

# SOIL EROSION ESTIMATION IN ArcGIS

## Tutorial



Developed By

**Dr. Mahesh Kumar Jat**

Email – [Mahesh.mnit@gmail.com](mailto:Mahesh.mnit@gmail.com)

Phone – 01412713412; 09549654186

Department of Civil Engineering  
Malaviya National Institute of Technology Jaipur

# SOIL EROSION ESTIMATION IN ArcGIS

## Tutorial (MNIT Jaipur)

**Key Words: Soil Erosion, RUSLE, GIS, Remote Sensing, Watershed, Hydrology**

### REVISED UNIVERSAL SOIL LOSS EQUATION

The Revised Universal Soil Loss Equation (Renard, 1997) is improved from of USLE (Wischmeier and Smith 1965, 1978), used to estimate average annual soil erosion potential,

$$A = R \times K \times L \times S \times C \times P \quad \dots(1)$$

Where,

$A$  = computed average annual soil loss (tons/ha/year),  $R$  = rainfall-runoff erosivity factor,  $K$  = soil erodibility factor,  $L$  = slope length factor,  $S$  = slope steepness factor,  $C$  = cover-management factor,  $P$  = conservation practice factor

However, over the period each component was further revised.

### **PARAMETERS**

#### ***Rainfall-Runoff Erosivity Factor R***

*Annual Relationship:*

$$R_a = 81.5 + 0.380 P_a \quad \dots(2)$$

*Seasonal Relationship :*

$$R_s = 71.9 + 0.361 P_s \quad \dots(3)$$

Where,

$R$  = average erosion index,  $P$  = average rainfall (mm), Subscript  $a$  and  $s$  stands for annual and seasonal.

#### ***Soil Erodibility Factor K***

In RUSLE,  $K$  is assumed to be constant throughout the year. Tables of  $K$  values are available in Soil Conservation Service Offices for most soils in the U. S. In the absence of published data, a widely used relationship for predicting erodibility is a nomograph by Wischmeier *et al.* (1971). Soil erodibility in the nomograph is predicted as a function of soil and soil profile parameters:

- Percent silt (MS; 0.002-0.05 mm)
- Percent very fine sand (VFS; 0.05-0.1 mm)

- Percent sand (SA; 0.1-2 mm)
- Percent organic matter (OM)
- Soil structure code (s)
- Soil permeability code (p)

The analytical relationship for the nomograph by Wischmeier *et al.* (1971) is given by following regression equation,

$$K = \frac{2.1 \times 10^{-4} (12 - OM) M^{1.14} + 3.25(s - 2) + 2.5(p - 3)}{759.4} \dots(4)$$

Where,

$K$  = soil erodibility (tons-yr/MJ-mm),  $OM$  = percentage organic matter,  $p$  = soil permeability code,  $s$  = soil structure code,  $M$  = a function of the primary particle size fraction given by;

$$M = (\% \text{ silt} + \% \text{ sand}) \times (100 - \% \text{ clay}) \dots(5)$$

Table 1 Attributes of Soil map used in RUSLE

Sr. No	Class name	% Sand	% Silt	% Clay	M	Soil Structure code (s)	Permeability Code (p)	Soil Org. Matter%
1.	Sand	90	6	4	9216	4	1	0.5
2.	Silty Loam	20	65	15	7225	2	3	1
3.	Silt	8	87	5	9025	2	3	1.4
4.	Loam	41	41	18	6724	2	3	1.5
5.	Sandy Clay Loam	60	13	27	5329	3	4	2
6.	Clay Loam	33	33	34	4356	2	4	0.8
7.	Clay	20	20	60	1600	1	6	0.6

**Soil structure code(s):**  
 1 - very fine granular  
 2 - fine granular  
 3 - medium or coarse granular  
 4 - blocky, platy, prism like

**Soil permeability code (p):**  
 1 - rapid (>150mm/hr)  
 2 - moderate to rapid (50-150 mm/hr)  
 3 - moderate (15-50 mm/hr)  
 4 - slow to moderate (5-15 mm/hr)  
 5 - slow (1-5 mm/hr)

6 - very slow (< 1mm/hr)

### **Conservation Practice Factor P**

The values of conservation practice factor, P for different management practices are tabulated in Hann *et al.*(1994).

Table 2 : Codes as per the Land Cover Classes in India

Sr. No.	Class name	Conservation Practice (P)	Organic matter(OM)
1.	Tropical Evergreen	1	4
2.	Subtropical Evergreen	1	4
3.	Temperate Broadleaved	1	2
4.	Tropical Montane	1	2
5.	Tropical semi-evergreen	1	4
6.	Temperate Conifer	1	2
7.	Subtropical Conifer	1	2
8.	Tropical Moist Deciduous	1	2
9.	Tropical Dry Deciduous	1	4
10.	Junipers	1	2
11.	Mangroves	1	0.5
12.	Degraded Forest	0.9	2
13.	Dry woodland	0.8	0.5
14.	Thorn forest/Scrub(North)	0.9	0.5
15.	Thorn forest/Scrub(South)	0.9	0.5
16.	Shrubs	1	2
17.	Abandoned Jhum	1	2
18.	Sparse Woods	1	0.5
19.	Bush	1	2
20.	Coastal Vegetation	0.8	2
21.	Savannah	0.1	4
22.	Plain Grasslands	0.7	0.5
23.	Slope Grasslands	0.5	0.5
24.	Desert Grasslands	0	0.5
25.	Alpine Meadow	0.5	2
26.	Alpine Grasslands	0.8	0.5

27.	Sparse Vegetation(Cold)	0.5	0.5
28.	Sparse Vegetation(Hot)	0.5	2
29.	Gobi	1.0	2
30	Desert(cold)	0	0
31	Thorn Scrub/Desert(Ho	0.9	0.5
32	Irrigated Intensive Agri.	0.3	0.5
33	Irrigated Agriculture	0.35	0.5
34	Slope Agriculture	0.2	0.5
35	Rainfed Agriculture	0.2	0.5
36	Current Jhum	0.1	2
37	Swamp	0.75	0.5
38	Coral Reef	0.9	2
39	Water Bodies	0	0.5
40	Snow	0	0
41	Barren	1	0.5
42	Bare Rock	0	0
43	Salt Pans	0.5	0
44	Mud Flats	1	0
45	Settlement	0	0

### ***Cover-Management Factor C***

The cover-management factor is the ratio of soil loss from an area with specified cover and management to that of an identical area in tilled continuous fallow. De Jong (1994) in his PhD thesis described the use of vegetation indices in order to extract vegetation parameters for erosion models. Based on his work following statement can be assumed to be valid in general: i) NDVI and RULSE C-factor are correlating; ii) There is a linear relation between NDVI and RULSE C-factor

Based on these assumptions the NDVI map can be analyzed to formulate the linear equation between NDVI and C factor. The NDVI values less than Zero (0) indicate the water and snow, so the negative values should not be considered in preparing the C factor equation. With this boundary conditions the regression equation for C factor can be developed.

$$C_i = 0 \quad \text{if } NDVI \leq 0$$

$$C_i = -\left(\frac{1}{NDVI_{max}}\right)(NDVI)_i + 1 \quad \text{if } 0 < NDVI \quad \dots(6)$$

**Slope Length and Slope Steepness Factor LS**

The effect of topography on erosion in RUSLE is accounted for by the LS factor. The slope length factor (L) is calculated using following equation,

$$L = \left(\frac{\lambda}{22.13}\right)^m \quad \dots\dots\dots(7)$$

Where,

22.13 = the RUSLE unit plot length (m) and *m* = a variable slope-length exponent. Slope length  $\lambda$  is defined as the horizontal distance from the origin of overland flow to the point where either (1) the slope gradient decreases enough that deposition begins or (2) runoff becomes concentrated in a defined channel.

The slope-length exponent *m* is calculated as,

$$m = \beta / (1 + \beta) \quad \dots\dots(8)$$

$$\beta = (\sin \theta / 0.0896) / [3.0(\sin \theta)^{0.8} + 0.56] \quad \dots\dots\dots(9)$$

Where,

$\theta$  = slope angle.

The slope steepness factor (S) is evaluated from (McCool *et al.*, 1987, 1993)

$$S = 10.8 \sin \theta + 0.03 \quad S < 9\% \text{ (i.e. } \tan \theta < 0.09)$$

$$S = \left(\frac{\sin \theta}{\sin 5.143}\right)^{0.6} \quad S \geq 9\% \text{ (i.e. } \tan \theta \geq 0.09) \quad \dots\dots(10)$$

To calculate the Slope Length and Slope Steepness factor the slope map (degrees) and flow accumulation map can be derived from DEM using Hydrology tools available in

**Spatial Analyst tool box of ESRI ArcGIS.**

Value 1 is assigned to all the grids having flow accumulation values equal to zero (since we are calculating the soil erosion at grid level). For further calculations the slope is converted in to radians (since all the trigonometric function in ESRI Arc-GIS are in radians).

The slope length factor map is derived by applying Eq. 7 on flow accumulation map and slope length exponent ( $m$ ) map in raster calculator environment of Arc-GIS 9.1. Eq. 7 is converted in to form of grid equation as given below –

$$L = \left( \frac{\text{Flow Accumulation} \times \text{Grid Size}}{22.13} \right)^m \quad \dots(11)$$

Where,

Grid size = 30 m, and slope length exponent  $m$  is taken from  $m$  map for respective grid.

The derived Slope Length Factor (L) map is shown in Fig. 7

The slope steepness factor (S) map is derived by applying Eq. 10 on slope map of India in Raster calculator of Arc-GIS. The Eq. 10 is converted in to grid equation as;

$$\begin{aligned} & \text{CON}(\text{Tan}([\text{slope\_deg\_c}] * 3.1428 / 180) < 0.09, \\ & 10.8 * \text{Sin}([\text{slope\_deg\_c}] * 3.1428 / 180) + 0.03, \\ & \text{Pow}((\text{Sin}([\text{slope\_deg\_c}] * 3.1428 / 180) / \text{Sin}(5.143 * 3.1428 / 180)), 0.6)) \end{aligned} \quad \dots(12)$$

## **Tutorial**

### **Soil Erosion Estimation Using RUSLE in Arc GIS**

**INPUT DATA:** Available in given drive and folder.

- 1) Digital Elevation Model (DEM) – raster
- 2) Station\_Location \_Annual Rainfall Map (rain) – location.shp
- 3) Land Cover Map (LULC) - lulc
- 4) Soil Map (Soil) - soil
- 5) NDVI map (NDVI) – ndvi\_subset.img

Add above mentioned data in the ArcMap.

#### **SOFTWARE REQUIRED: Arc-GIS**

**Steps:** First of all we should set the processing extent, raster resolution (Cell size) and other standard environmental parameters in the beginning of the project work to avoid repeated definition of these limits while using any tool in tool box.

First of all open ArcMap and go to Geoprocessing and click on Environments tool as shown below.

First of all define the current work place and select the given input data folder and then click ok. Also select the output\_RUSLQ.gdb folder in Scratch workspace.

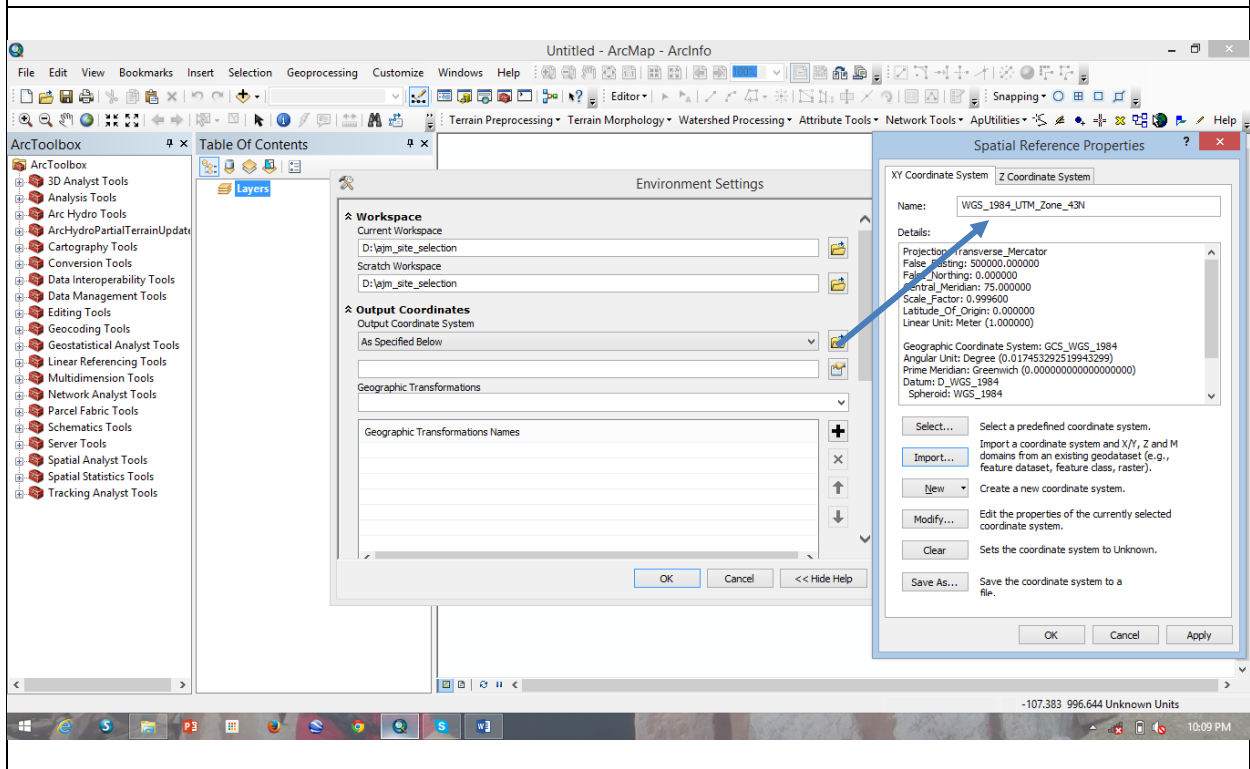
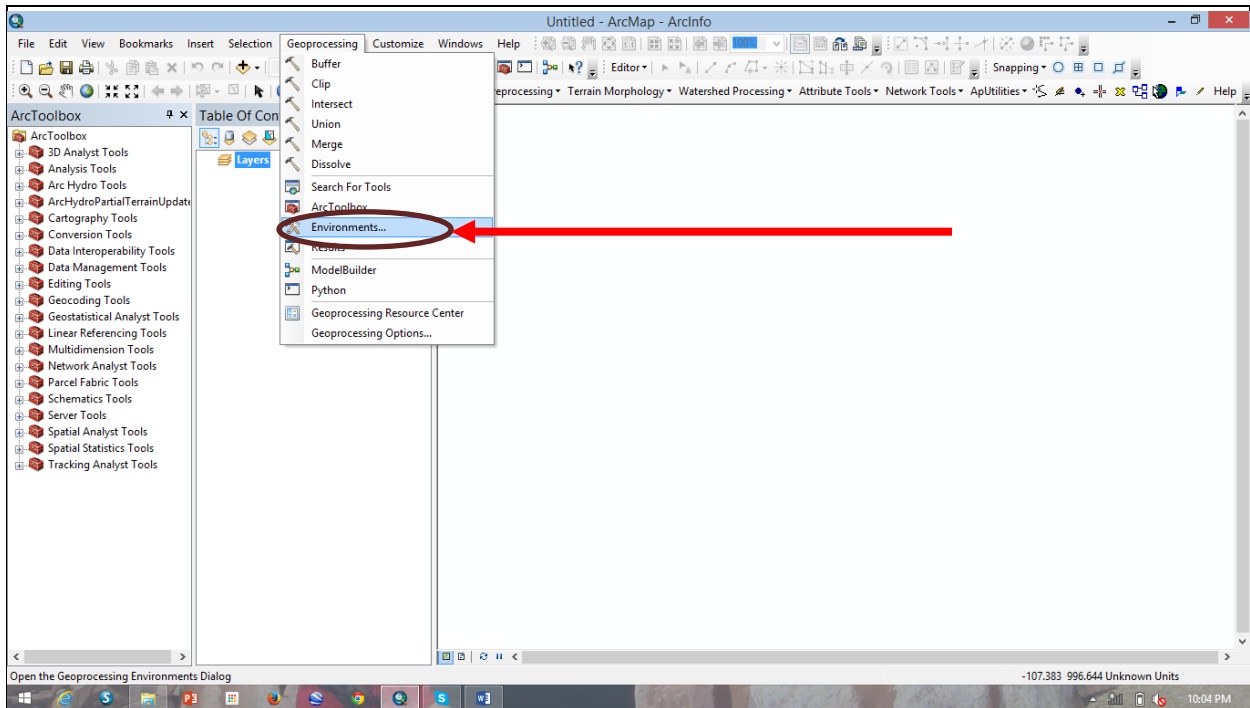
First of all we can define output coordinate system so that all the layers produced should be in same coordinate and projection system. Select output coordinates and then either select from already defined with some existing dataset or choose as specified below. If this option is selected then click on write side tab and either import or select the required coordinate and projection system. For our project we are using WGS coordinate system and UTM project system. Then select projected coordinate systems, then select UTM then select WGS 194 then select northern hemisphere and then select Zone 43 and click ok. We have defined the output coordinate and project systems.

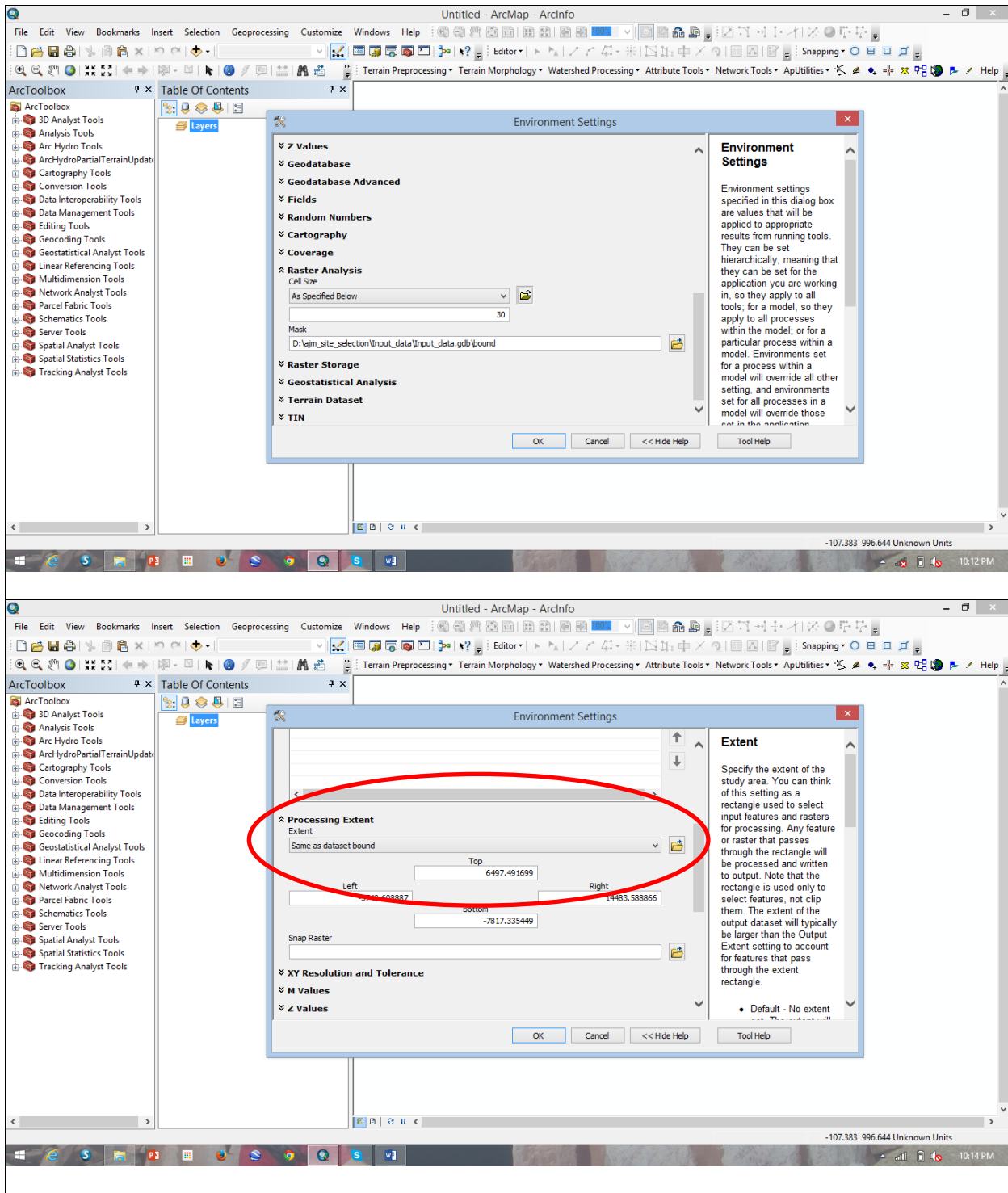
Now we need to define processing extent. In the present case processing extent is boundary of watershed which is available in supplied data with the name of *boundary.shp*. Now Go to processing extent in Environments and select the file boundary.shp file from the input data folder.

Now we will define the Cell size of all raster maps by clicking on Raster Analysis then select as specified below from dropdown menu and then write the required pixel size.



Here we can also define processing mask to confine our operations with in defined area. For our tutorial we will use boundary.shp which boundary of study area as mask layer. Click ok.





After completing these activities in Environments save all files available in ArcMap as .mxd and given name as soil\_erosion.mxd.

To calculate the RULSE parameters, we are going to use the *Raster Calculator*, Make sure that *Spatial Analyst Tools* is available in your system.

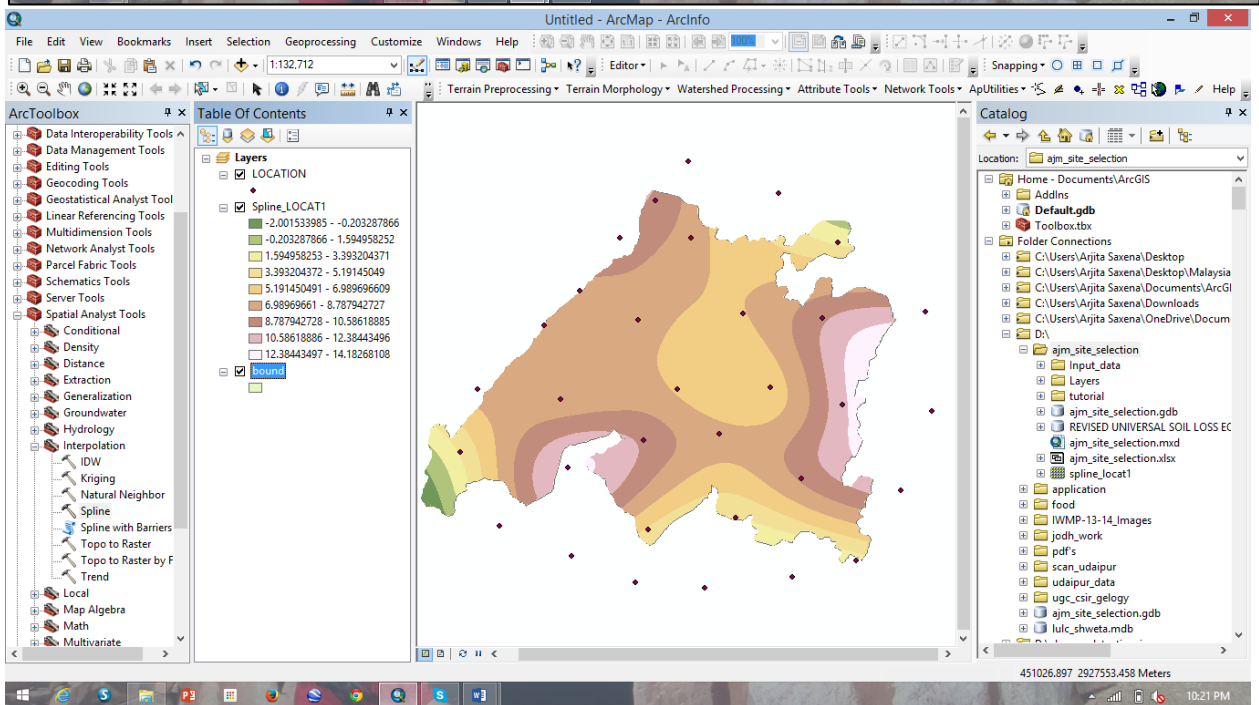
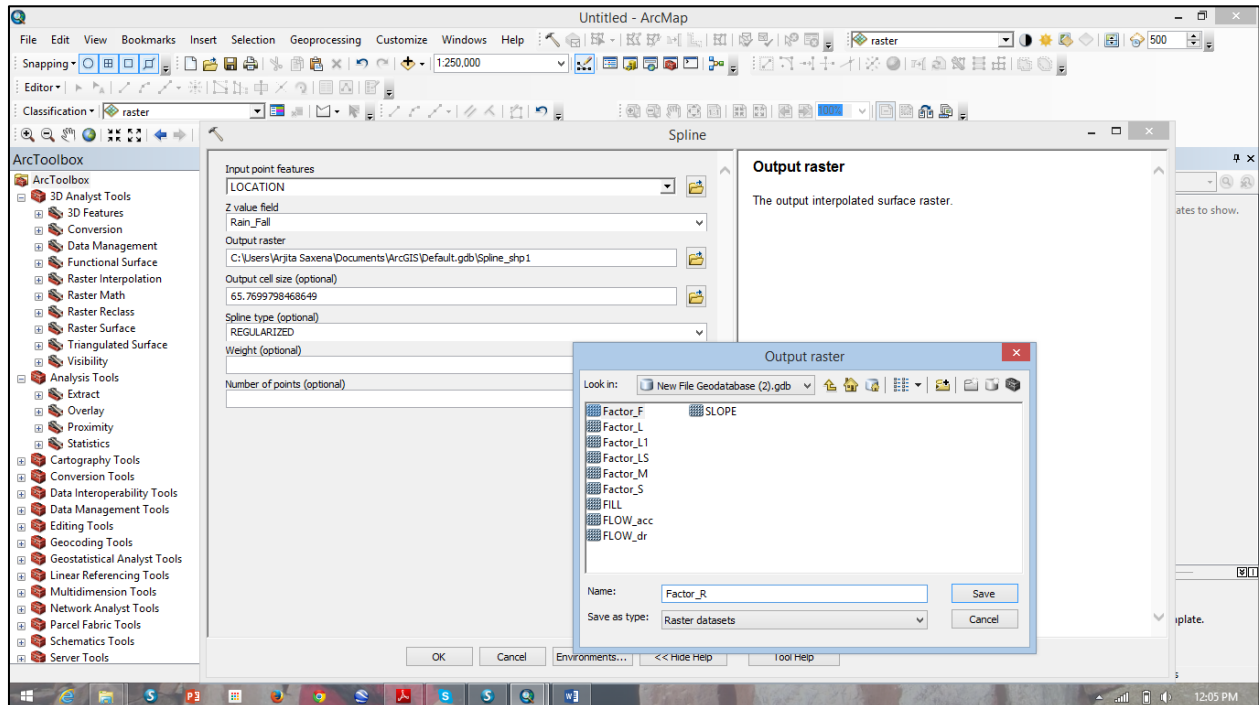
### **Calculation of R Factor**

Go to the *Spatial Analyst* >> *Interpolation* >> *IWD*

Input point feature – Location.shp

Z value field – select Rain\_Fall from dropdown menu.

Output- Factor\_R



Make sure the *Rain* map (Factor\_R) is added in the viewer, go to the *Spatial Analyst* >> *Raster Calculator*. The *Raster Calculator* window will open.

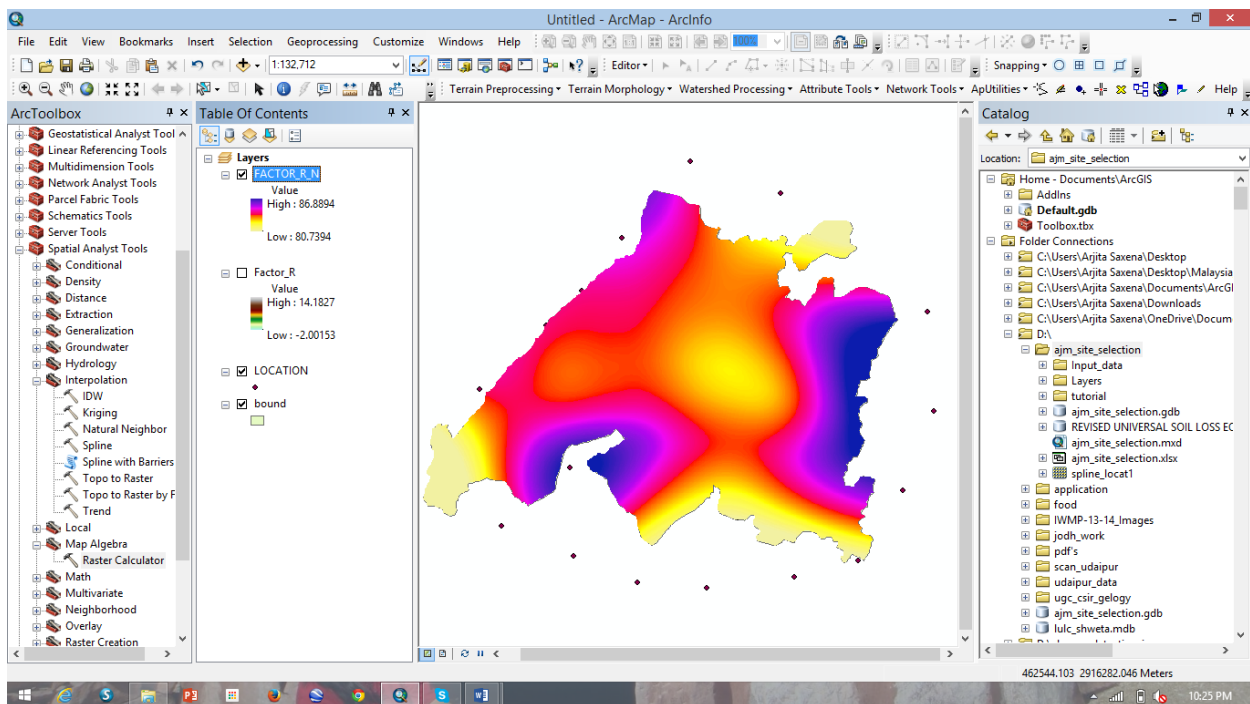
To calculate the *R* factor map use *rain* map (Factor\_R) as an input map and Equation 2, which is written as follows in raster calculator,

$$81.5 + (0.380 * [rain.img]) \quad (13)$$

Type this equation carefully in the raster calculator as shown below;

FACTOR_R_N	81.5 + (0.380 * "Factor_R")
------------	-----------------------------

Give the output name to the raster as Factor\_R\_N and store it in same folder from where the output has been used.



Add the *R\_N\_factor* map in the viewer and check that the *calculation* and *R\_N\_factor* maps are identical.

### **Calculation of K Factor**

Make sure that the *soil* map is added in the viewer, if not add *soil* map from input data folder.

Uncheck all other maps, so that only *soil* map is visible in the viewer. You can see that in the study area only five type of soil exists.

Open the *attribute table* of the *soil* map, read all the attribute columns in the table, refer to the Equation 4 & 5, all the required parameters for these equations are available in the attribute table.

To Calculate  $K$ , open attribute table click table option << add field << name =k value\_1,type=float. Right click on the k\_factor\_1,select field calculator type the below equation.

$$k\_factor\_1 = (((((2.1) * (10^{(-4)})) * (12 - [OM])) * ([M\_Value\_1]^{1.14})) + (3.25 * ([Soil\_Stru\_]-2)) + (2.5 * ([permeable\_]-3))) / 759.4$$

The analytical relationship for the nomograph by Wischmeier *et al.* (1971) is given by following regression equation,

$$K = \frac{2.1 \times 10^{-4} (12 - OM) M^{1.14} + 3.25(s - 2) + 2.5(p - 3)}{759.4} \quad \dots(4)$$

Where,

$K$  = soil erodibility (tons-yr/MJ-mm),  $OM$  = percentage organic matter,  $p$  = soil permeability code,  $s$  = soil structure code,  $M$  = a function of the primary particle size fraction given by;

To Calculate  $M$ , open attribute table click table option << add field << name =M value\_1,type=float. Right click on the M\_factor\_1,select field calculator type the below equation.

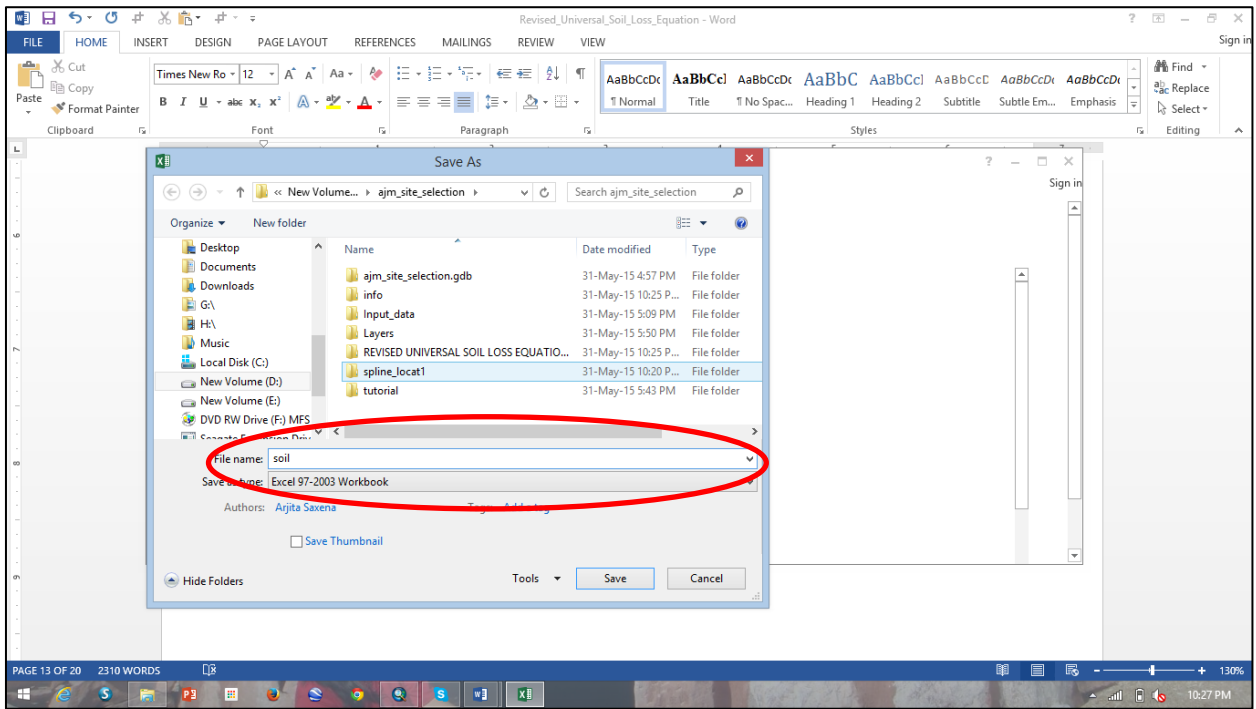
$$M\_factor\_1 = ([SILT\_PER] + [SAND\_PER]) * (100 - [CLAY\_PER])$$

$$M = (\% \text{ silt} + \% \text{ sand}) \times (100 - \% \text{ clay}) \quad \dots(5)$$

$M\_IMTI = ((G2 + H2) * (100 - F2)) \dots \dots \dots$  in excel

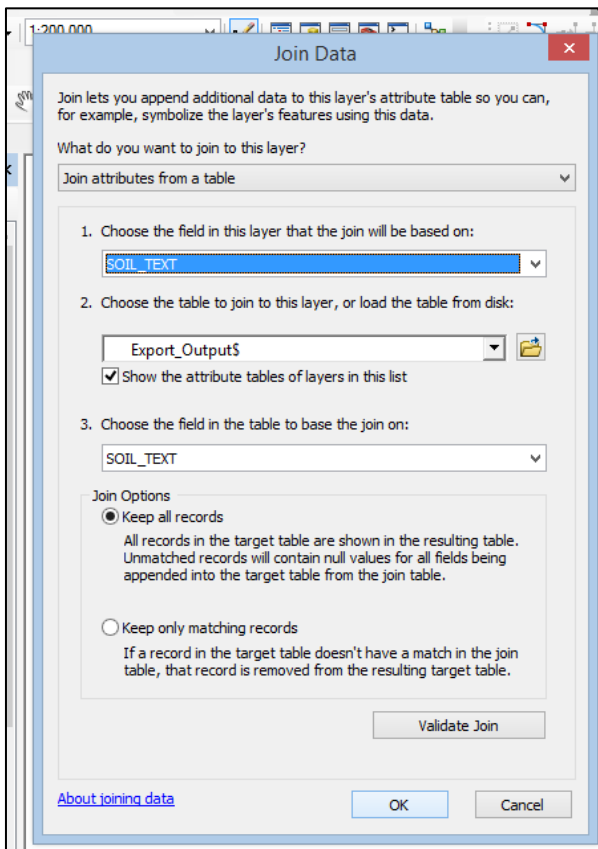
$K = ((2.1 * 10^{(-4)} * (12 - M2) * (Q2^{(1.14)})) + (3.25 * (N2 - 2)) + (2.5 * (O2 - 3))) / 759.4 \dots \dots$  in excel

Save the excel file in **Excel 97-2003 WorkBook** format



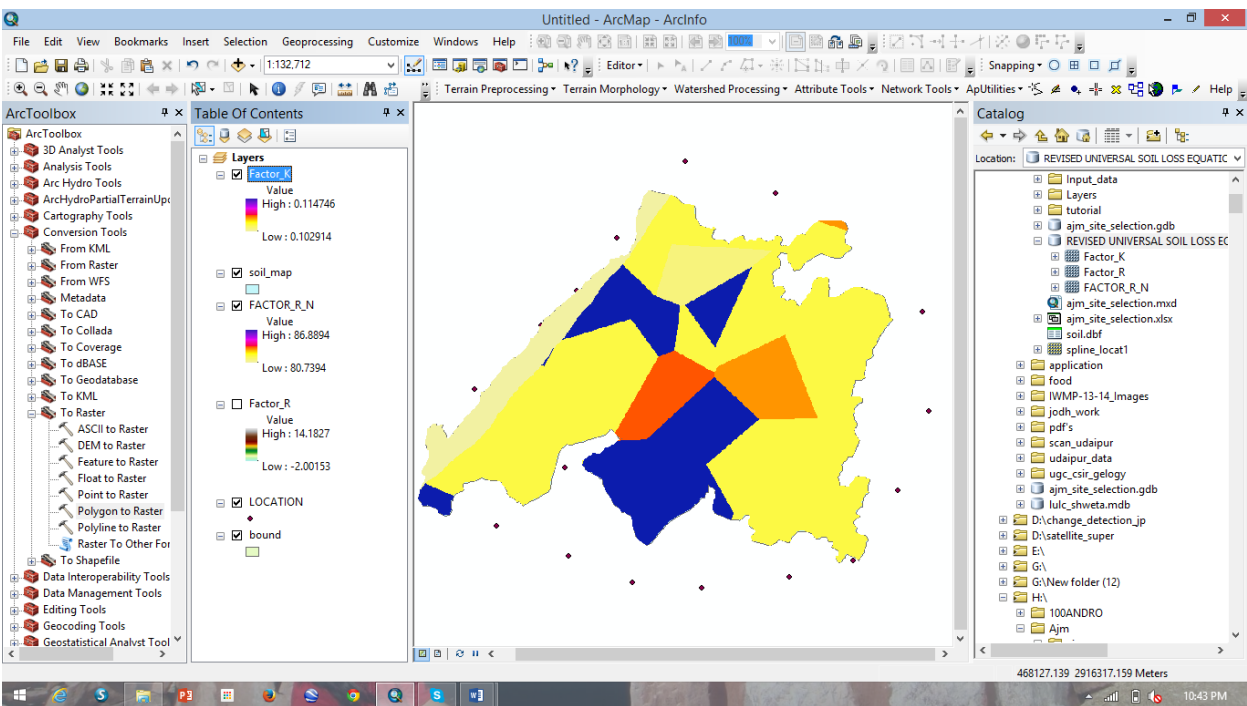
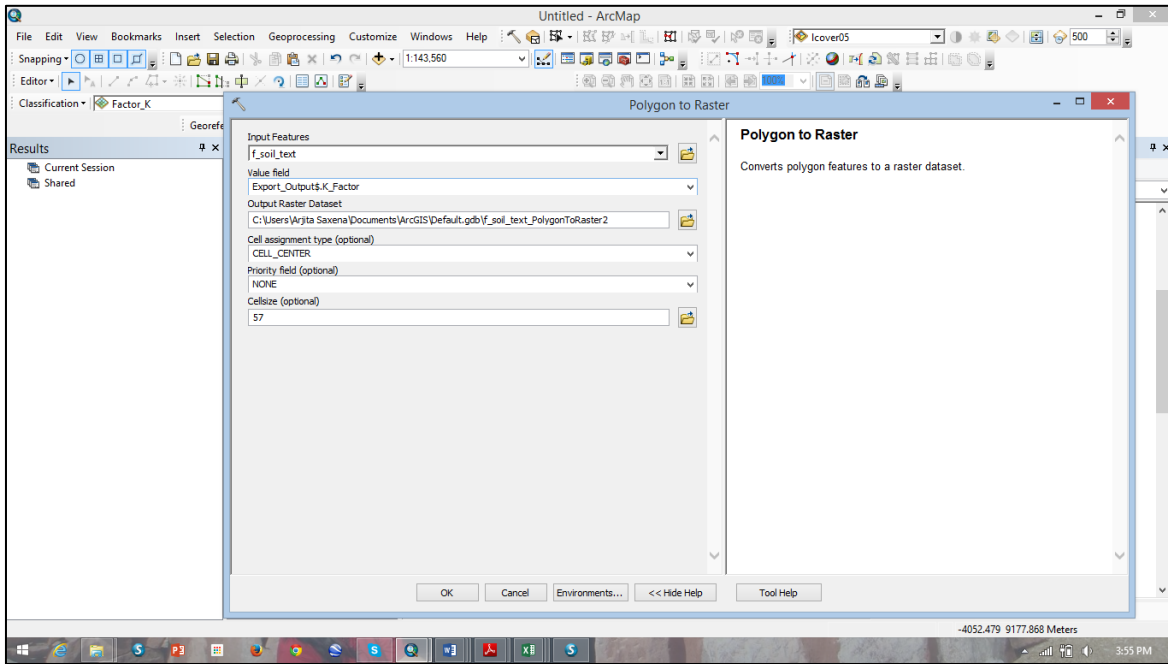
## To generate *K Factor*

*Right click on soil.shp << join and relate <<join*



Then go to Arc toolbox>>conversion tool>>to raster>>polygon to raster

Input – soil.shp, valuefield- Export\_Output\_k\_Factor, output- Factor\_K

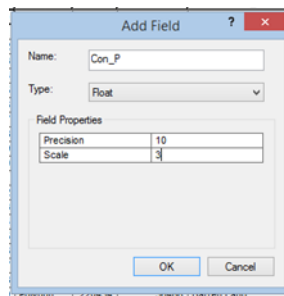
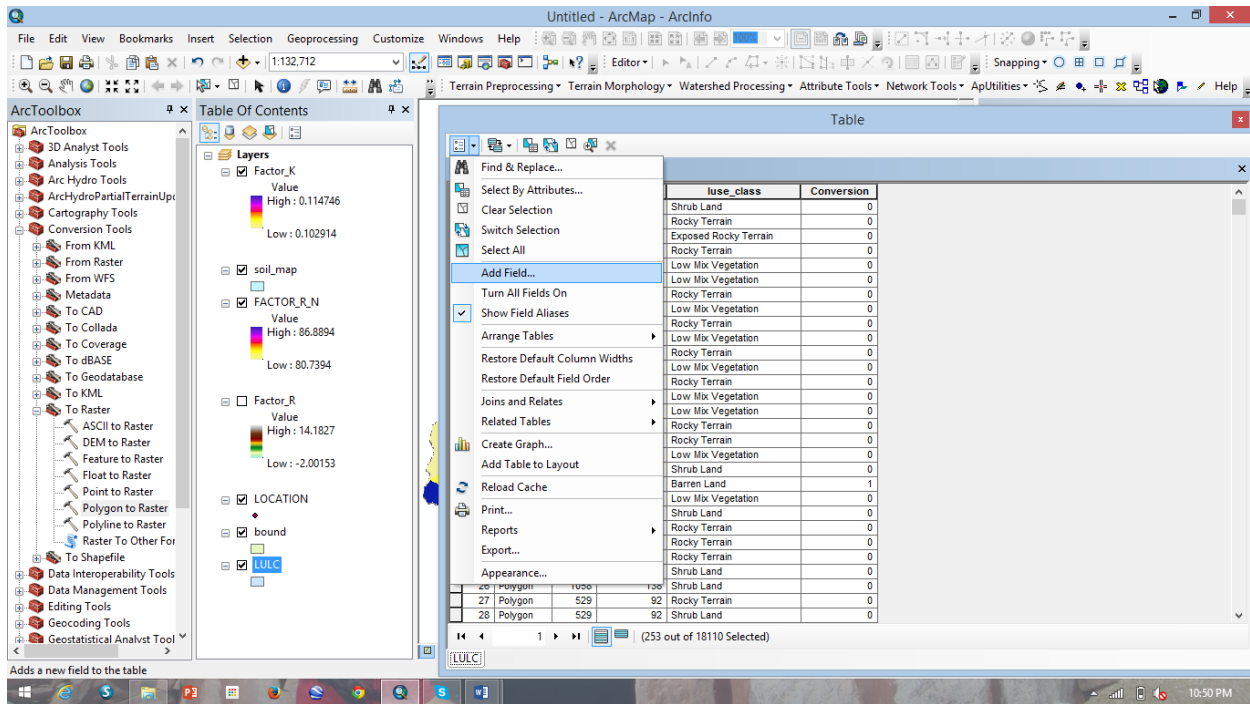


## ***Calculation of P Factor***

*Add LULC.shp*

*Open Attribute Table*

*Create a Add Field*



To generate P factor map, we can refer to the values of C factor for each land cover from literature (e.g. Table 2.).

LULC_CLASS	Conservation Practice (P)
Barren Land'	1
Dense Mix Vegetation	0.8
Exposed Rocky Terrain	0.1
Fallow Land	0.8
Low Mix Vegetation	0.8
Rocky Terrain	0
Sandy Soil	0.7
Settlement	0
Shrub Land	0.9
Water	0
Wet Alluvium Soil	1



Then goto system toolbox>>conversion tool>>to raster>>polygon to raster

**Input – soil.shp, valuefield- Con\_P, output- Factor\_P**

**Calculation of C Factor**

Make sure that the NDVI map is added in the viewer, if not add NDVI map in the viewer.

Note down the range of NDVI in the map

**(NDVI<sub>min</sub>= Low : -0.381443 and NDVI<sub>max</sub>= High : 0.518797).**

Prepare the linear equation for C Factor calculation, as described in the theory

$$C = 0 \quad \text{NDVI} \leq 0$$

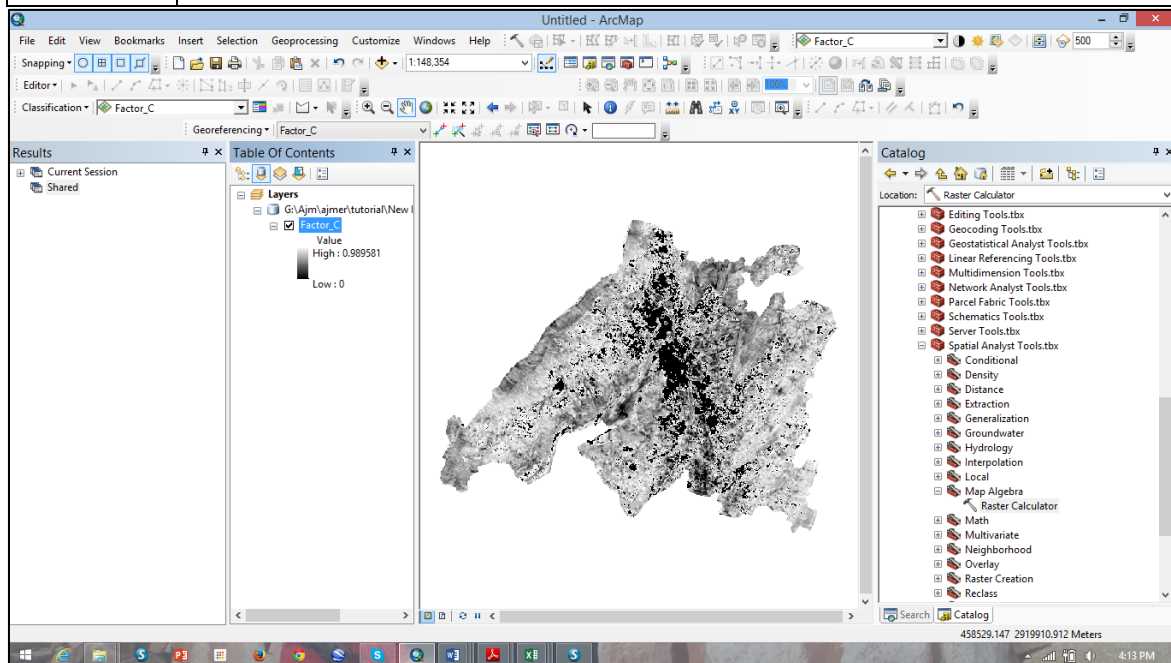
$$C_i = -\left(\frac{1}{\text{NDVI}_{max}}\right)(\text{NDVI})_i + 1 \quad \text{if } 0 < \text{NDVI} \quad \dots(6)$$

$$C = 0 \quad \text{NDVI} \geq 0.75$$

Now use conditional function in Raster calculator to generate the C Factor map using NDVI and the linear equations developed above;

Use following conditional expression in raster calculator to compute Factor\_C.

Factor_C	Con("ndvi_subset" <= 0,0,((- (1 / 0.518797) * ("ndvi_subset"))) + 1))
----------	---

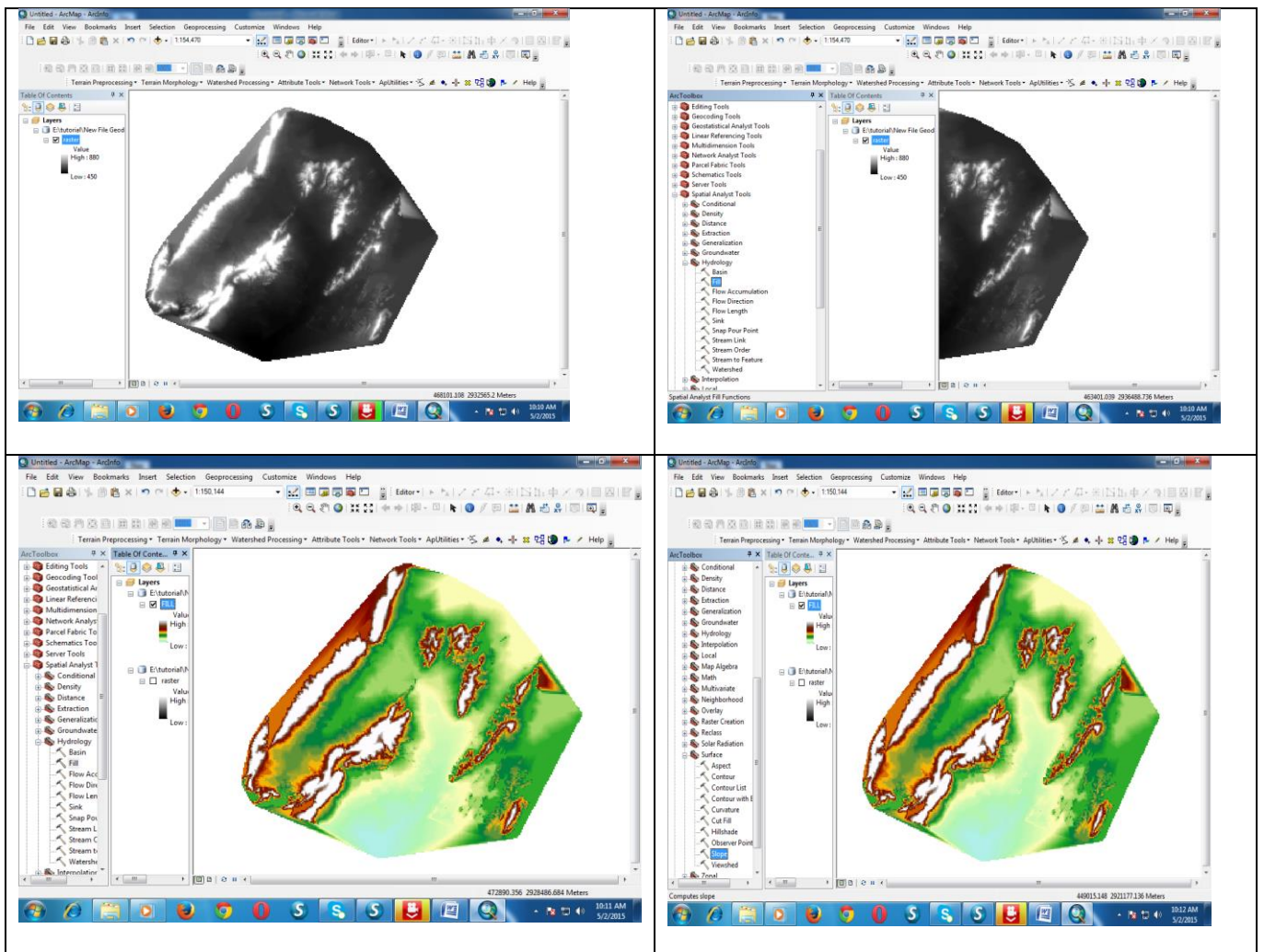


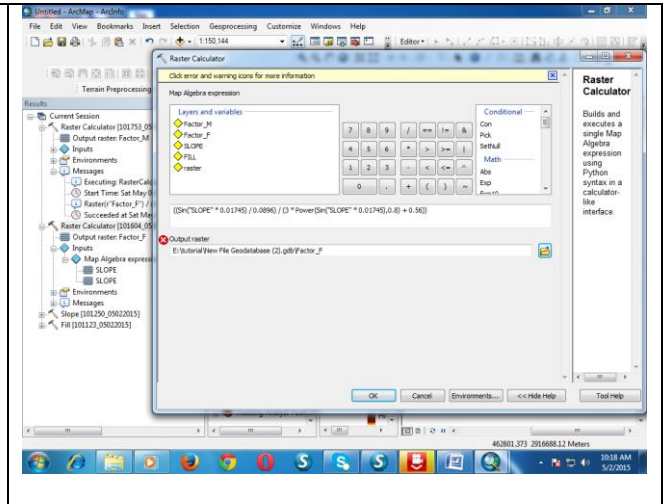
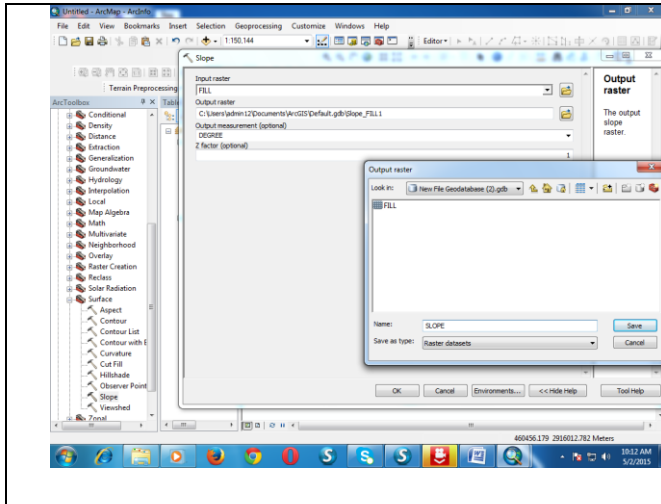
The temporary C Factor map will appear in the viewer, make it permanent.

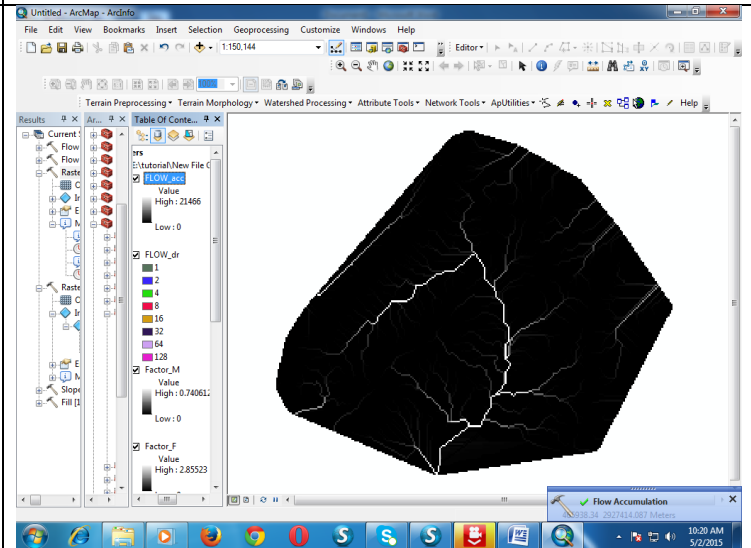
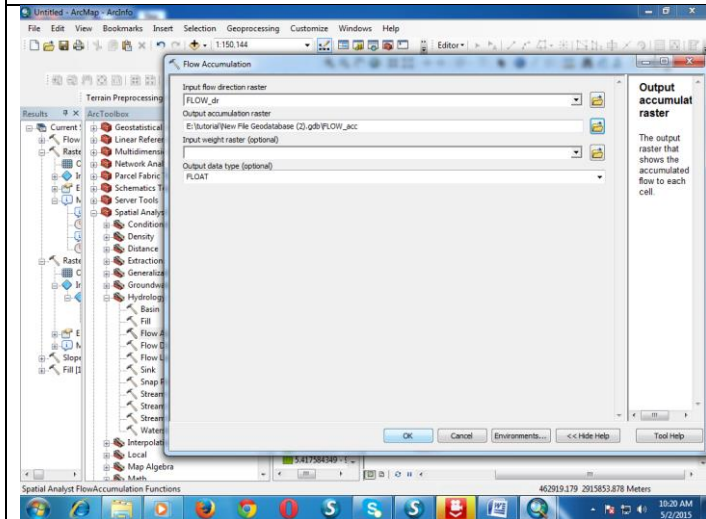
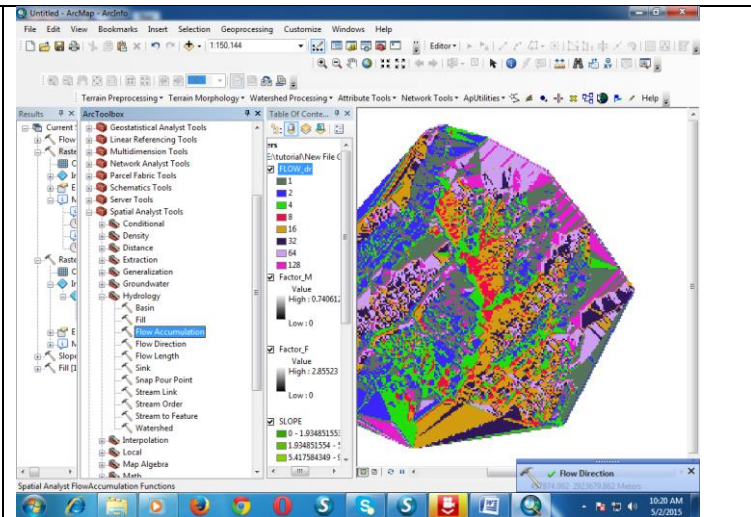
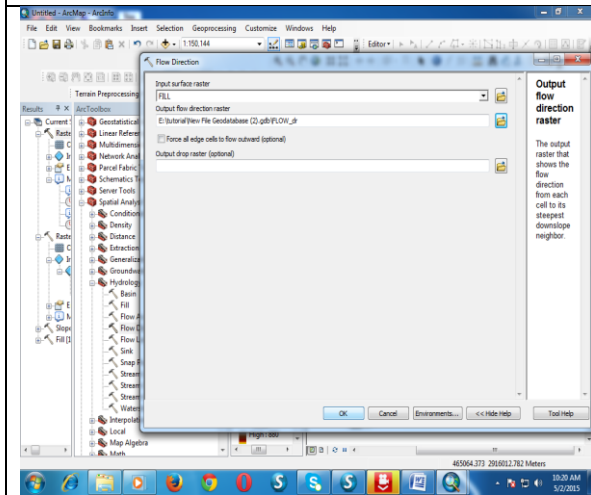
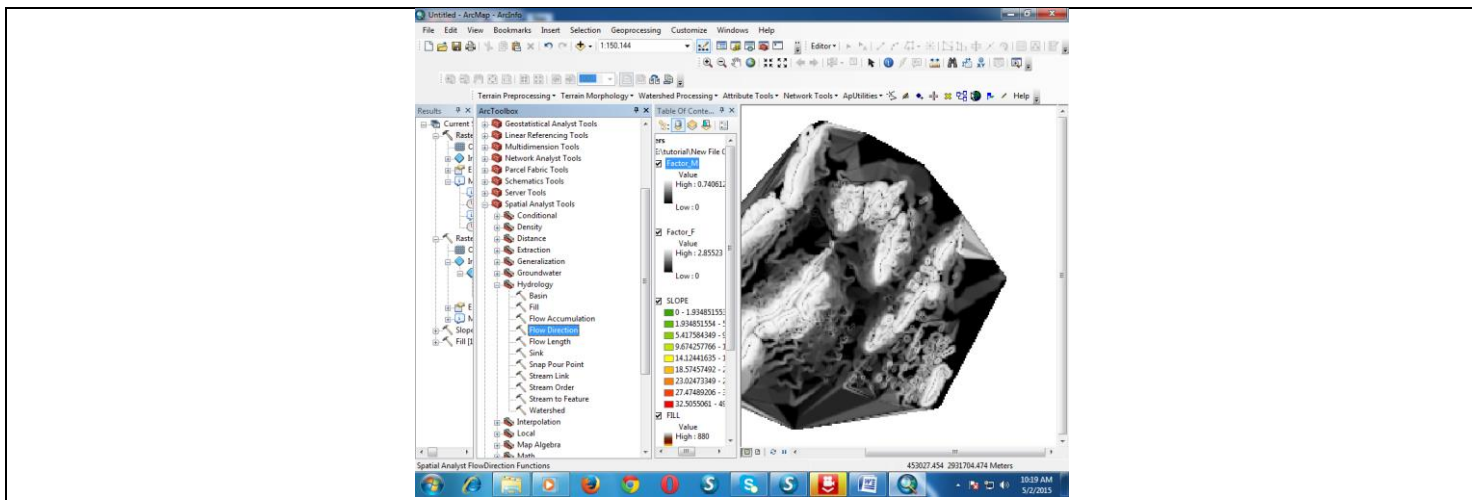
### Calculation of LS Factor

LS is a topographic factor, to calculate *LS* Factor, we need DEM, Flow Accumulation and Slope in Degree Map. Correct the Flow accumulation map as mentioned above in the RULSE theory section.

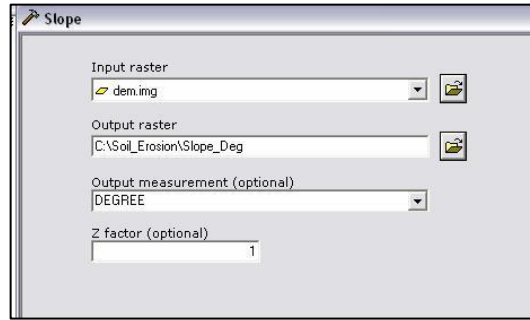
Add DEM in the viewer, generate the Corrected Flow Accumulation map as done in DEM and watershed analysis.







Derive the slope map using *Slope* Function in Spatial analyst tools or 3D Analyst tools in the Arc Toolbox. (3D Analyst Tools >>Raster Surface >>Slope) Make sure that the slope map is generated in **Degrees**.



Calculate the *m* map using the Equation 8 & 9,

**(Note :-** All the trigonometric functions available in the Arc GIS are in radians mode, so we need to convert the slope angle from Degrees to radians)

**Hint:-** Radians = Degree\*3.1416/180

Calculate the *L Factor* map, using *m* map and typing Equation 11, as it is in raster calculator.

Calculate the *S Factor* Map using *Slope* in degrees map and Equation 12 (as it is) in the raster calculator.

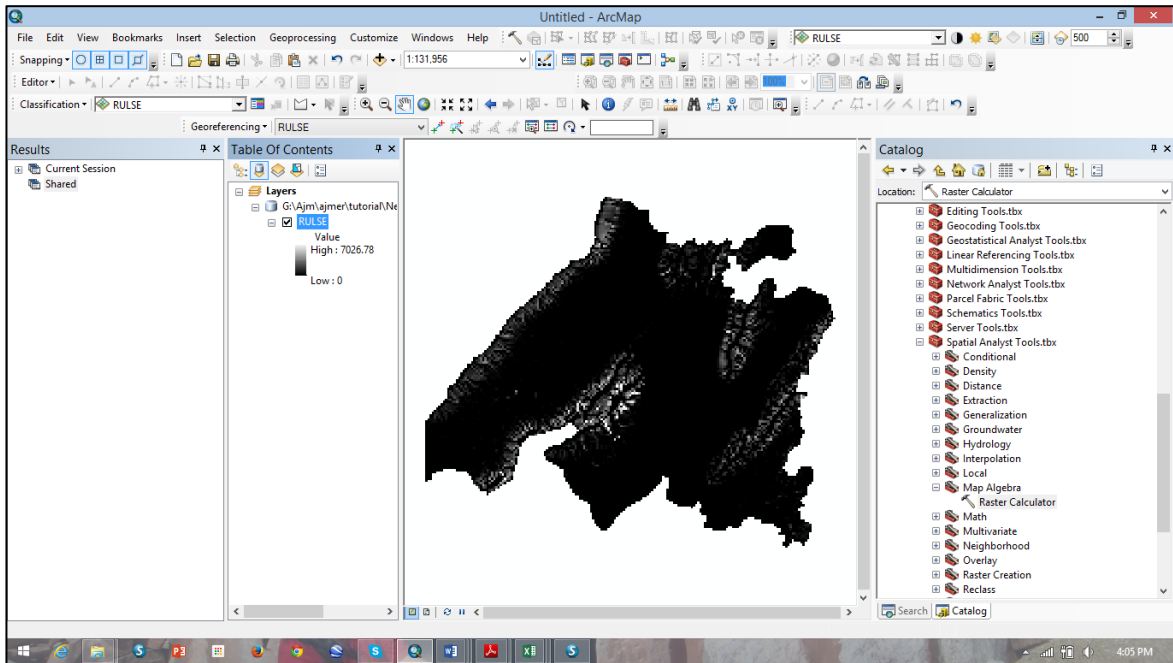
Factor_F	$((\sin(\text{"Slope"} * 0.01745) / 0.0896) / (3 * \text{Power}(\sin(\text{"Slope"} * 0.01745), 0.8) + 0.56))$
Factor_M	$\text{"Factor\_F"} / (1 + \text{"Factor\_F"})$
Factor_L	$\text{Power}(((\text{"Flow\_Accumulation"} * 30) / 22.13), \text{"Factor\_M"})$
Factor_S	$\text{Con}((\tan(\text{"Slope"} * 0.01745) < 0.09), (10.08 * \sin(\text{"Slope"} * 0.01745) + 0.03), (16.8 * \sin(\text{"Slope"} * 0.01745) - 0.05))$
Factor_LS	$\text{Factor\_L} * \text{Factor\_S}$

## SOIL EROSION CALCULATION

Add all the RUSLE parameter maps in the viewer (i.e. *R Factor* map, *K Factor* map, *C Factor* map, *P Factor* map, *L Factor* map, *S Factor* map)

Multiply all the maps in raster calculator, the final soil erosion map will appear in the viewer, make it permanent.

$$\text{RULSE} = \text{Factor\_R\_N} * \text{Factor\_K} * \text{Factor\_LS} * \text{Factor\_C} * \text{Factor\_P}$$



Go to properties >> symbology RULSE >> classified >> classes = 6 change the colour and apply -

