Humanitarian Masterclass: Earth Observation and Natural Hazards
GIS and AHP Landslide Risk Assessment Practical

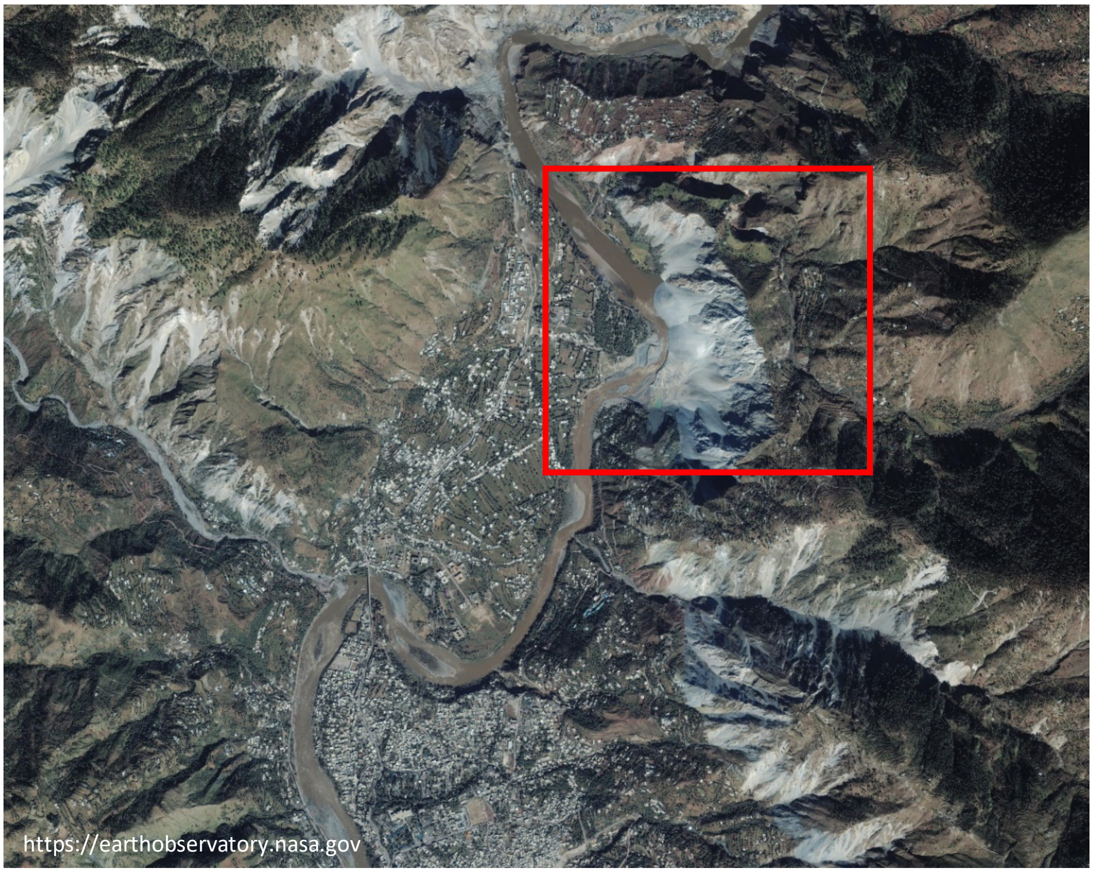

Image showing an earthquake triggered landslide blocking Neelum River in the northwest Himalaya [October 9, 2005]

Landslide Hazard Analysis

[User Guide]

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Contents

A. Background
B. Graphical guide for using the ArcGIS 10.3.1
C. Analytic Hierarchy Process (AHP).
D. Weighted Overlay Analysis using the ArcGIS 10.3.1

A. Background

Technological interventions provide essential provisions for the prevention and mitigation of the natural hazards. Earth Observation (EO) has been one of such technologies that completely transformed our understanding of the natural hazards, including wide range of processes operating on the earth. The data obtained through EO systems with varied spatial, spectral, and temporal resolutions particularly provide prospects for furthering knowledge on genesis, spatiotemporal patterns, and forecasting of natural hazards. The collection of data using earth observation (EO) systems has been very useful for alleviating the adverse effects of the natural hazards, especially with their near real-time capabilities for tracking extreme natural events. EO systems with different platforms also serve as an important decision support tool for devising response strategies, coordinating rescue operations, and making the damage and loss estimations.

Landslides are among the most widespread natural hazards of mountainous regions in the world. Each year landslides cause colossal loss to life, property, and disruption of land transportation services. EO based spatial information is valuable for landslide hazard zonation, implementation of policies and reducing the losses. Here we use 11 data layers that include information on slope, rainfall, land use, lithology, soil, elevation, aspect, hill cutting, streams, roads, and lineaments for landslide hazard analysis of an area in Bangladesh.

Aim

This exercise aims to develop a landslide hazard map with the complementary use of EO data, Geographic Information System, and Analytic Hierarchy Process (AHP).

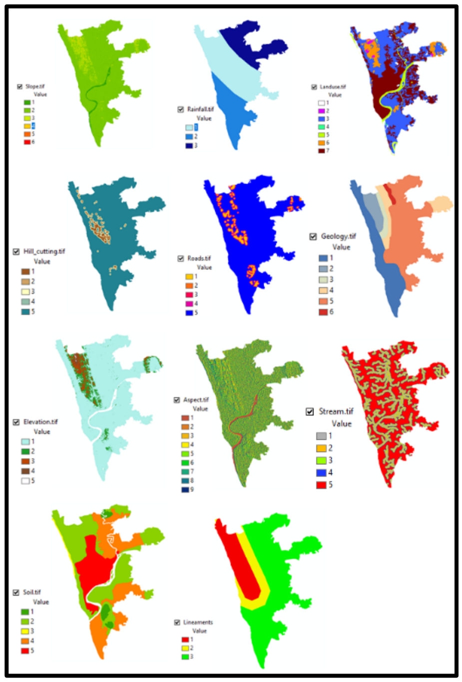
Expected learning outcomes

At the end of this exercise the participants should be able to:

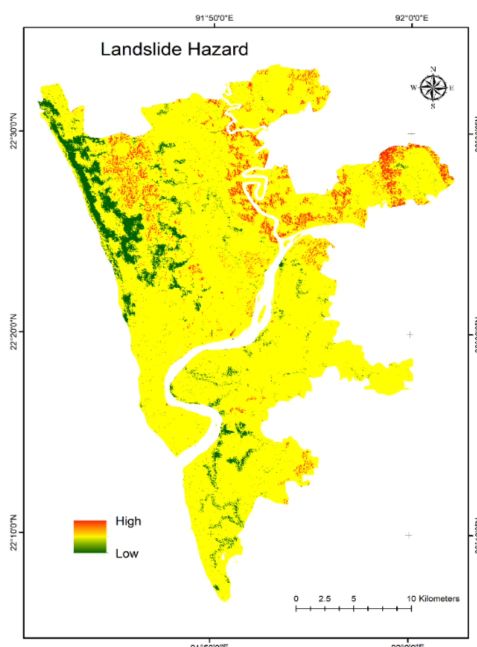
- Visualize, interpret and integrate the standardized raster data layers for weighted overlay analysis in ArcGIS 10.3.1.
- Derive weights of different parameters and check the consistency in weighting process using Analytic Hierarchy Process (AHP).
- Develop a landslide hazard map of the study area from the provided raster data layers.

Note:

- **Your data for this exercise is available at: https://tinyurl.com/v5ygrp5**
- **Please send your final map to:** akhtar.alam@ucl.ac.uk

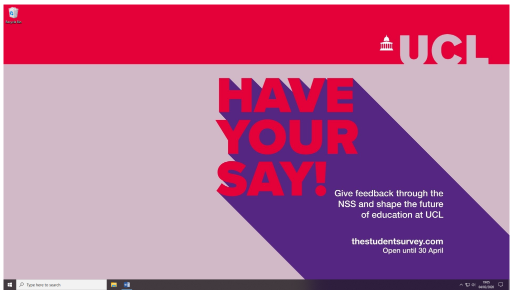


[11 Input raster data layers]

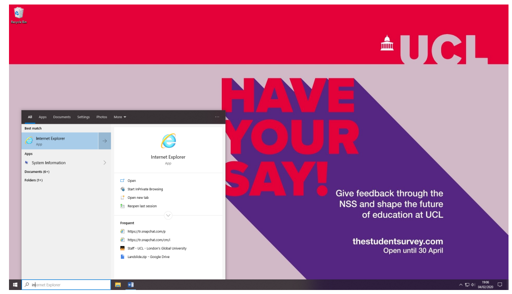


[Expected output of the analysis]

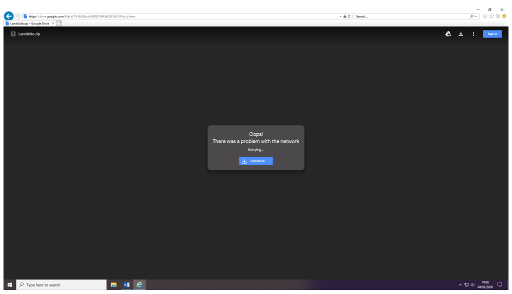
B. Graphical guide for using the ArcGIS 10.3.1



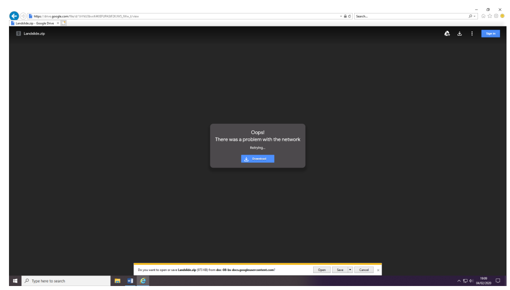
1. Home Screen.



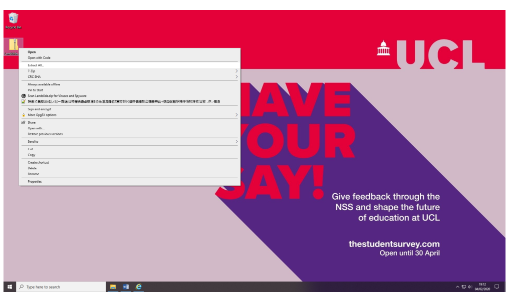
2. Open Internet Explorer.



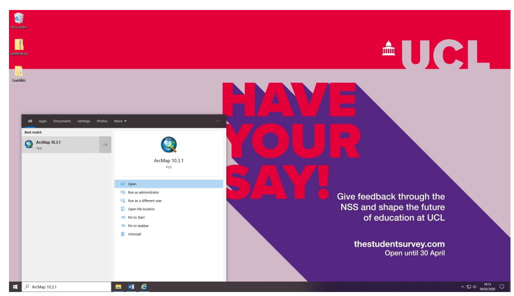
3. TYPE: https://tinyurl.com/v5ygrp5



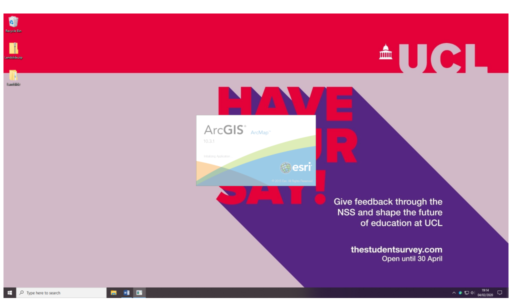
4. Download and save the data folder.



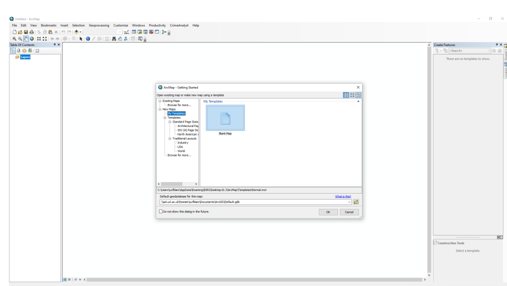
5. Extract (unzip) the files.



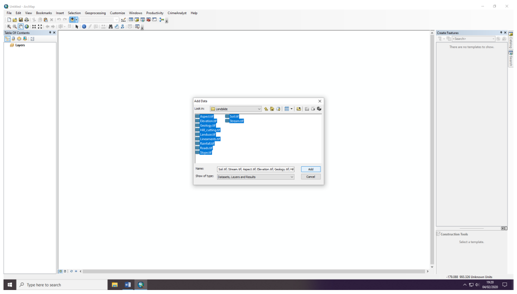
6. Open ArcMap 10.3.1.



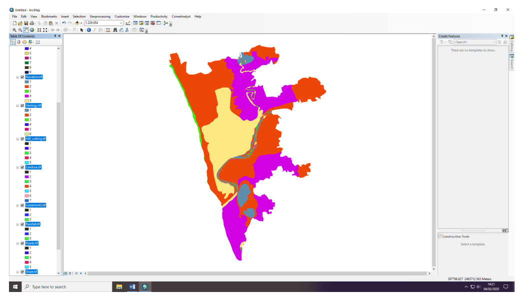
7. It may take a while.



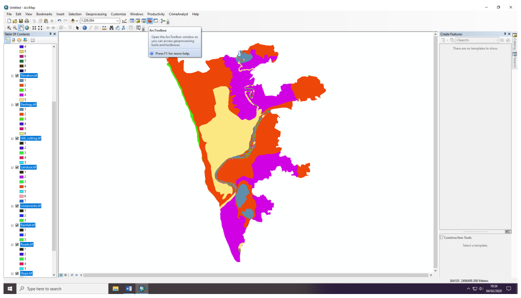
8. Click OK.



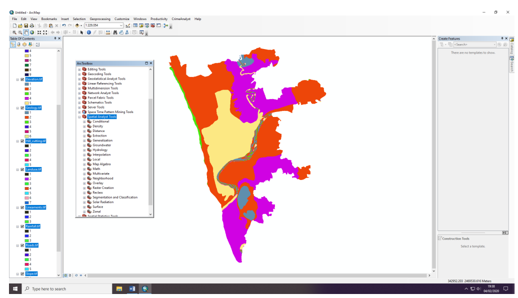
9. Go to + sign select all and add data.



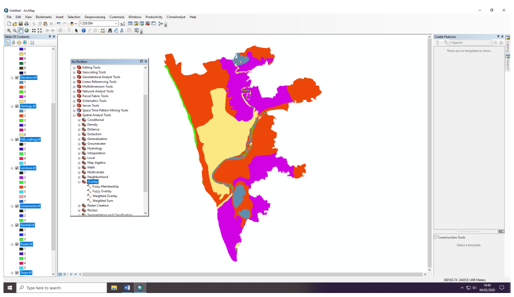
10. This would add 11 layers to your view.



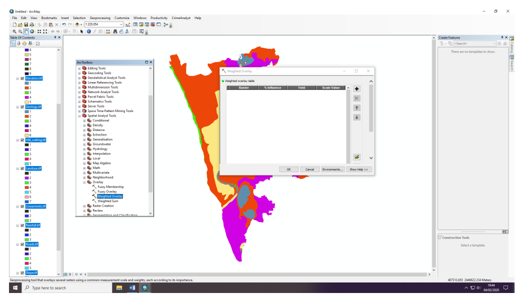
11. Go to Arc Toolbox.



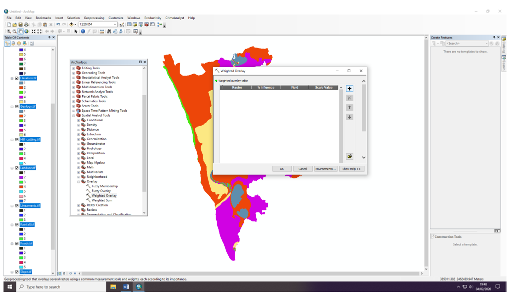
12. Click Spatial Analyst Tools.



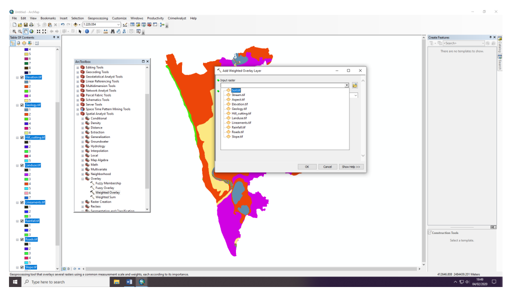
13. Click Overlay.



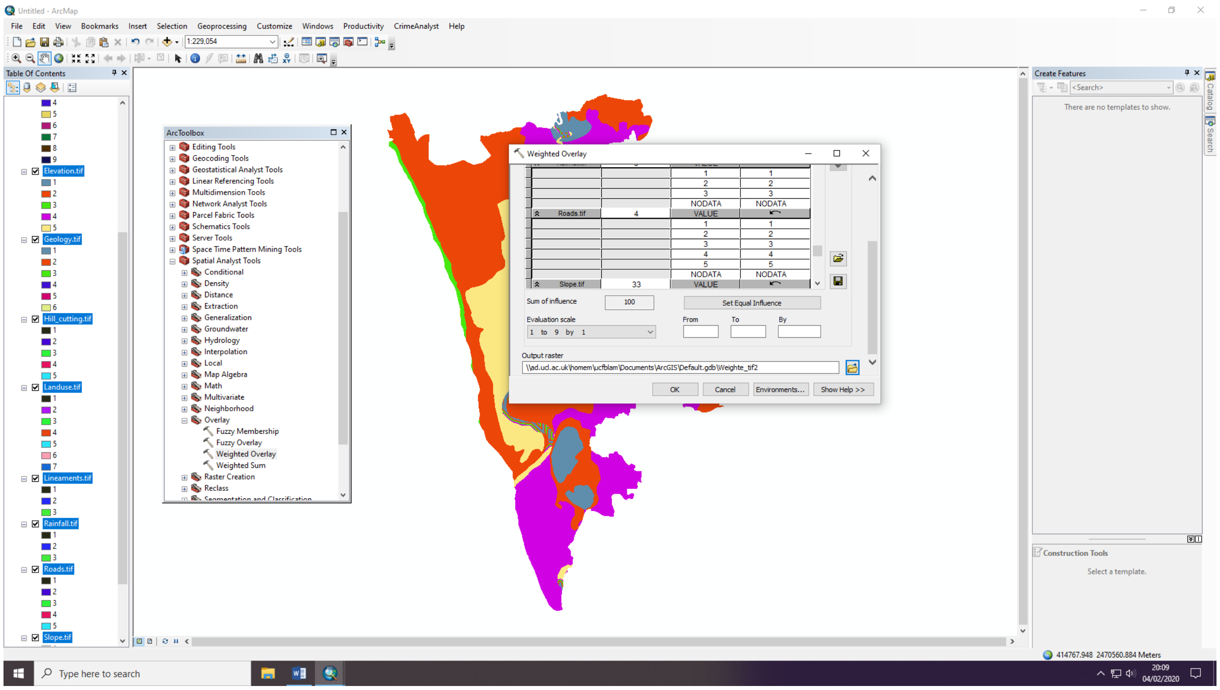
14. Click Weighted Overlay.



15. Click + sign to add layers.

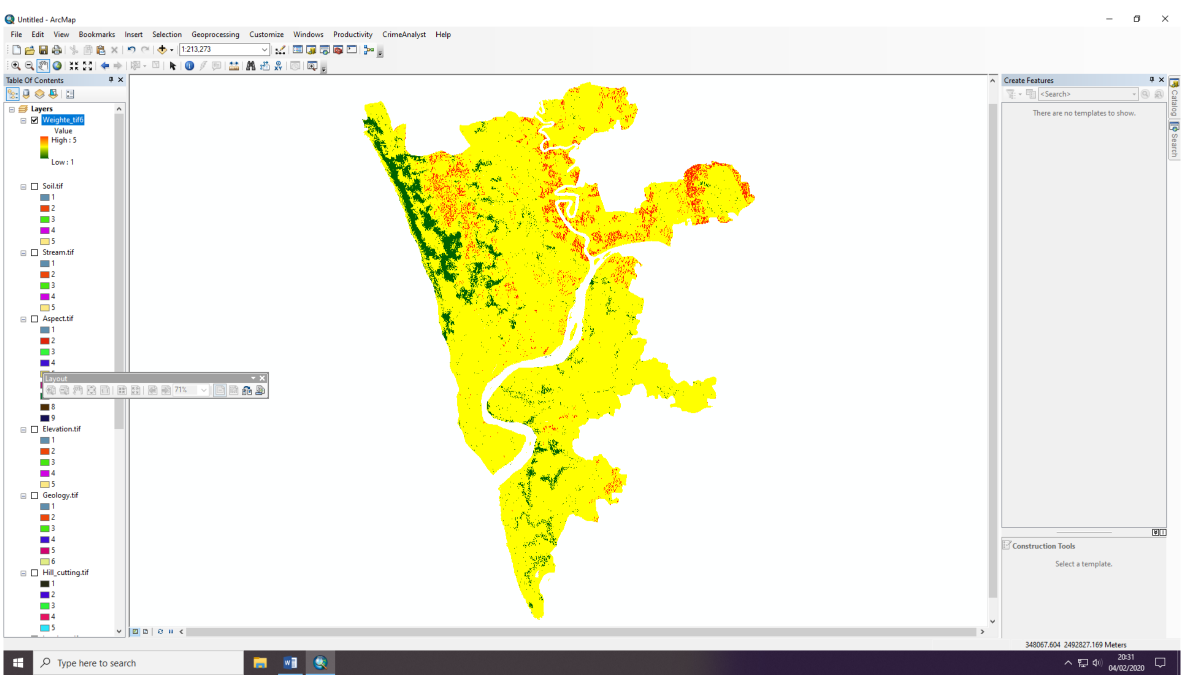


16. Click dropdown sign and add all the layers.

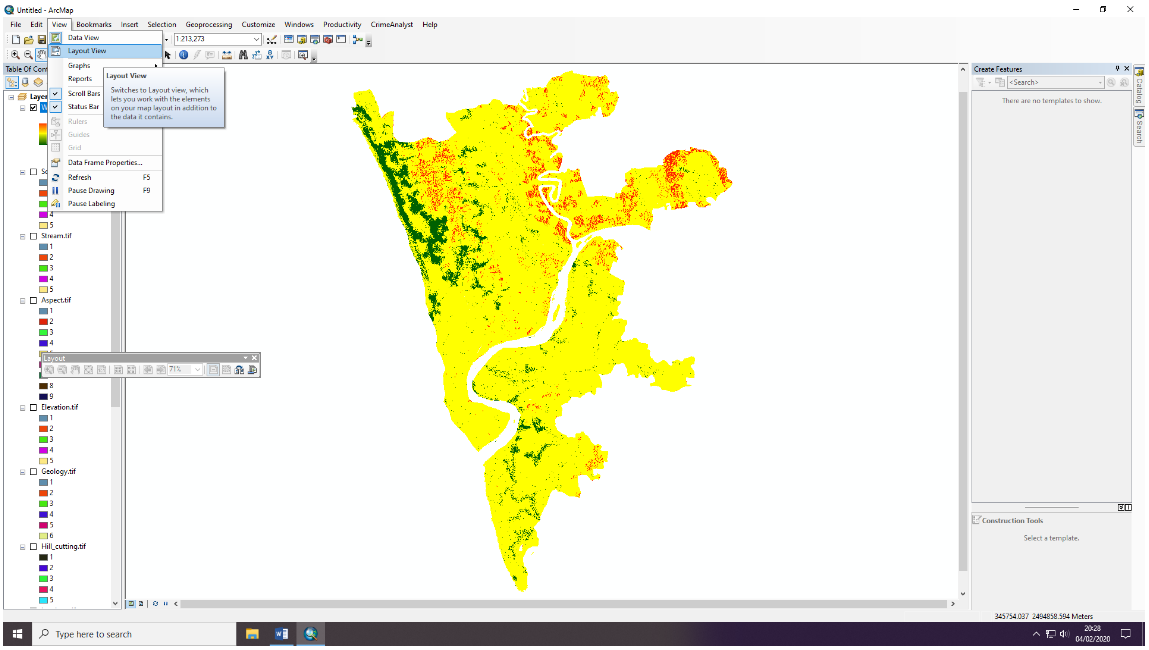


17. Click + sign and add all raster layers.

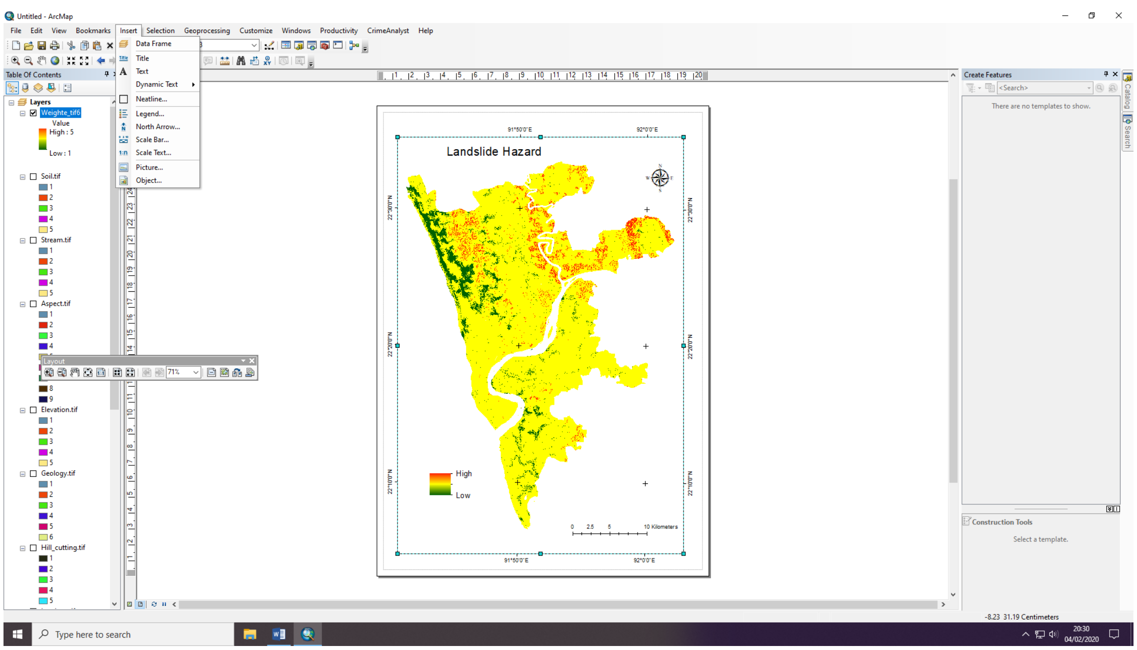
18. Assign % influence (derived through AHP) to each layer in the table and change scale value of each layer according to the nature of the layer. The higher index value of all the layers connotes higher landslide susceptibility except for the layers such as hill cutting, streams, roads, and lineaments where correlation is inverse (distance based); so you have to change the scale values accordingly.
19. Save the table and output layer and click OK.



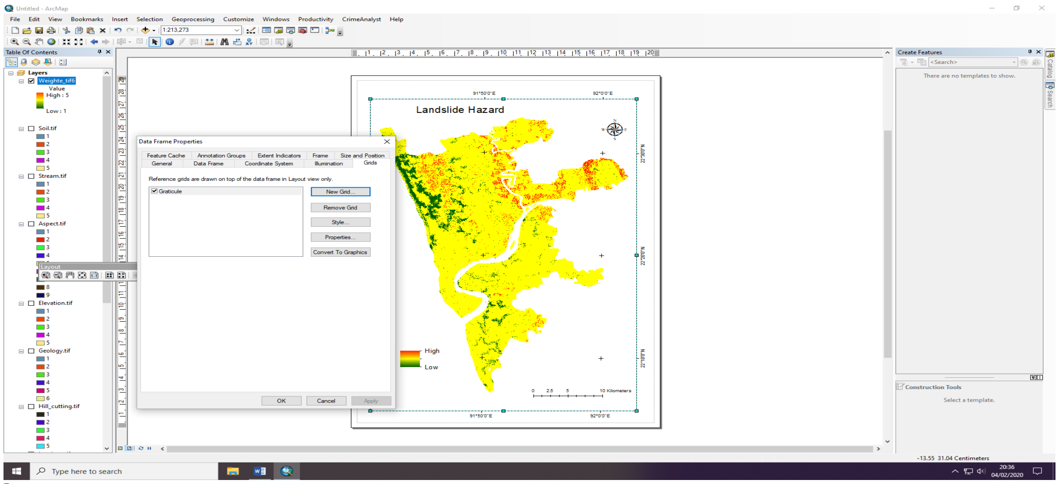
20. You will get a new raster layer showing the landslide hazard levels.

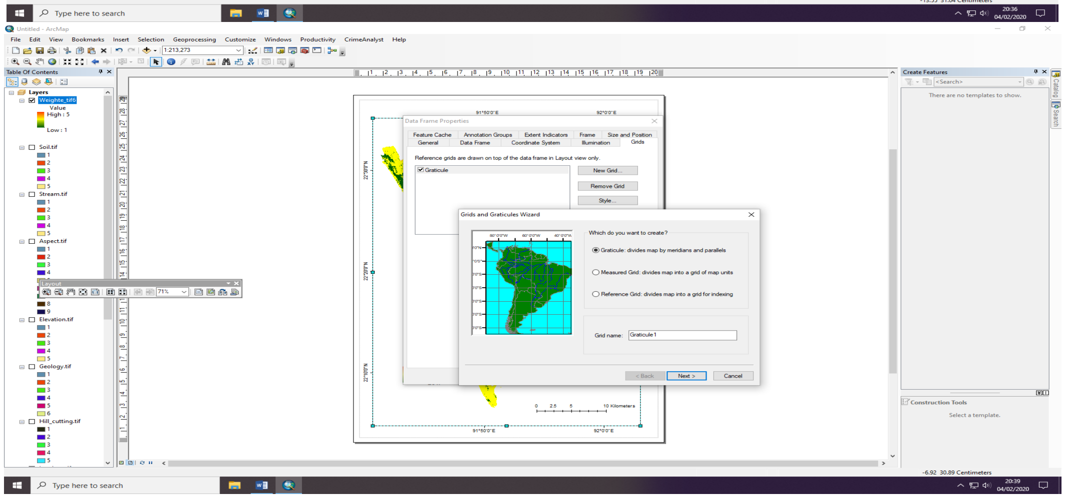


21. Go to view and click layout view for developing the final map.

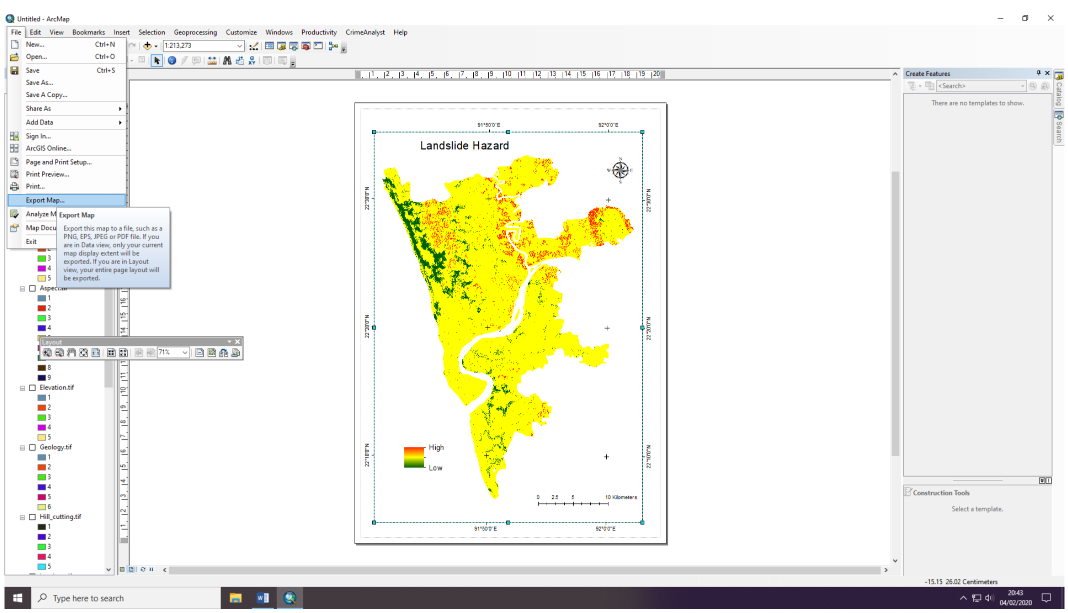


22. Click insert to add various map elements i.e., map title, scale, and north symbol.





23. Click view and select Data Frame Properties to add a reference system [lat/long].



24. Finally export the map to a commonly usable format (e.g., TIFF).

C. Analytic Hierarchy Process (AHP)

- AHP is a statistical measure to support complex decisions involving the comparison of elements that are difficult to quantify.
- The first step in the Analytic Hierarchy Process (AHP) is to develop a structure of the model.
- Followed by pairwise comparison of the model components; this gives weight to each element within a model.
- The process also involves determination of consistency ratio (CR): a consistency assessment of the comparisons.

How does AHP work?

- Define the Objective
- Select the criterion
- Set up criteria comparison matrix (n x n)
- Normalize the comparison matrix
- Derive weights
- Check the consistency

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two variables contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one variable over another
5	Strong importance	Experience and judgement strongly favour one variable over another
7	Very strong or demonstrated importance	A variable is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one variable over another is of the highest possible order of affirmation
2, 4, 6,8	Intermediate Importance	When compromise is needed

Scale of relative importance (Saaty, 2008)

Example: Comparison of 6 criterions A, B, C, D, E, and F.

Step 1: Set up a comparison matrix for deciding the importance of the criterions.

	A	**B**	**C**	**D**	**E**	**F**
A	1	0.33	0.2	0.11	0.14	3
B	3	1	0.33	0.14	0.33	3
C	5	3	1	0.2	0.2	3
D	9	7	5	1	3	7
E	7	3	5	0.33	1	9
F	0.33	0.33	0.33	0.14	0.11	1

Step 2: Sum up the columns.

	A	**B**	**C**	**D**	**E**	**F**
A	1	0.33	0.2	0.11	0.14	3
B	3	1	0.33	0.14	0.33	3
C	5	3	1	0.2	0.2	3
D	9	7	5	1	3	7
E	7	3	5	0.33	1	9
F	0.33	0.33	0.33	0.14	0.11	1
SUM	25.33	14.66	11.86	1.92	4.78	26

Step 3: Normalize the comparison matrix: dividing each criterion in each column by the sum of that column.

	A	B	C	D	E	F
A	0.04	0.02	0.02	0.06	0.03	0.12
B	0.12	0.07	0.03	0.07	0.07	0.12
C	0.2	0.2	0.08	0.1	0.04	0.12
D	0.36	0.48	0.42	0.52	0.63	0.27
E	0.28	0.2	0.42	0.17	0.21	0.35
F	0.01	0.02	0.03	0.07	0.02	0.04
SUM	1	1	1	1	1	1

Step 4: Sum and average each row in the normalized matrix (W).

	A	B	C	D	E	F	SUM	SUM/6 Weight (W)	%
A	0.04	0.02	0.02	0.06	0.03	0.12	0.280818	0.046803	4.680292
B	0.12	0.07	0.03	0.07	0.07	0.12	0.471813	0.078636	7.86355
C	0.2	0.2	0.08	0.1	0.04	0.12	0.747742	0.124624	12.46237
D	0.36	0.48	0.42	0.52	0.63	0.27	2.672064	0.445344	44.5344
E	0.28	0.2	0.42	0.17	0.21	0.35	1.62981	0.271635	27.16349
F	0.01	0.02	0.03	0.07	0.02	0.04	0.197754	0.032959	3.295894

Derive Consistency Ration (CR)

Since the decisions made about the priorities of the criterions may not be perfect, the AHP requires a consistency check of the pairwise comparison matrix, which is being done by calculating the consistency ratio (CR).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

where CI is the consistency index (CI), calculated as:

$$\mathrm{CI} = \frac{(\lambda max - \mathrm{n})}{\mathrm{n}-1}$$

where λmax is the average eigenvalue of the matrix and *n* represents the size of the matrix; RI is the random index representing the consistency of a randomly generated pairwise comparison matrix.

Step 5: Multiply each column in the original matrix with the derived weights.

	A	B	C	D	E	F
A	1	0.33	0.2	0.11	0.14	3
B	3	1	0.33	0.14	0.33	3
C	5	3	1	0.2	0.2	3
D	9	7	5	1	3	7
E	7	3	5	0.33	1	9
F	0.33	0.33	0.33	0.14	0.11	1

X

SUM/6 Weight (W)
0.046803
0.078636
0.124624
0.445344
0.271635
0.032959

Step 6: Sum and divide by W to derive the eigenvalue (λ).

	A	B	C	D	E	F	SUM	SUM/W
A	0.046	0.02574	0.0248	0.04895	0.03794	0.096	0.27943	5.970344
B	0.138	0.078	0.04092	0.0623	0.08943	0.096	0.50465	6.417544
C	0.23	0.234	0.124	0.089	0.0542	0.096	0.8272	6.637566
D	0.414	0.546	0.62	0.445	0.813	0.224	3.062	6.875584
E	0.322	0.234	0.62	0.14685	0.271	0.288	1.88185	6.927863
F	0.01518	0.02574	0.04092	0.0623	0.02981	0.032	0.20595	6.248673

Average 6.512929
(λ) Eigenvalue

Step 7: Derive the consistency ratio.

Size of matrix	1	2	3	4	5	6	7	8
Random consistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41

Size of matrix	9	10	11	12	13	14	15
Random consistency	1.45	1.49	1.51	1.48	1.56	1.57	1.59

$$CR = \frac{CI}{RI}$$

(Consistency Ratio)

0.1024

$$CI = \frac{(\lambda max - n)}{n - 1}$$

(Consistency Index)

1.24

RI

Random Index

CR = 0.08258

Note: A CR value ≤ 0.10 (10%) is acceptable; suggesting the comparisons have been consistent.

D. Weighted Overlay Analysis using ArcGIS 10.3.1

In Weighted Overlay analysis, a series of tools can complement the Weighted Overlay tool to follow the general overlay analysis steps described below.

1. Define the problem.
2. Break the problem into submodels.
3. Determine significant layers.
4. Reclassify or transform the data within a layer.
5. Weight the input layers.
6. Add or combine the layers.
7. Analyze.

The Weighted Overlay tool scales the input data on a defined scale (the default being 1 to 9), weights the input rasters, and adds them together. The more favorable locations for each input criterion will be reclassed to the higher values such as 9. In the Weighted Overlay tool, the weights assigned to the input rasters must equal 100 percent. The layers are multiplied by the appropriate multiplier, and for each cell, the resulting values are added together. Weighted Overlay assumes that more favorable factors result in the higher values in the output raster, therefore identifying these locations as being the best.

How Weighted Overlay works

The Weighted Overlay tool applies one of the most used approaches for overlay analysis to solve multicriteria problems such as site selection and suitability models. In a weighted overlay analysis, each of the general overlay analysis steps are followed.

As with all overlay analysis, in weighted overlay analysis, you must define the problem, break the model into submodels, and identify the input layers.

Since the input criteria layers will be in different numbering systems with different ranges, to combine them in a single analysis, each cell for each criterion must be reclassified into a common preference scale such as 1 to 10, with 10 being the most favorable. An assigned preference on the common scale implies the phenomenon's preference for the criterion. The preference values are on a relative scale. That is, a preference of 10 is twice as preferred as a preference of 5.

The preference values not only should be assigned relative to each other within the layer but should have the same meaning between the layers. For example, if a location for one criterion is assigned a preference of 5, it will have the same influence on the phenomenon as a 5 in a second criterion.

For example, in a simple housing suitability model, you may have three input criteria: slope, aspect, and distance to roads. The slopes are reclassed on a 1 to 10 scale with the flatter being less costly: therefore, they are the most favorable and are assigned the higher values. As the slopes become steeper, they are assigned decreasing values, with the steepest slopes being assigned a 1. You do the same reclassification process to the 1 to 10 scale for aspect, with the more favorable aspects, in this case the more southerly, being assigned the higher values. The same reclassification process is applied to the distance to roads criterion. The locations closer to the roads are more favorable since they are less costly to build on because they have easier access to power and require shorter driveways. A location assigned a suitability value of 5 on the reclassed slope layer will be twice as costly to build on as a slope assigned a value of 10. A location assigned a suitability of 5 on the reclassed slope layer will have the same cost as a 5 assigned on the reclassed distance to roads layer.

Each of the criteria in the weighted overlay analysis may not be equal in importance. You can weight the important criteria more than the other criteria. For instance, in our sample housing suitability model, you might decide, because of long-term conservation purposes, that the better aspects are more important than the short-term costs associated with the slope and distance to roads criteria. Therefore, you may weight the aspect values as twice as important than the slope and distance to roads criteria.

The input criteria are multiplied by the weights and then added together. For example, in the housing suitability model, aspect is multiplied by 2 and the three criteria are added together, or represented another way, (2 * aspect) + slope + distance to roads.

The final step of the overlay analysis process is to validate the model to make sure what the model indicates is at a site is actually there. Once the model is validated, a site is selected and the house is built.

Using the Weighted Overlay tool

The Weighted Overlay tool lets you implement several of the steps in the general overlay analysis process within a single tool.

The tool combines the following steps:

- Reclassifies values in the input rasters into a common evaluation scale of suitability or preference, risk, or some similarly unifying scale
- Multiplies the cell values of each input raster by the rasters' weight of importance
- Adds the resulting cell values together to produce the output raster

The tool only accepts integer rasters as input, such as a raster of land use or soil types. Continuous (floating-point) rasters must be reclassified to integer before they can be used.

Generally, the values of continuous rasters are grouped into ranges, such as for slope, or Euclidean distance outputs. Each range must be assigned a single value before it can be used in the Weighted Overlay tool. The Reclassify tool allows for such rasters to be reclassified. You can either leave the value assigned to each range (but note the range of values to which the new value corresponds) and assign weights to the cell values in the Weighted Overlay tool later, or you can assign weights at the time of reclassifying. With the correct evaluation scale chosen, simply add the raster to Weighted Overlay. The cells in the raster will already be set according to suitability or preference, risk, or some similarly unifying scale. The output rasters can be weighted by importance and added to produce an output raster.

If the Weighted Overlay tool was used for suitability modeling (to locate suitable areas), higher values generally indicate that a location is more suitable. If the tool was used to generate a cost surface (to find out how much it will cost to travel through the landscape, for instance), high values will generally indicate higher travel costs. You must understand the scale values you apply to input rasters so you know what the values in the output raster mean.

The steps for running the Weighted Overlay tool

The steps for running the Weighted Overlay tool are as follows:

1. Select an evaluation scale.

   Values at one end of the scale represent one extreme of suitability (or other criterion); values at the other end represent the other extreme.

   The default evaluation scale is from 1 to 9 in increments of 1 (least suitable being 1, most suitable being 9). If your input rasters are already reclassified to a common measurement scale using the Reclassify tool, it is important to select an evaluation scale that matches the scale used when reclassifying. For instance, if rasters were reclassified using a scale of 1 to 10 (1 being least suitable and 10 being most suitable), an evaluation scale of 1 to 10 by increments of 1 should be entered for the evaluation scale in Weighted Overlay.

2. Add rasters.

   Click the Add Raster button to open the Add Weighted Overlay dialog box. Click the Input raster arrow and click a raster, or click the browse button to browse to an input raster and click Add. Click the Input field arrow to change the field if desired. Click OK. The raster is added to the Weighted Overlay table. Click the Add Raster button again to enter the next raster, and so on.

   Note:

If land use is one of your inputs, you might have a description field that describes each land-use type. Using this field instead of the default Value field will make it easier to assign weights to this raster.

Note:

Only discrete integer rasters can be used. Reclassify continuous rasters before adding them to Weighted Overlay.

3. Set scale values.

   The cell values for each input raster in the analysis are assigned values from the evaluation scale. This makes it possible to perform arithmetic operations on rasters that originally held dissimilar types of values. You can change the default values assigned to each cell according to importance or suitability. For instance, a land-use raster that is added has values representing the land-use type (Forest = 7, Water = 3, Barren land = 1, Scrub land = 10). To find suitable locations on which to build, you would assign scale values depending on which land-use types are more suitable. For example, with an evaluation scale set at 1 to 9 by 1, you might assign the following scale values: Forest = 3, Water = Restricted, Barren land = 9, Scrub land = 7.

4. Assign weights to input rasters.

   Each input raster can be weighted, or assigned a percentage influence, based on its importance. The total influence for all rasters must equal 100 percent. For instance, it might be more important to build a shopping center on soils that are stable than to locate in a popular shopping area.

5. Run the Weighted Overlay tool.

   The cell values of each input raster are multiplied by the raster's weight (or percent influence). The resulting cell values are added to produce the final output raster.

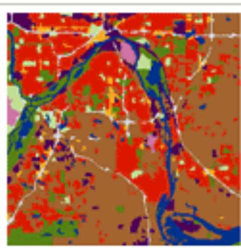
Using Restricted and NoData for the scale value

Setting a scale value to Restricted assigns a value to that cell in the output weighted overlay result that is the minimum value of the evaluation scale set, minus 1. If there are no inputs to Weighted Overlay with cells of NoData, you could use NoData as the scale value to exclude certain values. However, it is safest, and essential if you have NoData cells in any of your inputs, to use Restricted instead. Potentially you could have a result from Weighted Overlay that contains cells of NoData that have come from one or more of the inputs (NoData on any input equals NoData in the result) and restricted areas that you purposely excluded. NoData and Restricted values should not be confused. Each serves a specific purpose. There may be areas of NoData where you don't know the value, which are actually suitable areas. If you use NoData instead of Restricted to exclude certain cell values, and there is NoData in one or more inputs, you will not know if a cell of NoData means the area is restricted from use or whether there was no input data available in that location.

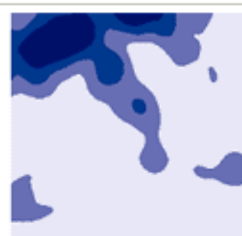
Take care using Restricted for the scale value when creating a cost surface. Since using Restricted gives a value to the cell that is the minimum value of the evaluation scale, minus 1, your restricted areas will appear to be given the lowest cost, when they are actually excluded from the analysis. Instead, you should assign a high cost or set the scale value to NoData for areas you want excluded from the analysis.

A weighted overlay example using the Weighted Overlay tool

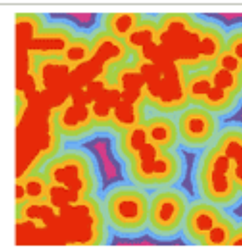
In the following example, a location for a new urban park is being chosen. Three factors will be considered: land use, population density, and distance to existing parks. The goal is to find an area of suitable land use, such as vacant land, in a neighborhood of high population density to provide green space in crowded areas that are not already served by an existing park.



Land use input



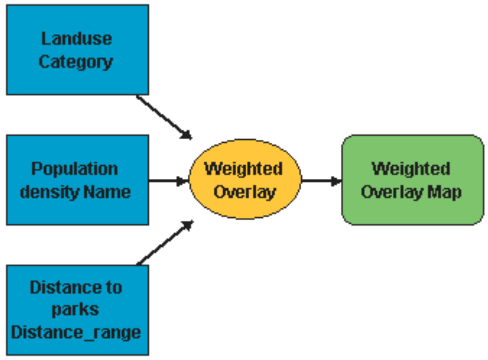
Population density input



Distance to parks input

The input rasters to the weighted overlay are displayed in the image above. They are (from left to right) land use, population density, and distance to parks.

The weighted overlay model is displayed in the image below as a process in ModelBuilder:

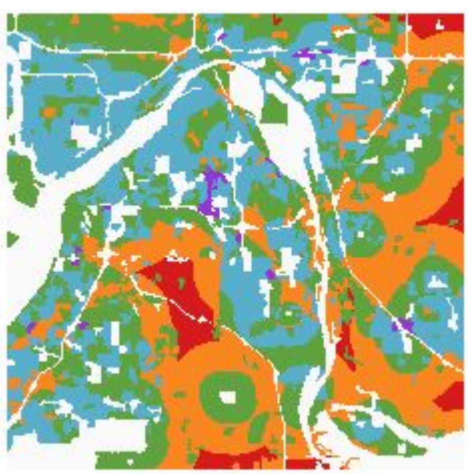


Weighted overlay model

Each value class in each input raster is assigned a new, reclassified value on an evaluation scale of 1 to 5, where 1 represents the lowest suitability and 5 the highest. For instance, in the land-use raster, vacant land is highly suitable, while commercial land is not. In the population density raster, suitability values are high for high-density areas and low for low-density areas. In the distance to parks raster, suitability increases with distance from existing parks because areas far from existing parks are inadequately served.

Any class can also be assigned a Restricted value, which means that the corresponding area is unacceptable or cannot be used. Restricted areas are excluded from the analysis. In the land-use raster, for example, airports and water bodies are restricted.

Each of the three input rasters is then weighted. In this weighted overlay, land use has a 50 percent influence, population density a 15 percent influence, and distance from parks a 35 percent influence.


Output suitability raster

The most suitable areas are shown in red. Orange areas are next, followed by green. Blue and purple areas are least suitable, and white areas are restricted. Modifying the suitability values or the influence percentages will produce different results.