

Landslide Susceptibility Analysis in GIS

What is Landslide Susceptibility?

Landslide susceptibility is a quantitative or qualitative assessment of the spatial distribution of landslides, which exist or potentially may occur in an area. Although it is expected that landsliding will occur more frequently in the most susceptible areas, in the susceptibility analysis, time frame is explicitly not taken into account.

Methods for Susceptibility Mapping

Landslide susceptibility is usually based on two assumptions:

- First, that areas which have experienced landslides in the past are likely to experience them in the future, and
- Second, that areas with a similar set of geo-environmental conditions, such as geology, slope, land use etc as that of the failed areas, are also likely to fail in future.

This means that the quantitative estimates of the spatial location of future landslide sources depend on the detailed information on the distribution of past landslides and a set of thematic variables such as slope angle, lithology etc. that has initiated these landslides. The second assumption facilitates in predicting the geographical location of future landslides in passive areas (i.e., areas presently devoid of landslides) provided the geo-environmental conditions remain the same. The above assumptions have been successfully used for statistically quantifying landslide susceptibility using landslide as dependent variable.

Landslide susceptibility can be estimated using a variety of statistical techniques. BIS has proposed Guidelines for a qualitative landslide susceptibility mapping (BIS-code; IS 14496, Part 2), which is an indirect heuristic approach. The methods can be either qualitative or quantitative. The qualitative ones are generated using landslide inventory analysis and knowledge driven methods, and quantitative ones are generated using data driven, deterministic, and probabilistic methods (Fig 2.1).

A susceptibility map gives the qualitative or quantitative estimation that the mapping unit will be affected by a future landslide source, but the “future” here is not connected to a particular time period, such as the next day or the next 5 years or 50,000 years. It only indicates the stability status of a slope irrespective of the time of an event. This temporal aspect is considered in landslide “Hazard”

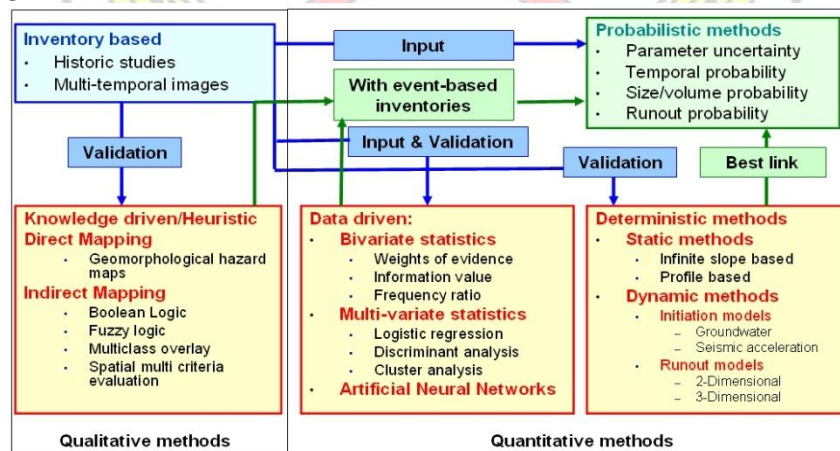
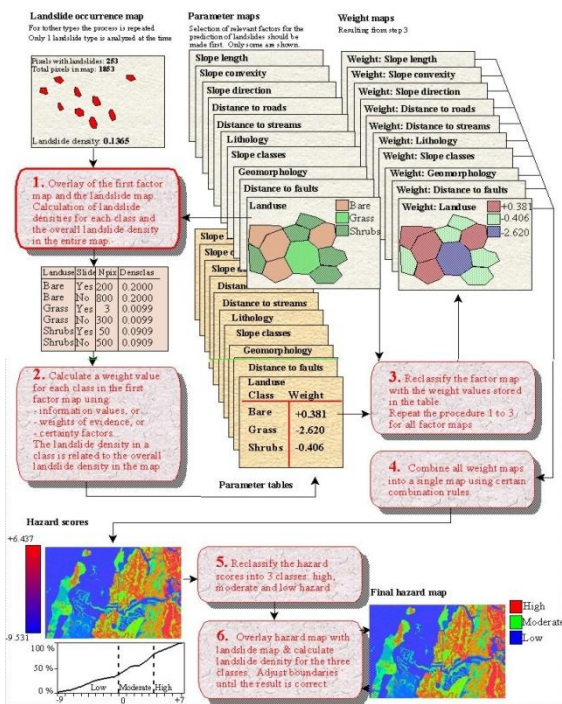


Fig. 2.1 Methods for susceptibility and hazard assessment. Blue relates to landslide inventories. Red to susceptibility and Green to Landslide hazard.

In this tutorial you will learn about landslide-dependent Bi-variate statistical method for susceptibility mapping.



In a bivariate statistical analysis (Fig. 2.2), each factor map (slope angle, lithology, land use etc.) is combined with the landslide distribution map, and weight values, based on landslide densities, are calculated for each parameter class (slope class, lithological unit, land use type etc). Several statistical methods can be applied to calculate weight values, such as the information value method, weights of evidence modeling, Bayesian combination rules and fuzzy logic. The analysis is mostly carried out on a grid (pixel) level.

There is a clear link between the scale of analysis and the type of method that can be used, basically related to the possibility of obtaining the required input data. Figure below gives a summary

Scale	Qualitative methods		Quantitative methods		
	Inventory	Heuristic	Statistical	Deterministic	Probabilistic
<1:10k	Yes	Yes	No	Yes	Yes
1:25k – 50k	Yes	Yes	Yes	No	Yes
>1:100k	Yes	Yes	Yes/No	No	No

Fig. 2.2 Bi-variate statistical method for susceptibility mapping (source: ITC)

The landslide susceptibility analysis should be carried out separately for debris type landslides and rock type landslides because factors governing slope instability in both cases are different. It is strongly recommended that landslide zoning be carried out in a GIS-based system so that the zoning can be readily be applied for land use planning and can be updated as more information becomes available.

Validation of susceptibility maps

The most important question to be asked for each susceptibility mapping is related to the degree of accuracy. The evaluation of the accuracy of a susceptibility map is generally very difficult. In reality a landslide prediction can only be verified by observing if the event takes (or has taken) place in time ("wait and see"), but this is not a very useful method, for obvious reasons.

For statistical and knowledge driven method the best way is to use success rate curves. The success rate is a statistical method to determine how well the resulting susceptibility map has classified the areas of existing landslides as susceptibility areas. It is merely a method that allows checking how many of the landslides occur in the high susceptibility areas (well classified) and how many occur in the low susceptibility areas (wrongly classified).

Landslide Susceptibility Analysis in GIS

In this practical, we will demonstrate how to analyse landslide susceptibility on a macro-scale (1:50,000/25,000) using landslide-dependent Bi-variate statistical method, being used in GSI under National Landslide Susceptibility Mapping (NLSM) Project.

The method is demonstrated in a series of steps with example from Mandakini valley, Uttarakhand for an area covering ~140 sq. km. The mapping-unit considered for analysis is 'pixel', a square grid.

Folder: **Training_data**

It contains File Geodatabase under name: Data.mdb (projection WGS84_UTM_44N)

It contains Feature dataset [a boundary file (boundary), mapped landslide polygons (landslide), a thematic map of Landuse and Landcover (lulc) and Geomorphology (Geom)]

It contains Raster layers [a DEM (dem50), a Slope map (slpcls50) and a susceptibility score map (susc_all)]

Step 1: Creating landslide raster layer

The first step is to create landslide raster layer for carrying out landslide dependent analysis. It requires selecting landslide polygon (landslide scars) from the landslide database. Here we consider only landslide scar for susceptibility analysis as we are interested to know the environment of the failed slope. Landslide runout and deposition may lead to misleading interpretation as these are deposits over the stable/on failed earth mass.

Selecting depletion area of specific landslide types: Open ArcGIS (ArcMap).

In Arc Catalog, explore to Geodatabase: *Data.mdb / maps / landslide*. Select *landslide* and drag to TOC of ArcMap. The landslide polygon map will be displayed.

Right click on *landslide* and select *Open Attribute Table*. A Table box will open. From dropdown click on *Select by Attribute* / and select *Name_of_sl* / *Get Unique Values*.

Double click on *Name_of_sl* and select same expression / *[Name_of_sl] = 'Debris slide' OR [Name_of_sl] = 'Debris subsidence' OR [Name_of_sl] = 'Rock slide' / click Apply*

The screenshot displays the ArcGIS interface during a selection process. On the left, the 'Table' view of the 'landslide' feature class is shown, listing attributes: ID, TARGET_FID, Toposheet, and Name_of_sl. The 'Name_of_sl' column contains values like 'Debris subsidence', 'Rock slide', 'Debris slide', 'Debris flow', 'Debris runout', 'Rock fall', and 'Rock slide'. The middle panel shows the 'Select by Attributes' dialog with the WHERE clause: '[Name_of_sl] = 'Debris slide' OR [Name_of_sl] = 'Debris subsidence' OR [Name_of_sl] = 'Rock slide''. The right panel shows the 'Select by Attributes' dialog with the WHERE clause: '[Name_of_sl] = 'Debris flow' OR [Name_of_sl] = 'Debris slide' OR [Name_of_sl] = 'Debris subsidence' OR [Name_of_sl] = 'Rock fall' OR [Name_of_sl] = 'Rock slide' OR [Name_of_sl] = 'Runout'.'

Landslide scar polygon smaller than one-pixel size, if rasterised will lead to deletion of the polygon. In this exercise we intend to carry out pixel-based analysis using pixel of size 50 m × 50 m. In the following steps you will understand how to select smaller landslide polygons from the landslide database for making a composite landslide layer for analysis.

Selecting smaller landslides (area <2500 sq. m i.e., one pixel size)

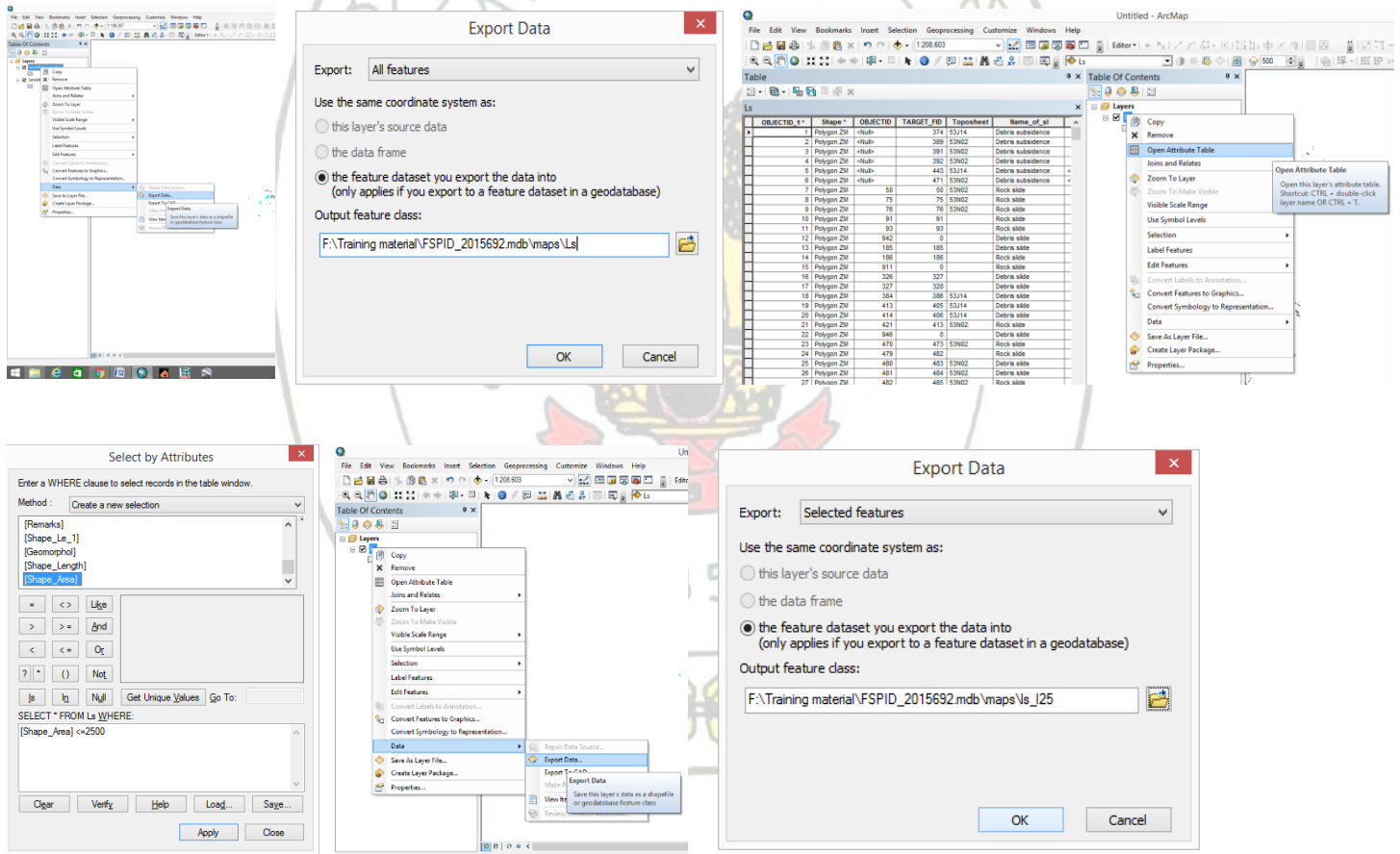
Right click on *landslide* in Table of Contents (TOC) / *selection* / *Create layer from selected feature*. A new layer of the selected file will be created and opens up

Right click on *landslide selection* in TOC / *Data* / *Export Data* / select a destination folder (or working geodatabase) and name it *Ls* / *Click OK*

Right click on *Ls* in TOC / *Open Attribute table*

Select by Attribute box will open (as in figure) and select [Shape_Area] and select expression [Shape_Area] <=2500 / click Apply [all landslide polygons smaller than or equal to 2500 will be selected].

Right click on *Ls* in TOC / *Data* / *Export Data* /select destination folder and name it *Ls_I25* / *OK* [this gives all landslide scar with area <=2500 sq. m]



In the following steps you will understand how to select landslide polygons larger than one-pixel size for ratserisation.

Right click on *Ls* in TOC / *Open Attribute table/select switch selection* [If the selection is removed then step above to select landslide with area >2500 sq. m]

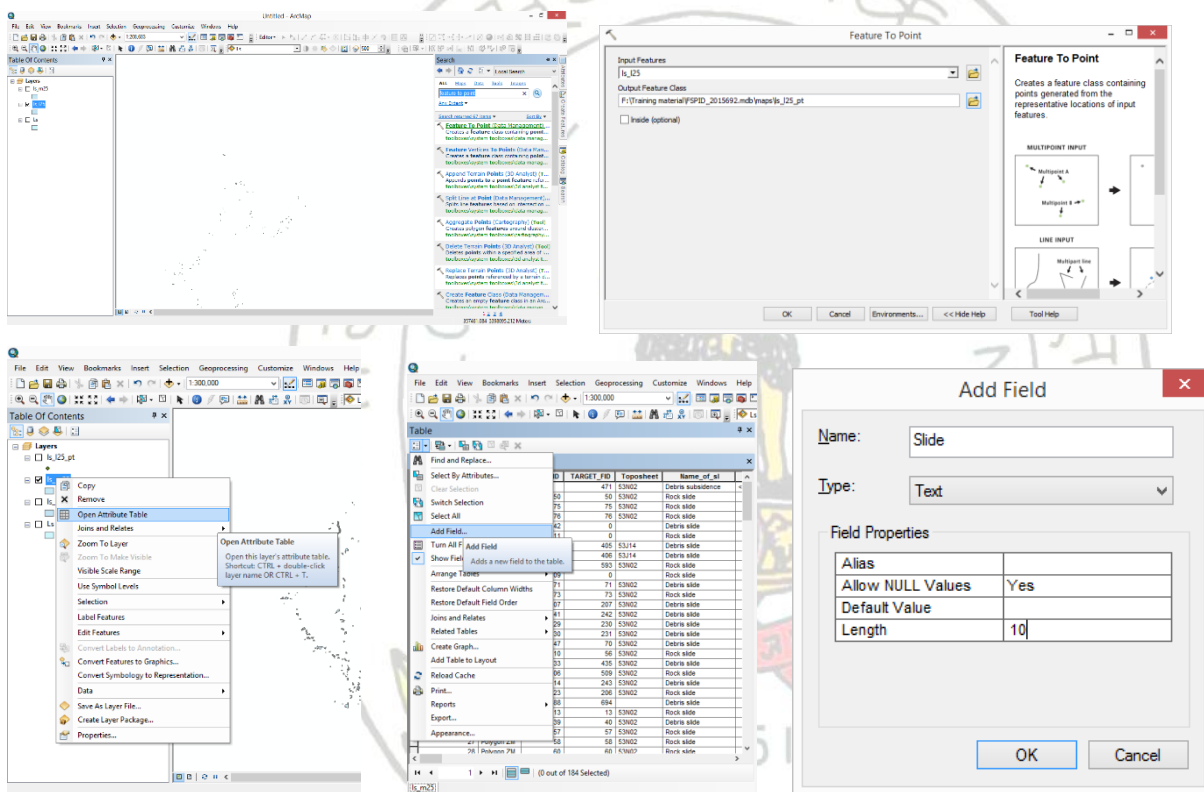
Right click on *Ls* in TOC / *Data / Export Data /select destination folder and name it *Ls_m25* / select OK* [this gives all landslide scar with area >2500 sq. m]

[Now you will see how to convert polygon layer into point layer].

In search window type "feature to point" and select feature to point tool (Data Management)

In Feature to Point box, Select Input as *Ls_L25* and in output select the destination folder and name as *Ls_L25_pt*. Check Inside (optional). [this will generate point file with area less than 2500 sq.m].

Right click on *Ls_m25* in TOC / *Open Attribute table/ click Add Field /Give Name as *Slide*, Type as *Text* and Length as *10* / click OK*



In attribute table go to *Slide* column and right click and press *Field Calculator* and in field calculator write "*LS*" / click *OK* [use "" to write the text attribute]

Now you will see how to convert polygon layer into raster layer. In search window type "polygon to raster" and select polygon to raster tool.

A Polygon to Raster box opens. Select *Ls_m25* as input and output name as *Ls_m25_r/* Give Value as *Slide* / set cell size at *50/* click *OK*. [this is the Raster landslide file with area more than 2500 sq.m]

What you have done in the above steps, can you guess?

[If you convert the landslide polygon <2500 sq. m to a raster layer of 50 m pixel then more likely you loose many of the smaller landslides as these may not get converted into a raster map. Therefore, we take two-way approach: First we convert smaller landslides to point to get at least one point per slide polygon and then converting it to raster. This

also results in miss representation of actual landslide size (Can you guess how?). Second we directly convert larger landslide to raster and add both together to get a composite landslide raster map]

In search window type "raster to point" and select raster to point tool (Data Management)

Select Input as *ls_m25_rand* give output name as *ls_m25_pt/* Select Field as *Slide* / click OK. [this is the point landslide file with more than 2500 sq.m].

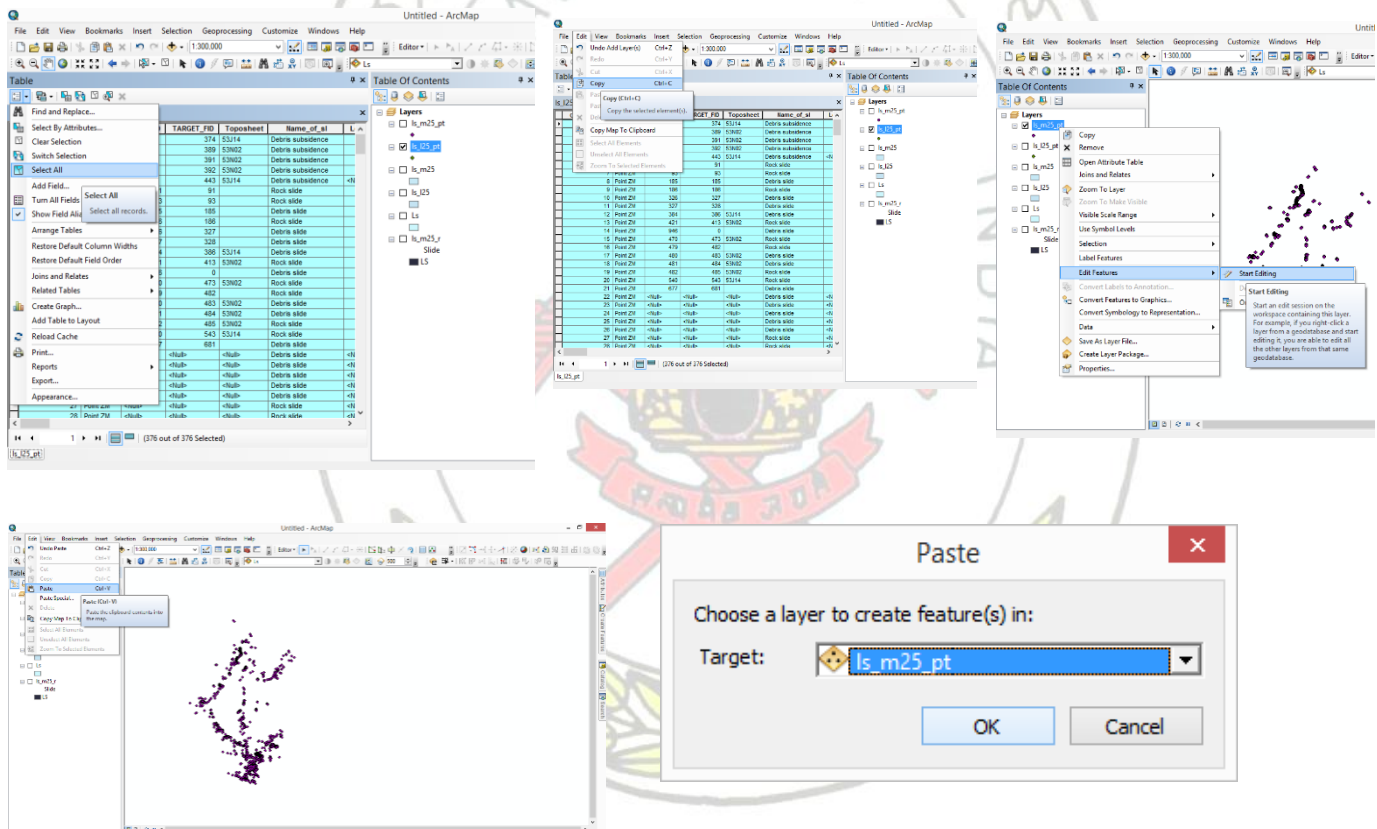
[Now you will see how to join two landslide maps to get a composite map].

Right click on *ls_125pt* in TOC / Open Attribute table / select *Select All* option / go to "Edit" and select Copy [copying all *ls<2500* sq. m for merging it with *ls>2500* sq. m].

Right click on *ls_m25_pt* in TOC and select Edit Features from main window of ArcGIS / Start Editing.

Now again select Edit Features from main window of ArcGIS / Paste (select Target as *ls_m25_pt*, if this layer is not appeared make sure this layer is on in TOC) / click OK

Now go to editor / Save Edit / Stop Edit



Right click on *ls_m25_pt* on TOC / Open Attribute table / Select *grid_code* / right click *grid_code* and select "Field Calculator" / write 1 in calculator field.

In search window search for "point to raster" and select "point to raster" tool (Conversion)

Give Input feature as *ls_m25_pt* / Value field as *grid_code* / Cell size set as 50/Output Raster as *ls_all*/ click OK. [This is your final raster landslide with 50 m pixel used for further calculation].

NOTE: Here you can have two raster landslide dataset; 1. For calibration of the model (using 75% of the landslide points selected randomly or event-wise) and 2. For Validation (rest of the data).

Step 2: Calculating Ratings and Weights of thematic maps

Thematic data preparation: Here we learn how to convert a polygon feature dataset to a raster for facilitating calculation of ratings and weights

Open Geodatabase: Data.mdb / maps / lulc

Right click on *lulc* on TOC and select *open attribute table* [see the attributes, there are 11 lulc classes and all polygons are dissolved]

In search window type "polygon to raster" and select "polygon to raster tool" (Conversion)

In a polygon to raster tool box, select Input Feature as *lulc*, Value field as *class*, Cellsize as 50, and give filename as *lulc_raster* and output location under Output Raster Dataset. Leave all other as default. [this will create a raster layer of lulc map]

Right click on *lulc_raster* map on TOC and select *open attribute table* [see the attributes, there are 11 lulc classes as shown under VALUE and COUNT is the number of pixel. To know the area multiply pixel value with 2500 (50 m × 50 m pixel size)]

Open an excel sheet and name it as *Analysis*. Name one sheet as LULC and make column as ID, Name etc as shown in the training material. Under *Name* put all the class name of *lulc* as given in *lulc_raster*. *NpixC* is the total pixel count of a given class (read the COUNT field in *lulc_raster*).

Calculation of Ratings and Weights: Here we learn how to calculate ratings and weights with landslide as dependent variable

Open *lulc_raster* and *ls_all* in TOC.

In search window type "combine" and select tool 'combine (Spatial Analyst)' [this tool is used to superimpose landslide with thematic map]

Use Input rasters as *lulc_raster* and *ls_all*; create output raster as *lulcXls_all* / OK

Right click on *lulcXls_all* in TOC / Open Attribute table

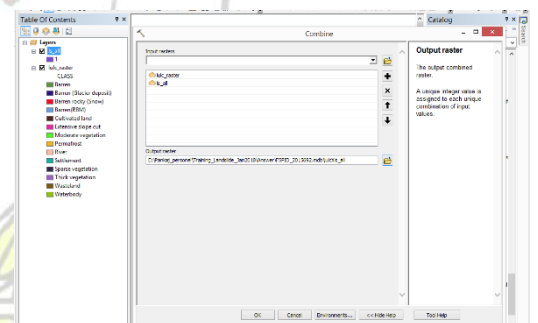
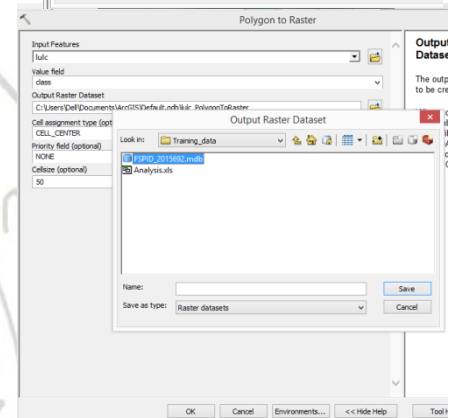
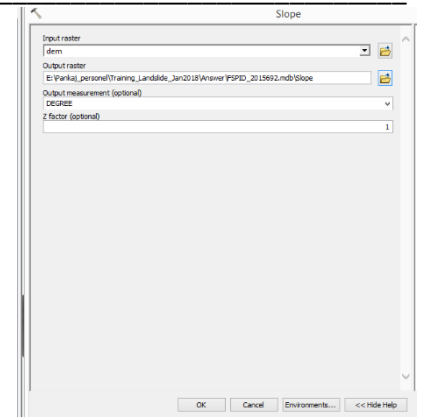
Select by Attribute *lulc_raster* and sort it as ascending. [the numbers under *lulc_raster* denote the 11 lulc classes and Count denotes the number of pixel of landslide falling within each lulc class]

Open an excel sheet *Analysis*. Enter 'Count' values under field T11 [T11 is the npix that intersected the lulc of a given class]. Now calculate all other values in the excel. LOFS is the rating of the factor class computed based on the spatial distribution of landslide considering also the spatial area coverage of the class.

[Similarly calculate LOFS for all categorical factor class such as Geom provided in the training dta] Example of slope is shown below

Generating SLOPE map from DEM.

Open 'dem50' in TOC



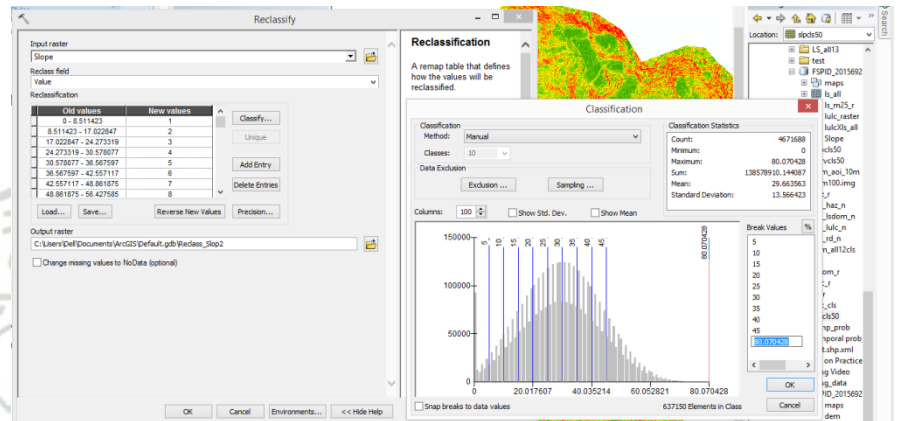
OID	Value	Count	lulc_raster	ls_all
2	3	225	1	1
5	6	7	2	1
1	2	24	3	1
12	13	6	4	1
11	12	169	5	1
3	4	267	6	1
9	10	99	7	1
0	1	14	8	1
4	5	8	9	1
10	11	16	10	1
7	8	464	11	1
6	7	372	12	1
8	9	2	13	1

In search window type "slope" and select tool 'Slope' (3D Analyst) [this tool is used to calculate slope angle map from DEM]

In Slope tool, give Input Raster as *dem50*, Output Raster as *Slope* and rest leave as default / OK

In search window type "Reclassify" and select tool 'Reclassify' (3D Analyst) [this tool is used to reclassify slope angle into discrete class]

In Reclassify tool, put Input Raster as *Slope*, Reclass field as 'value' / Classify / in Classification window, select Classes as '10' and give Break Values as shown below / OK / Output Raster as *Slp_cls* and rest leave as default / OK



Right click on *Slp_cls* in TOC / Open Attribute table / [see the attributes, there are 10 slope classes as shown under VALUE and COUNT is the number of pixel]

Open *Slop_cls* and *ls_all* in TOC

In search window type "combine" and select tool 'combine' (Spatial Analyst) [this tool is used to superimpose landslide with thematic map]

Use Input rasters as *Slp_cls* and *ls_all*; create output raster as *SlpclsXls_all* / OK

Right click on *SlpclsXls_all* in TOC / Open Attribute table

Select by Attribute *Slop_cls* and sort it as ascending. [the numbers under *Slp_cls* denotes the 10 slope classes and Count denotes the number of pixel of landslide falling within each slope class]

[SIMILAR to LULC above fill the excel Analysis sheet for SLOPE]

[FOR LINEAR FEATURE USE BUFFER/MULTIPLE RING BUFFER TOOL TO GET POLYGON and proceed]

In 'Analysis' table calculate Ratings and Weights as documented.

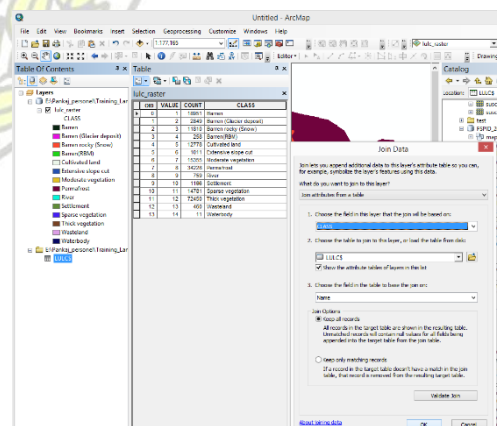
Preparation of LOFS maps: Here we learn how to combine excel sheet containing ratings and weights with thematic maps in GIS to generate attribute (LOFS) maps

Open *lulc_raster* and excel worksheet 'LULC' in TOC. Right click on *lulc_raster* and select *open attribute table* / *Table Options* / *Join and Relates* / *Join* [This opens Join Data box]

In Join Data box, under 1 put CLASS (Class field in LULC will act as a key for joining), in 2 select LULC sheet from excel, in 3 put Name (Name field in excel LULC sheet will act as a key for joining). Keep all as default / OK.

Right click on *lulc_raster* map and select *open attribute table*

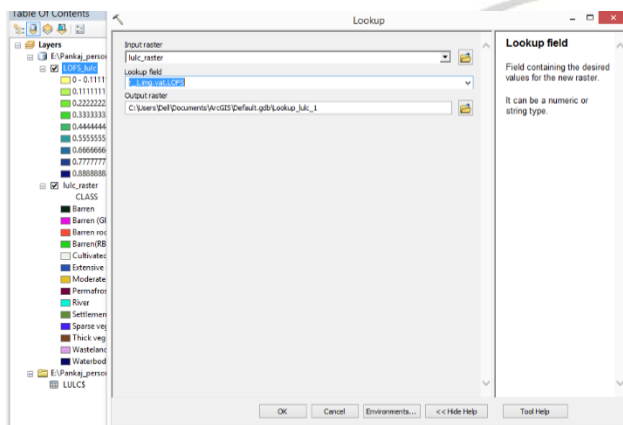
[You can now see the two tables to be joined. Note this joining is temporary and will be removed if ArcGIS is closed OR you can export the table and save it]



1.img.vat.COUNT	1.img.vat.CLASS	1.img.vat.SIPIXT	1.img.vat.LULC	1.img.vat.L.SALL	1.img.vat.XYZ	1.img.vat.NIKL.S	1.img.vat.T12	1.img.vat.T21	1.img.vat.T22	1.img.vat.YC	1.img.vat.YC.C	1.img.vat.MAX.YC.C	1.img.vat.LOFS	LULC.V
18951	Barren	18957	1	1	173	1491	1318	18778	100588	0	0.038012028488	0.706910528788	0.0502850223404	
2849	Barren (Glacier deposit)	18957	2	1	7	1491	1484	2842	182254	0	-0.28997542091	0.706910528788	0	
11810	Barren rocky (Snow)	18957	3	1	26	1491	1486	11385	173581	0	-0.330276976111	0.706910528788	0	
258	Barren(RBM)	18957	4	1	10	1491	1481	248	185128	0	0.383683222787	0.706910528788	0.50890970102	
12778	Cultivated land	18957	5	1	141	1491	1388	12637	172738	0	0.0887788447413	0.706910528788	0.1172910888	
10111	Extensive slope cut	18957	6	1	281	1491	1230	750	164628	0	0.706910528788	0.706910528788	1	
16365	Moderate vegetation	18957	7	1	74	1491	1417	15281	170095	0	-0.13475688881	0.706910528788	0	
34028	Permafrost	18957	8	1	14	1491	1477	34214	151182	-1	-0.06024533284	0.706910528788	0	
769	River	18957	9	1	12	1491	1478	747	184628	0	0.17222222889	0.706910528788	0.227833140893	
1186	Settlement	18957	10	1	1	1491	1480	1186	184211	-1	-0.508065318378	0.706910528788	0	
14781	Sparse vegetation	18957	11	1	419	1491	1972	14362	171014	0	0.389054787882	0.706910528788	0.484277580102	
72450	Thick vegetation	18957	12	1	352	1491	1138	72088	113278	0	-0.178675359855	0.706910528788	0	
400	Wasteland	18957	13	1	2	1491	1489	458	184918	0	-0.18179627211	0.706910528788	0	

In search window type "Lookup" and select 'Lookup' (3D Analyst) [This tool will help to generate attribute map of LOFS Lulc]

In 'Lookup' box, put input raster as *lulc_raster*, lookup field as 'LOFS' and Output raster as *LOFS_lulc* / OK.



[SIMILAR to LOFS_LULC, generate LOFS maps for all factors].

Preparation of SUSCEPTIBILITY SCORE map: Here we learn how to integrate all LOFS maps to generate a susceptibility score map

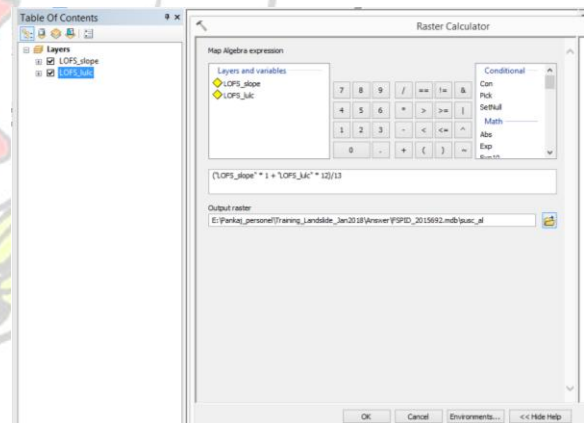
Open all LOFS raster maps in TOC.

In search window type "Raster Calculator" and select 'Raster Calculator' (Spatial Analyst) [This tool will help to add all raster layers]

In 'Raster Calculator box, put the expression as indicated below and Output raster as *susc_all* / OK. [add all LOFS raster map by double clicking on it and multiply it by weight and finally divide all by summation of weights]

Open *susc_all* in TOC. This a continuous raster map showing range of cumulative LOFS value per pixel.

This map needs to be classified into different landslide susceptibility zones (High, Moderate and Low).



Preparation of success rate curve and classified susceptibility map: Here we learn how to generate success rate curve for getting boundary condition for different susceptibility zone.

Open *susc_al* and *ls_all* raster maps in TOC

In search window type "Reclassify" and select tool 'Reclassify' (3D Analyst) [this tool is used to reclassify susceptibility score map into discrete classes]

In Reclassify tool, put Input Raster as *susc_all*, Reclassfield as 'value' / Classify / in Classification window, select Method as *Quantile* and Classes as '20' and (Note the Break Values and write down in excel) / OK / Output Raster as *susc_relas20* and rest leave as default / OK

Open an excel sheet *Success rate Calculation*. Under field *Class-break* enter break value in reverse order, starting with highest value on top and lowest break value on bottom.

