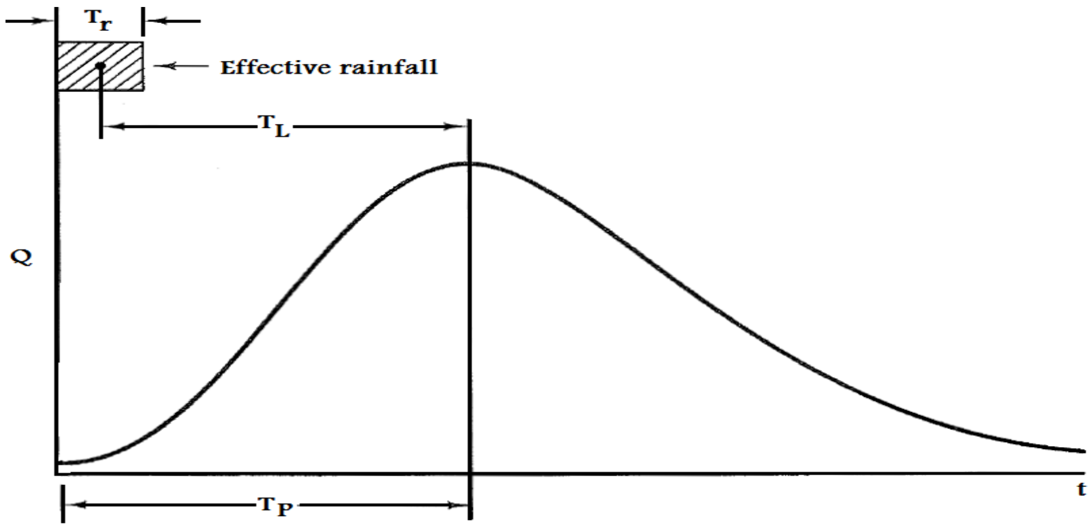

Figure.3.7 Soil Conservation Service synthetic unit hydrograph

3.7 Watershed Modeling

The Watershed Modeling System (WMS) was used to find Hydrological properties of Catchment and to determine outlet for catchment and to divide the catchment.

The WMS software used DEM to delineate Wadi Hadramout catchment and integrate with GIS data to complete the simulation by (HEC-HMS).

3.7.1 Importing DEM data

The imported (DEM) data displayed in Figure.3.8. Open (WMS) watershed modeling system select file with extension (USGSDEM) /Open DEM.

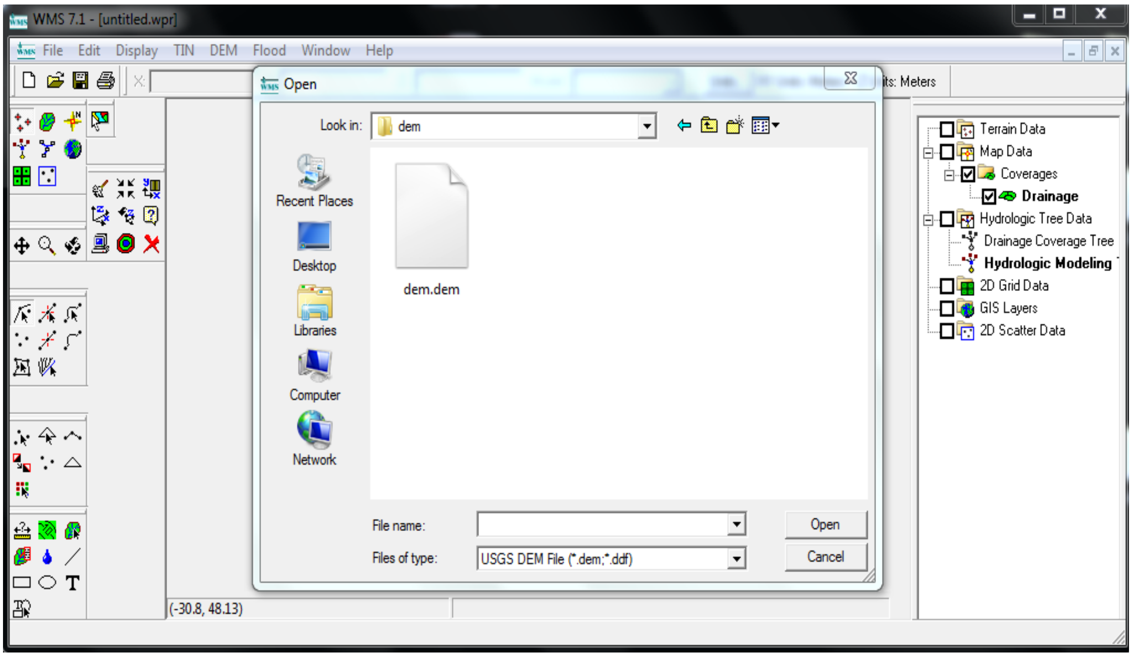

Figure.3.8 Import DEM to WMS.

After downloading DEM, WMS can modify the coordinate through Edit project coordinate system from Geographic to UTM WGS 1972, UTM Zone 38 should be selected in WMS as given Figure 3.9.

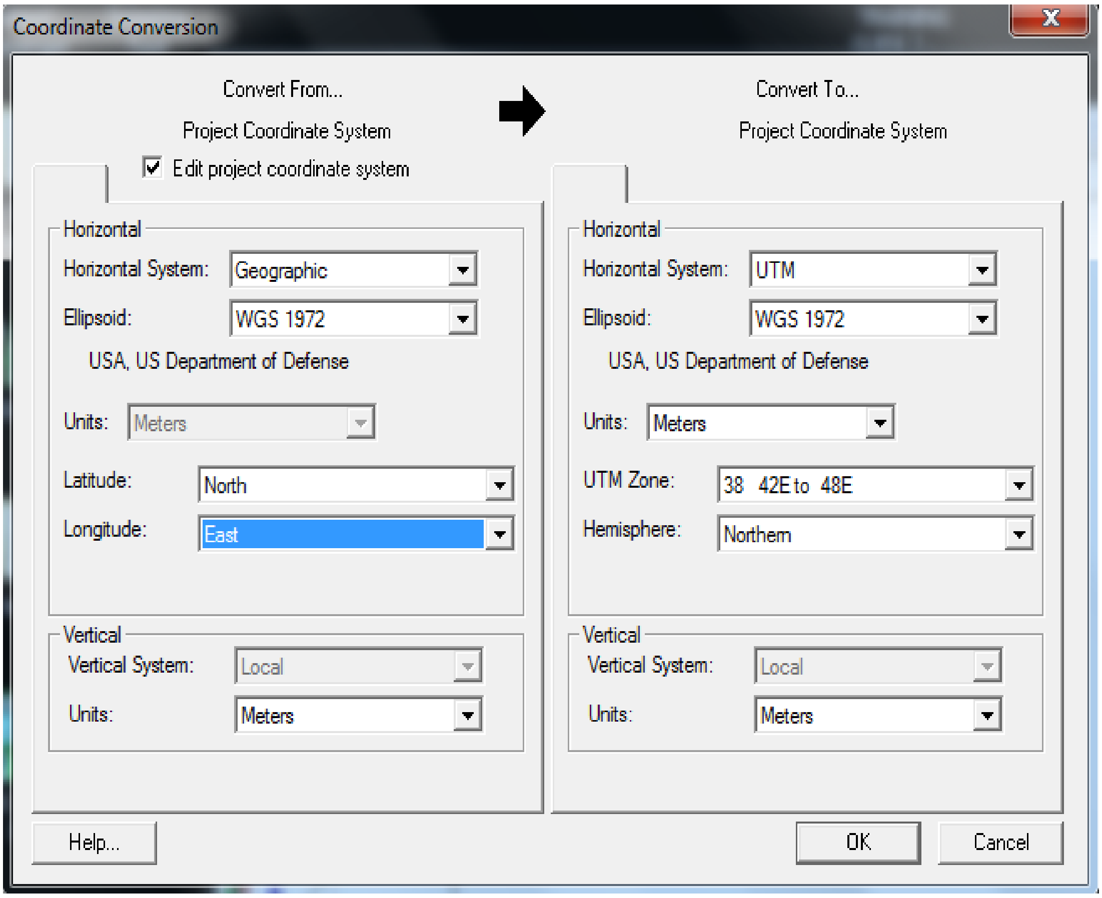

Figure.3.9. Coordinate conversion DEM.

3.7.2 Computing flow direction

The generation of stream network and flow direction was computed in WMS. The creation of streams direction from the DEM of the study area was done using the TOPAZ computation within the WMS software.

Click the Drainage module, Select Dem / Compute Topaz Flow Data, Select Ok after finish, Create Outlet Point of the catchment like in Figure .3.10.

Figure.3.10. Compute topaz flow data

Open (WMS) watershed modeling system select file of type (USGS) / Open DEM, Select Dem, delineate basin wizard and select close.

3.7.3 Analysis of catchment (Delineation)

Accurate delineation of Catchment boundaries, calculation of catchment areas and the determination of stream channel locations are critical tasks for the Hydrological processing. These items can be calculated from field surveys however these processes can be time consuming.

The delineation process played an important role in the analysis of the catchment in finding hydrological parameters, to generate runoff effects of rainwater and tracking the stream flow in the watershed by (DEM) as Figure.3.11.

The flow of surface water of catchment in stream channels and the characteristics of the catchment such as its area, slope and frequency of runoff help to explain the likelihood of flooding. (Ajibade, 2010).

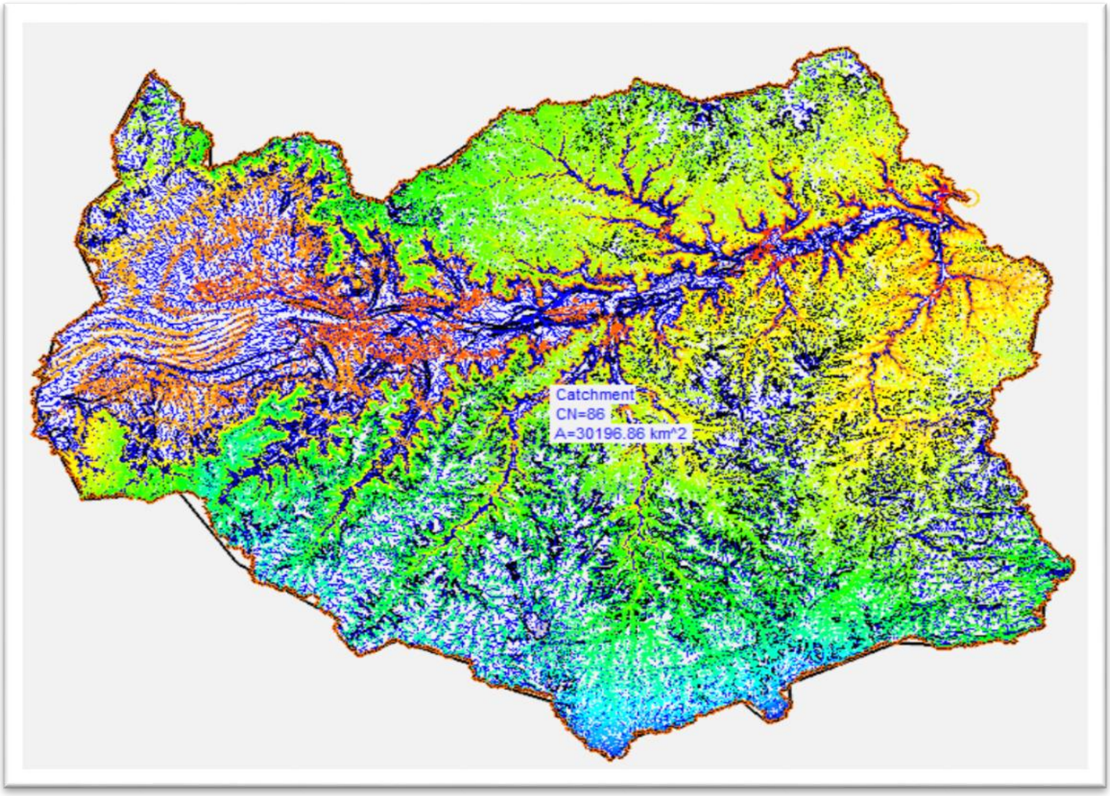

Figure.3.11.Wadi Hadramout Catchment.

3.7.4 Analysis of sub-catchments (Delineation)

Sub-catchments are a network of computational hydrological units to simulate runoff and account hydrographs discharge.

Sub-catchment area and its topography attributes (average slope, shape, length etc.) are needed for all physically based hydrological models.

Once when drainage units are known, the catchment area partitioning (or delineation) should be done according to the elevation map, following the natural surface flow paths. (Freeman, 1991).

Manually add outlets to divide the catchment into 8 sub-catchments represent all the topographic surface area by hydrological unit and the delineation of boundaries by the WMS software package. These sub-catchments have been established to find a various hydrological characteristics such as area, slope and other parameters.

3.7.5 Outlet points for sub-catchments

When you create multi sub-catchments the outlet must be identified and is directly related to the formation of network stream.

To select outlet points follow the steps:

1. Switch the Drainage module to selected outlet point.

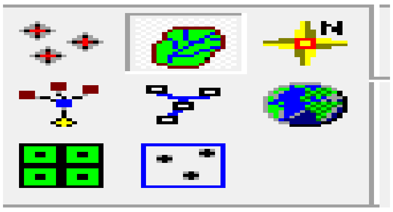

Figure.3.12. Drainage module.

2. Select feature tool vertex to be a point of outlet selection as shown in Figure.3.13, 3.14.

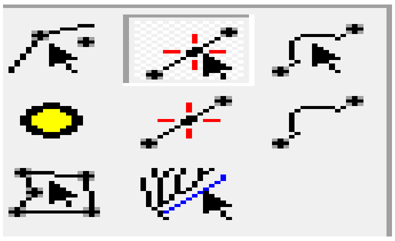

Figure.3.13. Vertex Tool.

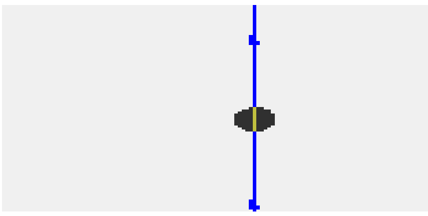

Figure.3.14. Outlet Point.

3. Choose DEM / Node outlet and repeat this process to make outlet points and select DEM / Delineate Basins wizard and select Close.

3.8 Geographic Information System (GIS)

A geographic information system was used to draw a shape file that describes the geographical and spatial nature of the catchment as follows:

3.8.1 Soil Type Shape File.

The soil is one of the fundamental factors on the surface that cover the catchment during the process of generation of runoff from rainfall. Are determined the properties of soil composition due to the direct effect on the runoff. The important role in the flow of water into waterways is to identify the different soil types and study the parameters that affect the flow rate of water. This affects infiltration of water in the soil and soil's ability to retain water during the flow.

Low infiltration of water into the soil leads to an increase in the amount of runoff and resulting in an increase in the influence of the size of the risks posed by floods.

To describe the hydrological group of different types of soils, the soil has been categorized into four types (A, B, C, D) for Wadi Hadramout catchments.

Geological maps were used that have a sufficient description of each soil type to the area of Wadi Hadramout and setting standards which represent each type of soil. To analyze these geological shape file maps GIS was used to integrate the topographic with the soil type data. It is considered a powerful tool to store, manage, and analyze information.

Shape file has spatial characteristics as it contains a set of coordinates by drawing topographical features of the study area. This contains drawing on different forms may be polygonal; each polygon expresses different types of soil's, which are described in attributes table. The types of soil are depending on the available database in geological maps. Soil Hydrology Group is included in the Attributes table for Soil’s data and represented in the form of an integrated map.

The purpose of this method is to make Shape file of Soil Type. This is done through the following steps. Open GIS, select Arc Catalog, Create a New Personal Geodatabase Open a New Personal Geodatabase, Create a new feature class and name it Soil then select type of feature stored in the Feature Class Polygon Feature as shown in Figure.3.15.

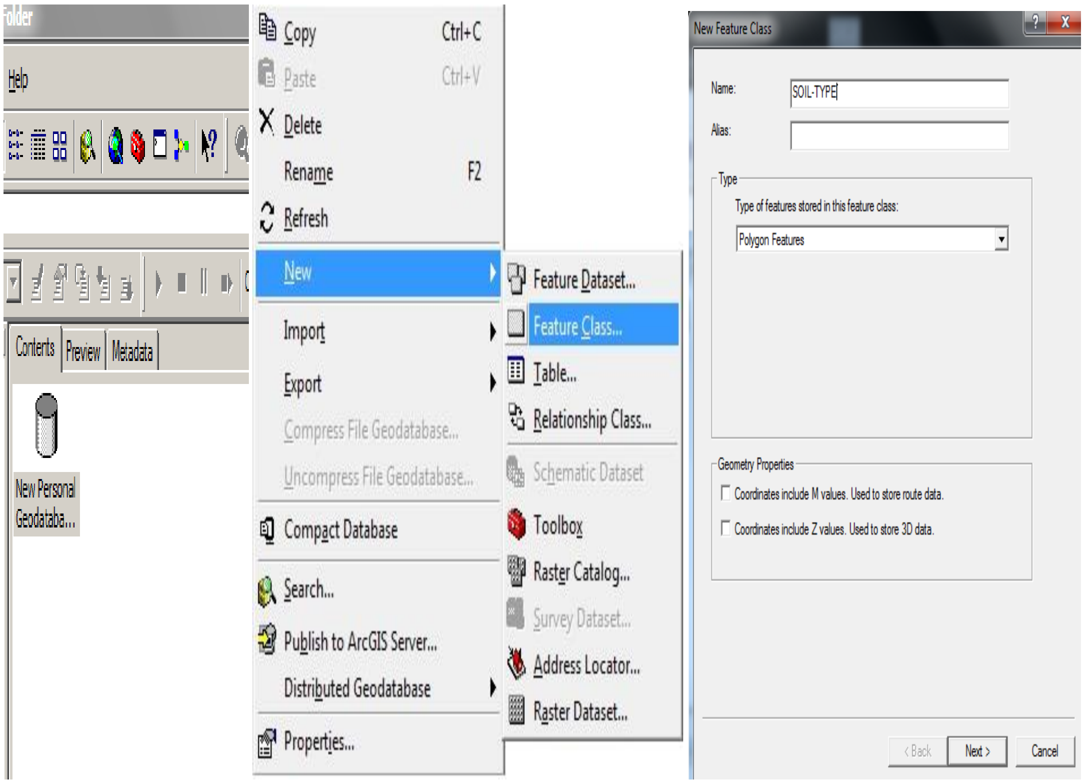

Figure.3.15. Create a New files Personal Geodatabase Soil-Type.

Coordinate system

Coordinate system enable a range of geographic data to be integrated as a reference which is used to represent the geographical location of the Wadi Hadramout catchment in the framework of joint coordination for display and analysis on the ground.

Spherical coordinates measured from the center of the Earth to map projection to the selected location. The Coordinate system which represents Wadi Hadramout are the Universal Transverse Mercator (UTM) and world geodetic system (WGS 1972) (Zone 38).The spatial reference coordinates system was acquired from the Yemen geological surveying authority.

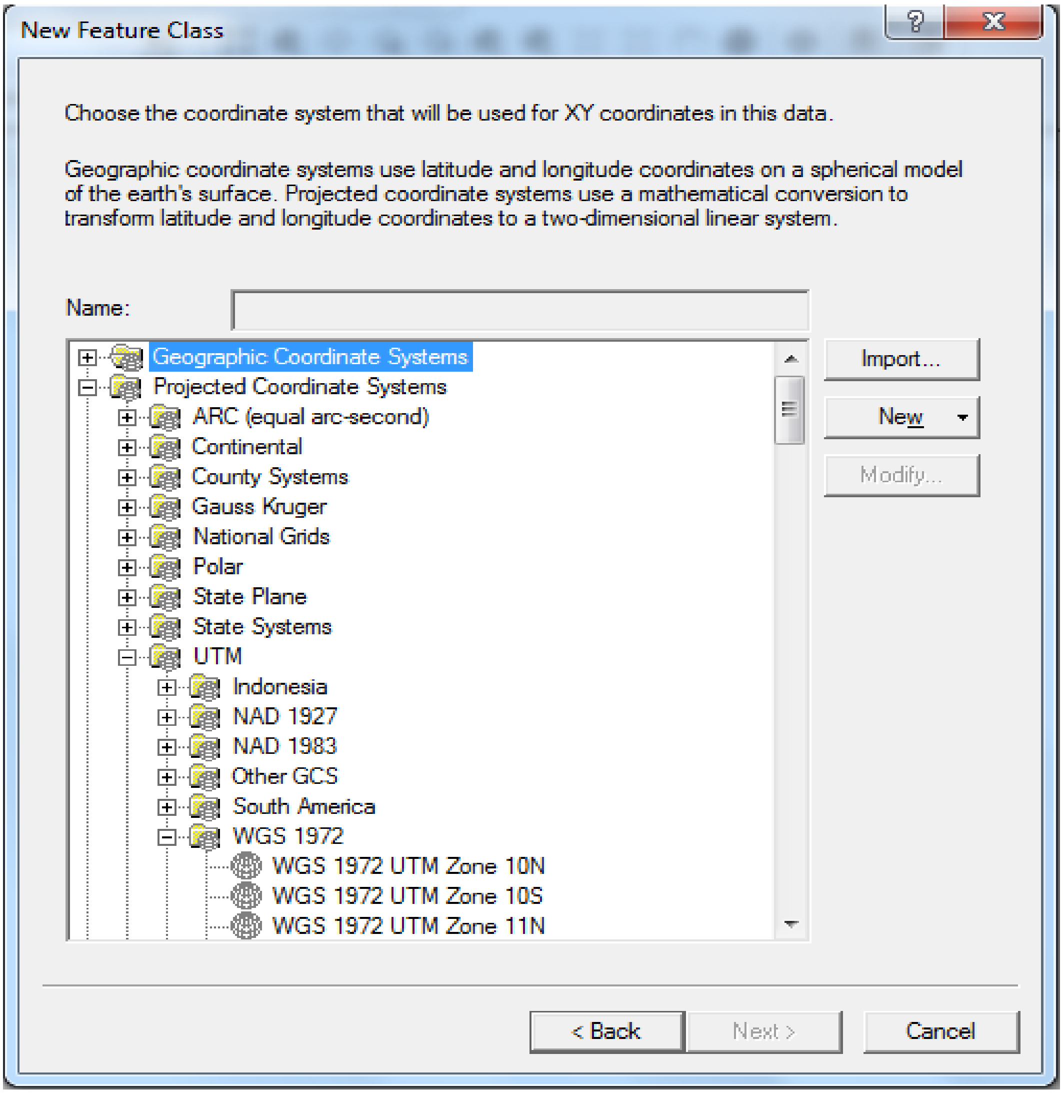

Figure.3.16.It appears coordinate system of shape file soil type.

To complete the establishment of shape file, a field in the attributes table must be added to determine the different characteristics of the data stored in the shapefile to store an integrated database of the actual numeric values.

This data is entered manually and is considered an essential step for the work of the shapefile in geographic information systems. A table of new feature class appears after clicking next as given in Figure 3.17.There are different types of data entered into the field of data type column as follows:

In this field there are seven items.

a. Short integer.
b. Long integer.
c. Float.

d. Double.

e. Text.

f. Data and binary large object.

On starting to draw, a field is added automatically in the attributes table to the area beside the length of the shape decree for each form of drawn shapes.

The steps to make Soil Type Shape file is: Select Next, Add Field

(Soil Classification) and Select Finish.

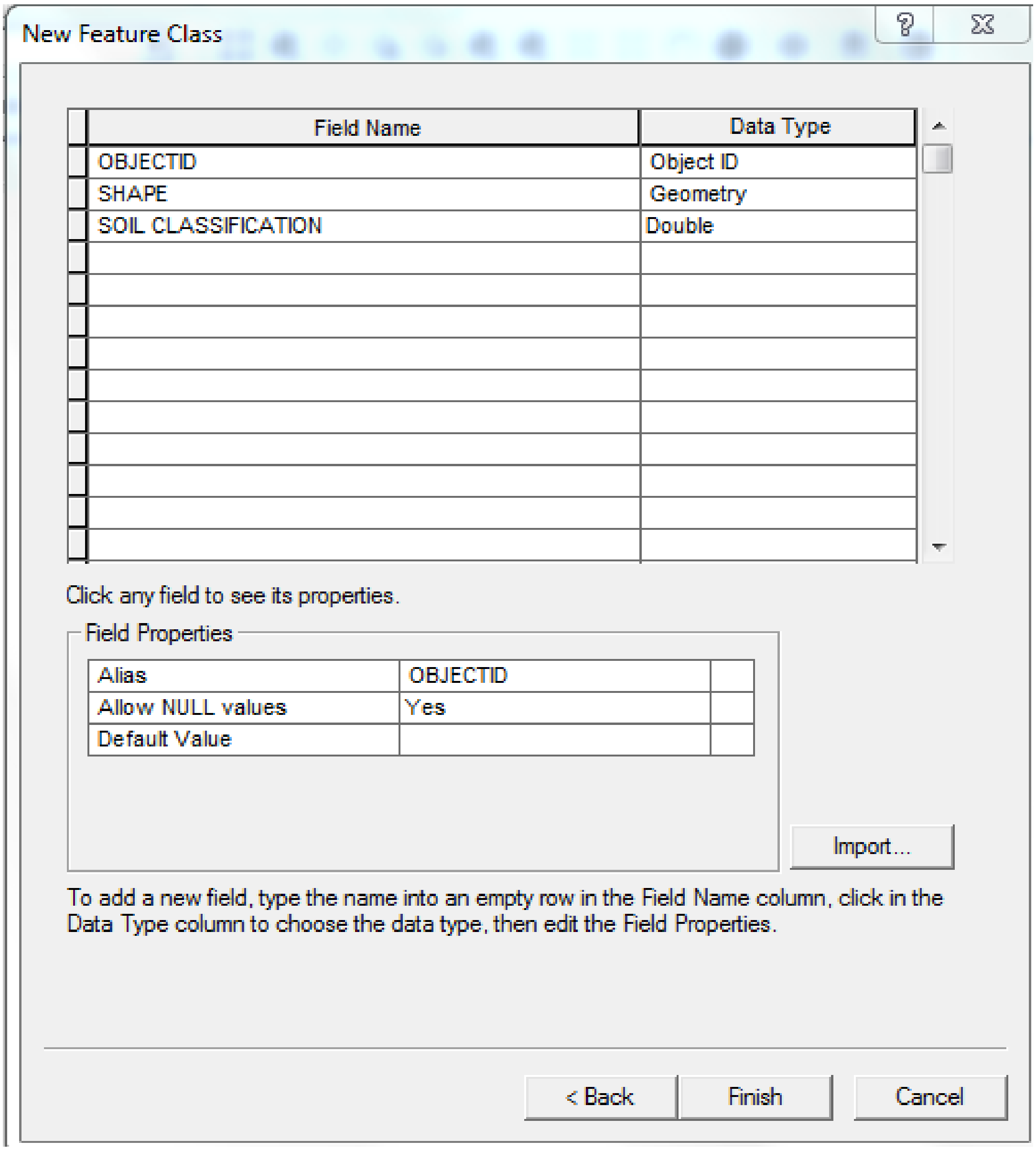

Figure.3.17. Adding new fields to a shape files attribute table soil classification in arc map.

Go to the arc map, Select add data to import geological maps in jpg.

Geological map provides information on the nature and the different physical properties of surface cover. The nature of Earth's crust of rocks and soil that contribute to hydraulic analyses are also included.

Geo-Referencing

Geo-referencing is one of the necessary steps in the process of digitizing in GIS.

It supports cross-geographic coordination of points on the scanned image with the data points referenced geographically. This is created by polynomial conversion of the coordinates of latitude, longitude of the geological map and converted to its geographical location. When you start to enter control points in Geographic Information Systems a geographical reference point is selected to add the coordinates of the selected point.

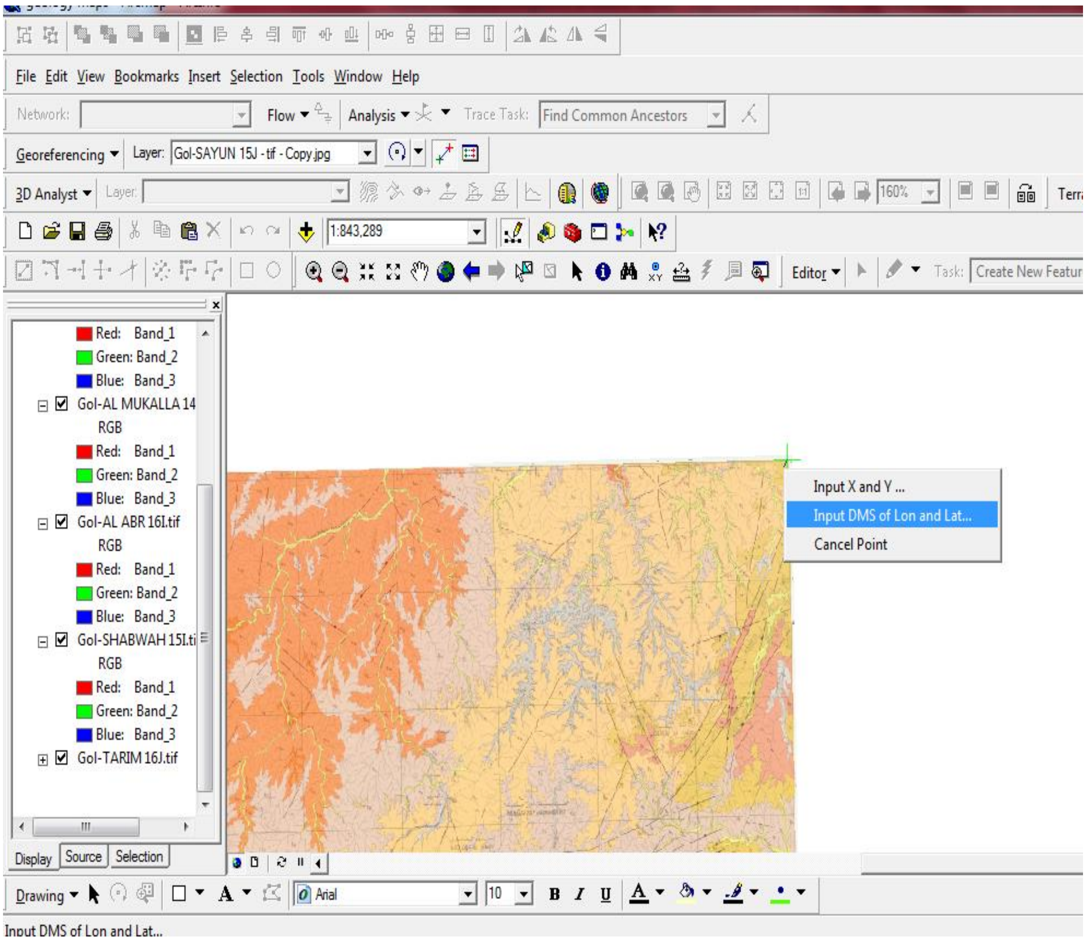

Figure.3.18.georeferencing geological map of Wadi Hadramout

Editing

Editing process is considered a basic step to draw polygon in the shape file and represents a database of the different types of soil in the attribute table.

The following steps can be processed after applying the Hadramout catchment on the geological map.

1) Open the Editor Toolbar.

2) Choose Editor / Start Editing.

3) Navigate to Editor / Snapping, set snapping to the edge of the polygon that will be created and draw the form specified.

4) When finished, select Editor / Stop Editing and click (Yes) when to save edits.

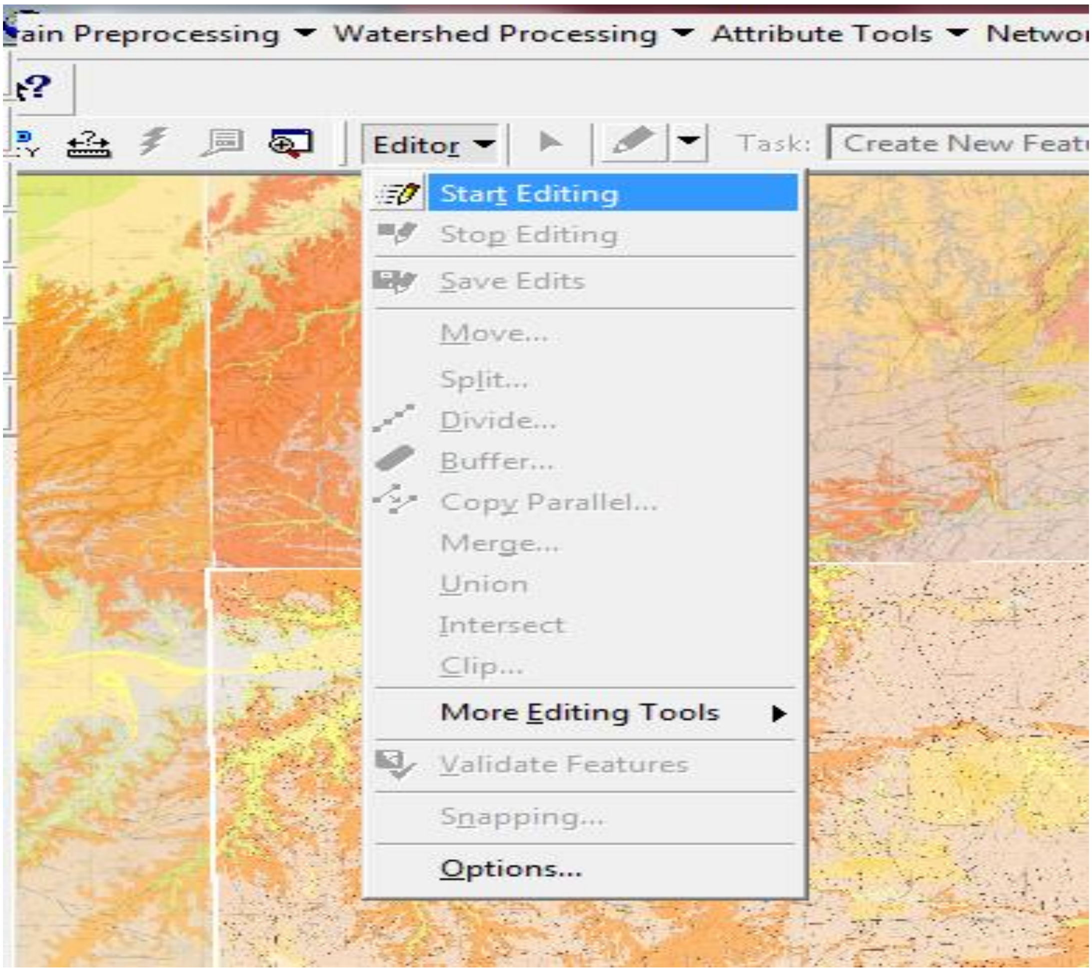

Figure.3.19. Editing for shapefile.

Attribute table

Soil Data has limits and forms of separate polygons for different types of soil. Each polygon expresses the type of soil. After the completion of the drawing process, the storage of data in Attributes Table to describe the soil layer and the inclusion of infiltration percentages rate for each type of soil is started.

Four values of Wadi Hadramout catchment are shown in Tables (3-5, 3-6).

Table 3-5 limits of hydrological soil groups.

Hydrological soil group	Description	Infiltration rate from mm/hr	Infiltration rate from mm/hr	Average infiltration rate from mm/hr
A	Deep sand, aggregated silts	More than 7.6		
B	Shallow silts, sandy loam	3.8	7.6	5.7
C	Clay loams, shallow sandy loam, soils low in organic content, soils usually high in clay.	1.3	3.8	2.55
D	Soils that swell significantly when wet, heavy plastic clays, certain saline soils	0.0	1.3	0.65

Table 3-6 Antecedent moisture Condition and Hydrologic Soil Groups

Antecedent moisture Condition	Soil Condition	Hydrologic Soil Group	Distribution of the Hydrologic Soil Group
AMC I	Low moisture, soil is dry	A	Soil with high infiltration rate, even when wet. Mostly sand and gravel.
AMCII	Average moisture, common for design	B	Soil with moderate rate of infiltration when wet. Coarse to fine texture.
AMCIII	High moisture heavy rain in last few days	C	Soil with slow infiltration rate when wet. Moderately fine to fine texture.
		D	Soil with low infiltration rate when wet, Clay or soil with high water table.

The introduction of the specific information of soil types can be prepared by the Attribute table of legend for data description of the available soil and geological maps. Attribute table is configured for soil data for each polygon through the establishment of field in the Attribute table.

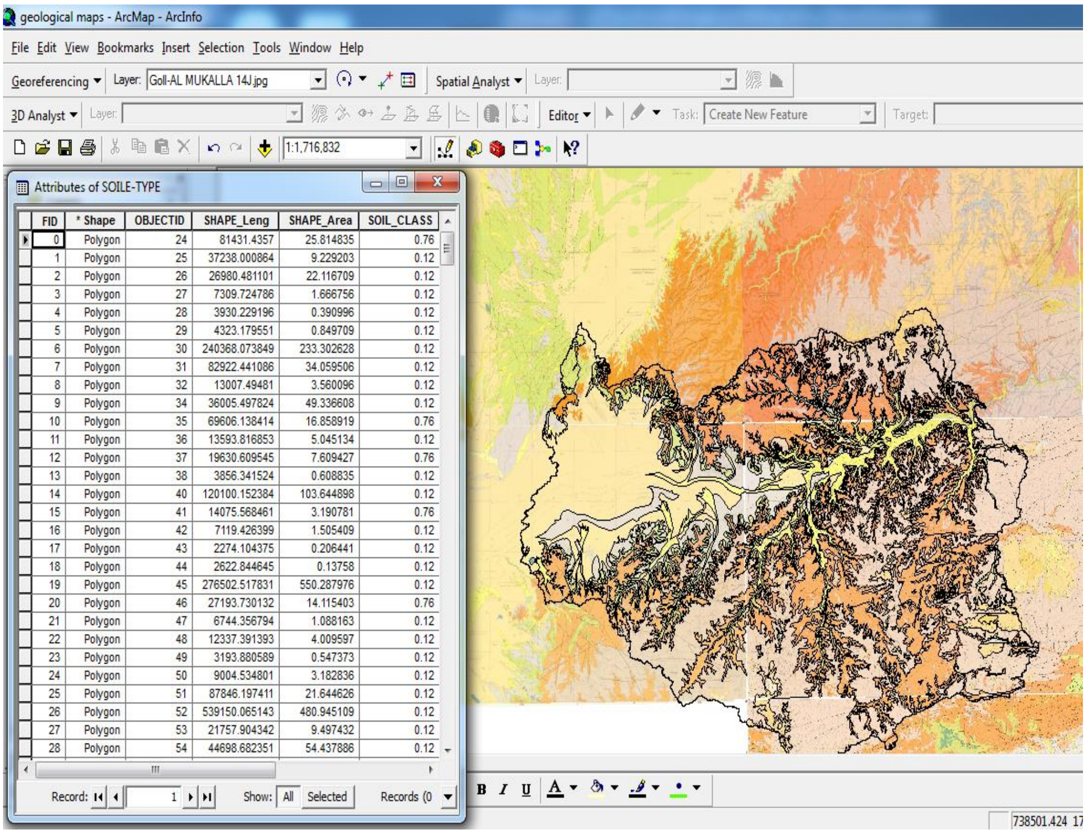

Figure.3.20 Attribute table of soil type.

The last step to complete all polygons at the Shape file is to select soil layer by right click to Data / Export Data Shape file.

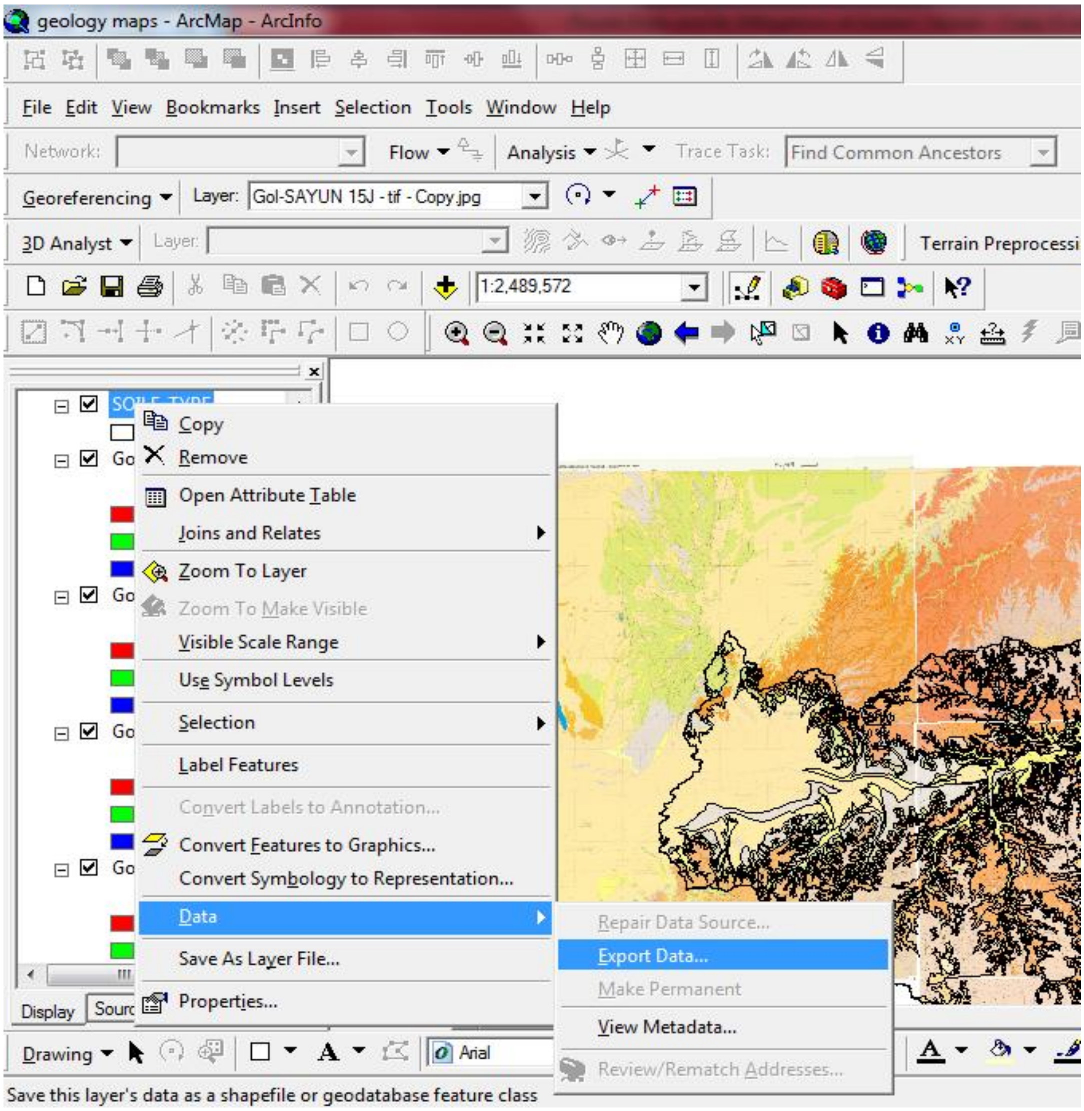

Figure.3.21.The Soil layer is converted to the Shapefile

After obtaining hydrological data for different soil types in the catchment area of Wadi Hadramout and the spatial characteristics of the different landuse for the catchment area by shape file, the landuse can be given in similar way.

3.8.2 Land use Shapefile.

The aim of study is the analysis of land use (the type of ground cover) which is an important factor during the floods. The land use has an impact on the characteristics of runoff as the density of vegetation affect the rate of flow of runoff.

The same steps in the formation of soil types is followed to get the land use shapefile as given in the following Figures. (3.22, 3.23) the area is determined by drawing a specific area and specifies if this area is a residential area, cultivated or bare area as following Figure .3.25.

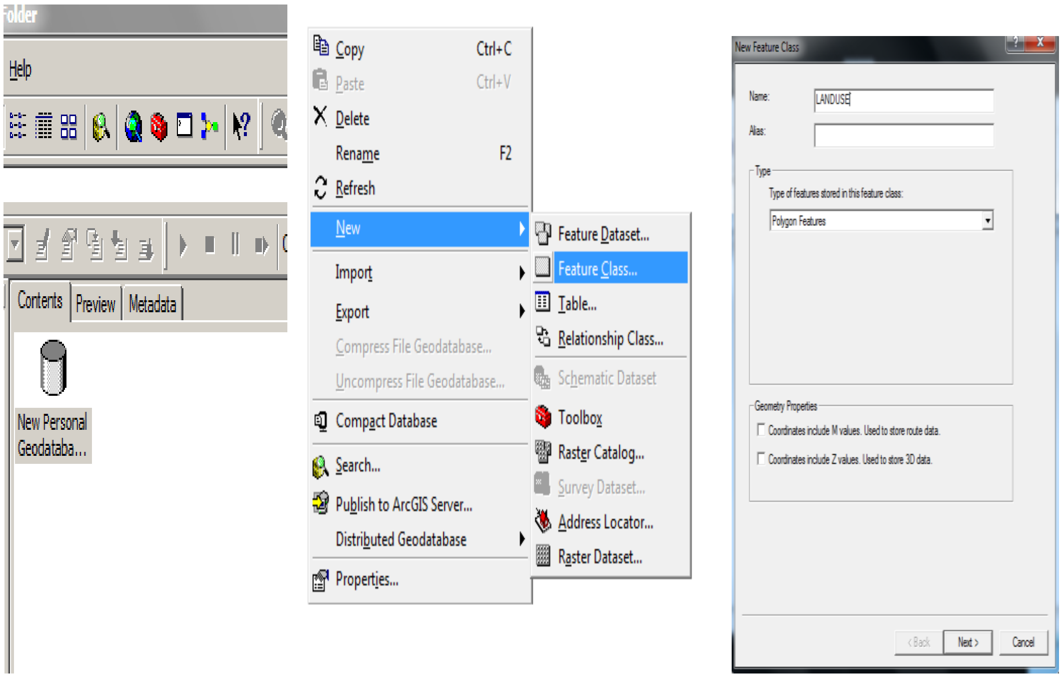

Figure.3.22. Create New files Personal Geodatabase Land use.

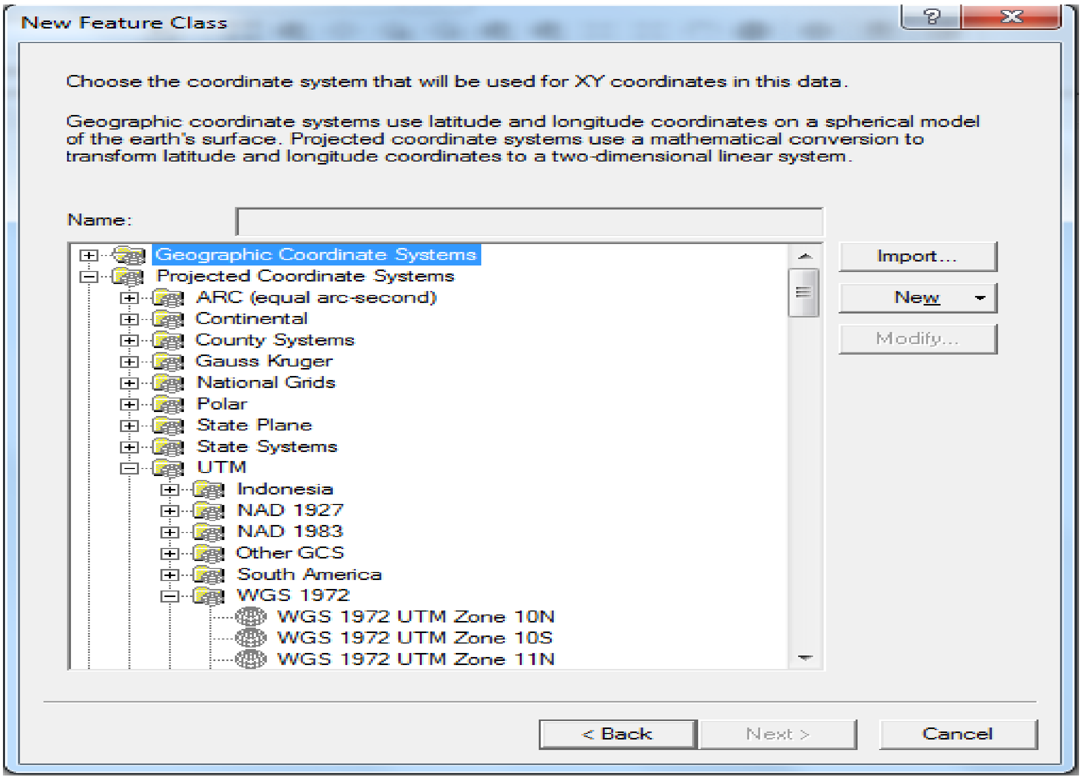

Figure.3.23. it appears coordinate system of landuse shape file.