

Tools for map analysis applied to the selection of a waste disposal site

By:

C.J. van Westen

Department of Earth Resources Surveys,

International Institute for Aerospace Survey and Earth Sciences (ITC),

P.O. Box 6, 7500 AA Enschede, The Netherlands

Tel: +31 53 4874263, Fax: +31 53 4874336, e-mail: WESTEN@ITC.NL

Summary

This case study deals with methods of combining multiple maps for empirical modelling in a GIS. Several approaches to analyse multiple maps (Boolean logic models, Binary evidence maps, Index overlay with multi-class maps, and Fuzzy logic method) are introduced by means of a number of basic exercises that follow closely the chapter "Tools for map analysis: multiple maps" from the book *Geographic Information Systems for Geoscientists*, by Graeme Bonham-Carter (Pergamon, 1994, 398 p.). A landfill site selection problem is used as an example.

Getting started

The data for this case study are stored on the ILWIS 2.1 CD-ROM in the directory `d:\appguide\chap18`. If you have already installed the data on your hard-disk, you should start up ILWIS and change to the subdirectory where the data files for this chapter are stored, `c:\ilwis21\data\appguide\chap18`. If you did not install the data for this case study yet, please run the ILWIS installation program (see ILWIS Installation Guide).



- Double-click the ILWIS program icon in the ILWIS program group.
- Change the working drive and the working directory until you are in the directory `c:\ilwis21\data\appguide\chap18`.

18.1 Problem definition: landfill site selection

The Municipality of the town of Chinchina, located in the Central Cordillera of the Andes in Colombia (South America), wants to investigate areas suitable for waste disposal. Up till today all the garbage from the city (150.000 inhabitants) is dumped in the river. However due to an increase in environmental awareness the Municipality of Chinchina has decided to construct a proper waste disposal.

For this purpose assistance from the regional planning department has been requested. The planning department forms a team, consisting of a geologist, a geomorphologist, a hydrologist and an engineer.

18.1.1 Objectives

After a one month period in which field studies were conducted and multi-disciplinary plenary meetings were held, the team submitted a report to the municipality in which the following criteria in selecting areas suitable for waste disposal were considered:

1. The waste disposal should not be built on landslides which are active or which may become active in the future.
2. The waste disposal site should be located on a terrain with a slope less than 20 degrees, to prevent erosion and to assure accessibility.
3. The waste disposal site should only be constructed in areas which do not have an important economic or ecological value. The Chinchina area is one of the most important coffee producing regions in Colombia. The site should therefore not be built on areas where coffee is grown, nor on forested areas. Of course also built-up areas are excluded.
4. The waste disposal sites should be located within 2 km distance from the city centre of Chinchina, but further than 300 meters from any existing built-up area.
5. The waste disposal site should be constructed on clay-rich soils, with a minimum thickness of 5 meters and a permeability lower than 0.05 meters/day.
6. The waste disposal site should have an area of at least 1 hectare.

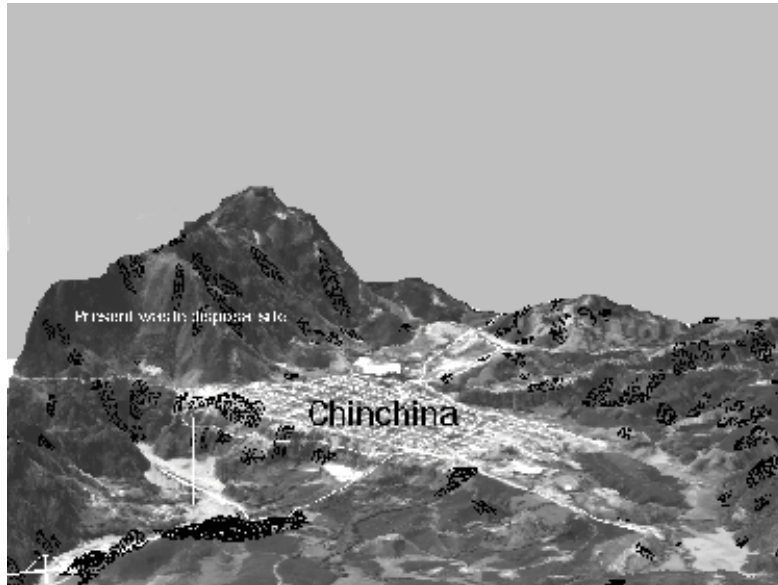


Figure 18.1: Three-dimensional view of the city of Chinchina. The present waste disposal site in the Chinchina river is indicated

18.1.2 Available data

Based on the report further assistance was asked from the planning department to set-up a GIS to tackle the waste site selection problem. The following data set became available for modelling:

Slope	a slope map of the study area with slopes indicated in degrees, derived from a digital elevation model (DEM).
Landuse	a landuse map of the study area, derived from the classification of a SPOT multispectral image, improved with an air photo-interpretation and fieldwork.
Geol	a geological map of the study area, derived from existing geological maps and fieldwork.
Slide	a landslide distribution map of the area, derived from photo-interpretation. The landslides are classified according to their activity into three categories: Stable, Dormant and Active.
City	a map displaying the centre of the city of Chinchina, derived from the topographic map and photo-interpretation.
Borehole	a table containing the generalised borehole data, with the location of the borehole, the lithology, the thickness of overburden, its percentage of clay and its permeability.
Road	a vector map containing the major roads in the area.



- Display the maps and use **PixellInfo** to verify the names or meaning of the different units.

After having verified the input data of the modelling we will start with delineating the areas that are suitable sites for waste disposal for each of the input maps individually by deriving a series of bitmaps from the input raster maps. Each raster cell is assigned an output value of 0 or 1 based on the criteria mentioned under section 18.1.1. If a criterion for the suitability for waste disposal for that particular theme is met, the output value assigned is 1 otherwise 0. After we have created the bitmaps for each of the input maps, they will be combined using the so called Boolean logic model.

18.2 Boolean logic model

The flowchart for the Boolean logic model is presented below (figure 18.2). From the input maps 6 bitmaps: **Suitslid**, **Suitslop**, **Suituse**, **Suitbuil**, **Suitchin** and **Suitgeol** are derived. First we will create these bitmaps, and then we will combine them with Boolean AND.

Step 1: The waste disposal should not be built on landslides which are active or which may become active in the future

The map **Slide** on which landslides are delineated contains three classes of landslides: active, dormant and stable.



- Calculate a map **Suitslid** in which the areas with active or dormant landslides are indicated with pixel value 0 (unsuitable) and the rest with pixel value 1 (suitable).

Step 2: The waste disposal site should be located on a terrain with a slope less than 20 degrees

For each cell of the raster map **Slope**, the slope angle is represented in degrees.



- Calculate a map **Suitslop** in which the areas with slopes less than 20 degrees are indicated with pixel value 1 (suitable) and the rest of the map with pixel value 0.

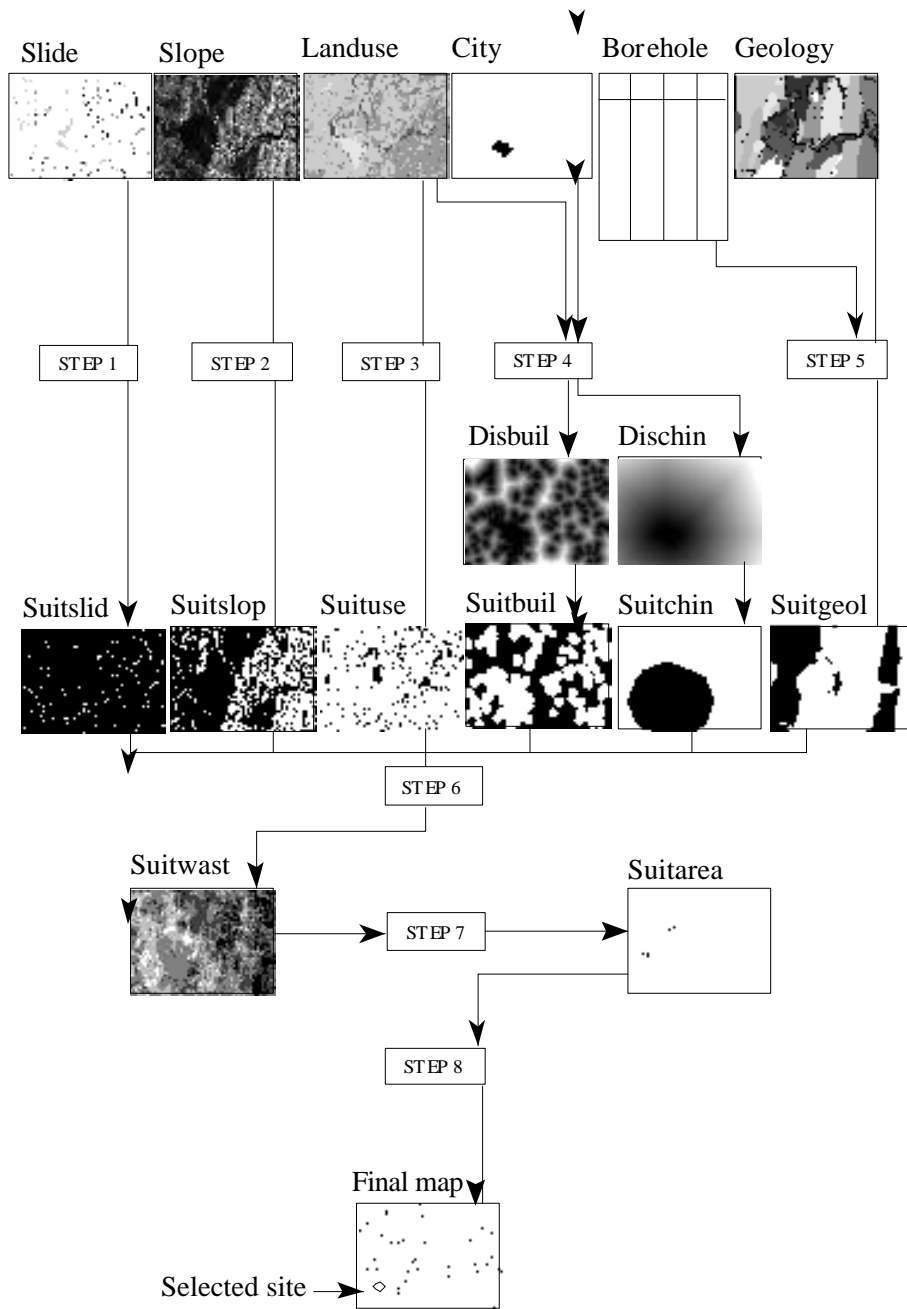


Figure 18.2: Flowchart for the Boolean logic model

Step 3: The waste disposal site can only be constructed in areas which do not have an important economic or ecological value. The only suitable land use classes are: shrubs and bare

The map `Landuse` contains the main land use types of the area.



- Calculate a map `Suituse` in which the areas with areas with the land use classes `Shrubs` and `Bare` are indicated with pixel value 1 and the rest of the map with pixel value 0.

Step 4: The waste disposal sites should be located within 2 km distance from the city centre of Chinchina, but further than 300 meters from any existing built-up area

Note that this criterion can be subdivided into two criteria. For calculating the suitability map you will need two input maps: `Landuse` (in which all built-up areas are indicated) and `City` (on which the city centre of Chinchina is delineated).

The calculation of distances is performed using the `Distance` program (note that the source areas from which distances are calculated are assigned zero values, and the areas through which distances are calculated with values 1).

First calculate the map `Switchin` in which the areas located at distances less than 2000 meters from the city of Chinchina are indicated with pixel value 1 and the rest with 0. This procedure is done in three steps:



- First calculate a source map (called `Csource`) in which the all pixels except the city of Chinchina are `Undefined`.
- Calculate the distance from the source map `Csource` and store the result in the map `Cdist`.
- Calculate a buffer of 2000 meters around the city, and create a map `Switchin` in which the areas less than 2000 meter have a value 1 and the rest a value 0.

The second part of the calculation is the creation of the map `Suitbuil` in which the areas located less than 300 meters from built-up areas are indicated with pixel value 0 and the rest with 1. This procedure is done in three steps:



- First calculate a source map (called `Bsource`) in which all pixels except the built-up areas (which can be derived from the map `Landuse`) are `Undefined`.
- Calculate the distance from the source map `Bsource` and store the result in the map `Bdist`.
- Calculate a buffer of 300 meters around the built-up areas, and create a map `Suitbuil` in which the areas less than 300 meters obtain a 0 value and the rest 1.

Step 5: The waste disposal site should be constructed on clay-rich soils (with more than 50 percent of clay), with a soil thickness of more than 5 meters and a permeability lower than 0.05 meters/day

To create the suitability map for this criterion, you will first need to analyse the borehole data, stored in the table `Borehole.tb1`, in **Table Calculation**. The original borehole records were already restructured in such a way that for each borehole the geological unit, the thickness of soil cover, the percentage of clay and the permeability are given. The table contains 203 borehole records.



- Calculate for each geological unit the average of each of the three variables (average thickness, average clay content and average permeability). In order to do this the different borehole records need to be grouped according to the geological units. This is done by using the option **Join** and the function **Average** of the three variables from the table `Borehole` into the table `Geol`. Store the resulting average values in the columns `Avgthick`, `Avgclay` and `Avgperm`. Make sure not to round off the values

(Hint: take care about the different domains of the tables and columns involved).

After the average values for clay content, soil thickness and permeability have been calculated, a column `Suit` will be derived from these columns in which the geological units will receive a value of 1 if the conditions, mentioned above, are met.



- Calculate the column `Suit`, taking into account that the average thickness should be more than 5 meters, the average clay content more than 50 percent and the average permeability less than 0.05 m/day. The units fulfilling these 3 requirements will get a value 1 whereas the rest will be assigned to 0.

The last step in the calculation of this criterion is to calculate a map `Suitgeol` in which the areas with suitable geological units (average thickness >5 m, average clay percentage > 50, and average permeability <0.05 m/day) are indicated with a 1 and the rest with a 0. This can be done by reclassifying the map `Geology` with the column `Suit` from the table `Suitgeol`.



- Create the map `Suitgeol` by renumbering the map `Geol` with the column `Suit` from the table `Geol`.

Step 6: Combining the suitability maps

In the previous five steps six suitability maps `Suitslid`, `Suitslop`, `Suituse`, `Suitbuil`, `Suitchin`, and `Suitgeol` were derived. The clue of Boolean logic modelling is that if we want to delineate areas where all conditions are met, we can combine the six maps with the Boolean AND operator, which maps the intersection of all six binary patterns.



- Combine all maps into one map, `Suit1`, using the Boolean AND operator.
- What would we map if we combine the six maps with the Boolean OR operator ?

Step 7: Calculate which suitable sites have sufficient capacity

After having selected the most suitable areas for waste disposal, the next condition to be met is that the suitable areas are large enough for storing the waste for a prolonged period. For this purpose we have to know the surface area of each of the patterns with a value 1 in the map `Suit1`.

In order to be able to use the site for a longer period, the minimum area should be 1 hectare (10.000 m²).



- Create a map *Suitarea* in which the most optimal sites with an area larger than 1 hectares are indicated with a value 1 and the rest with a value 0. Use the program *AreaNumbering* (8 connected), to assign to each area a unique number. The surface area can be calculated for each of these areas by calculating the histogram.

(Hint: run the *AreaNumbering* from the command line).

Step 8: Final site selection

Now that you know where the most suitable sites for waste disposal are located, and what their surface area is, you have to make a final selection between the different sites. In this final selection some other criteria may play a role, for example the accessibility of the site by road.



- Evaluate the remaining sites of the map *Suitarea*, and give the coordinates of the most optimal site.

18.3 Binary evidence maps

In the Boolean logic model the criteria as modelled in the six binary maps were assigned equal weighting. All binary maps were considered of equal importance of delineating areas suitable for waste disposal. If, for example, the team judges that criterion 5 is much more important in determining the suitability for constructing a waste disposal compared to criterion 2, we obviously need a different method in which we can assign weights proportional to the importance assigned to each of the six binary maps.

A method that offers a solution is called *Index overlaying*, which provides a method for assigning different weights to map patterns depending on the importance of the pattern to the model under consideration. The simplest kind of index weighting is applied on binary maps where each map carries a single weight factor. Each binary map is multiplied by its weight factor, summed over all the maps being combined and normalised by the sum of the weights. At any location, the output score *s* is defined as:

$$s = \frac{\sum_i^n w_i \text{Class}(\text{MAP}_i)}{\sum_i^n w_i} \quad [18.1]$$

where w_i is the weight of the i -th map, and $\text{Class}(\text{MAP}_i)$ is either 1 for presence or 0 for absence of the binary condition. The output score is between 0 (implying extremely unfavorable) to 1 (implying highly favorable). The result is to produce a map showing regions that are ranked according to the score.

If you consider the map modelling procedure for the landfill case, we have already prepared six binary maps with the different conditions: *Suitslid*, *Suitslop*, *Suituse*, *Suitbuil*, *Suitchin* and *Suitgeol*.

18.3.1 Assigning equal weights

The first thing we will do is to assign equal weights to the six binary maps, and then compare the result with the map obtained from the Boolean logic modelling.



- Combine the six maps with the formula given above. Create the result map *Suit2*.
- Reclassify this map in 3 classes: *Unsuitable*, *Moderately suitable*, *Suitable*.
- Compare the maps *Suit1* and *Suit2*. What can you conclude about the differences of the two methods (Boolean logic models versus Binary evidence maps)?

18.3.2 Assigning different weights

Now we will assign different weights to the various input maps. The weights that are assigned to each of the binary maps *Suitslid*, *Suitslop*, *Suituse*, *Suitbuil*, *Suitchin*, and *Suitgeol* are subjective and are related to the importance you give a certain criteria. To repeat the meaning of the different binary maps:

<i>Suitslid</i>	The waste disposal can not be built on landslides which are active or which may become active in the future.
<i>Suitslop</i>	The waste disposal site should be located on a terrain with a slope less than 20 degrees.
<i>Suituse</i>	The waste disposal site can only be constructed in areas which do not have an important economic or ecological value. The only suitable land use classes are: shrubs and bare.
<i>Suitbuil</i>	The waste disposal sites should be located further than 300 meters from any existing built-up area.
<i>Suitchin</i>	The waste disposal sites should be located within 2 km distance

from the city centre of Chinchina.

Suitgeol The waste disposal site should be constructed on clay-rich soils (with more than 50 percent of clay), with a soil thickness of more than 5 meters and a permeability lower than 0.05 meters/day.



- Assign a weight factor, ranging from 0 to 10 to each of the six bitmaps Suitslid, Suitslop, Suituse, Suitbuil, Suitchin and Suitgeol.
- Calculate an output map Suit3 by applying these weights in equation 18.1.
- Classify the map Suit3 in three classes and compare it with the maps Suit1 and Suit2. What can you conclude?
- Compare the result of your calculation (the weights you used and the result) with your colleagues working next to you. What can you conclude about the effect of the weights?

18.4 Index Overlay with Multi-class Maps

In this case the map classes occurring on each input map are assigned different scores, as well as the maps themselves receiving different weights than in the previous exercise. It is convenient to define the scores in an attribute table for each input map. The average score is defined by:

$$\bar{s} = \frac{\sum_i^n S_{ij} w_i}{\sum_i^n w_i} \quad [18.2]$$

where \bar{s} is the weighted score for an area object, w_i is the weight for the i -th input map, and S_{ij} is the score for the j -th class of the i -th map, the value of j depending on the class actually occurring at the current location.

Since we are now working with scores for each class in a map, we cannot use the bitmaps Suitslid, Suitslop, Suituse, Suitbuil, Suitchin, and Suitgeol anymore. In fact we have to work with the original maps, and the tables associated with those maps.

The method requires class maps as input. Since only the maps Geol, Landuse

and *Slide* are class maps, we will have to create class maps out of the other ones. In this exercise we will also split up the different criteria related to geology. For each of the input maps we will now determine the weights of the individual classes in a range from 0 (totally unsuitable) to 10 (very suitable).

Step 1: The waste disposal can not be built on landslides which are active or which may become active in the future

As you have seen in the previous section, landslide information is present in the map *Slide*. This map contains three classes: active, dormant and stable.



- Determine the scores of the three classes in the range from 0 to 10, and fill in a column *Suit1* added to the attribute table connected to the map *Slide*.
- Create a map *Sslide* in which you renumber the map *Slide* with the values from the column *Suit1*. Do not forget to assign a weight value to the areas without landslides!

Step 2: The waste disposal site should be located on a terrain with a slope less than 20 degrees

Slope angle information is present in the raster map *Slope*. Because this map is not classified it should be classified first.



- Classify the map *Slope* in 9 classes of 10 degrees each (1: 0-10 degrees, 2:10-20 degrees, 3:20-30 degrees, etc.). Call the result *Slopec*.
- Create a table connected to the map *Slopec* in which you define a column *Suit1*.
- Assign weight values in the range of 0 to 10 to each of the classes.
- Renumber the map *Slopec* with the values from the column *Suit1* and create the map *Sslope*.

Step 3: The waste disposal site can only be constructed in areas which do not have an important economic or ecological value

Land use information is present in the map *Landuse*. The land use map contains the following classes:

1 = built-up area	2 = coffee
3 = shrubs	4 = forest
5 = pasture	6 = bare
7 = riverbed	8 = lake



- Determine scores for the land use classes in the range from 0 to 10, and assign them to a column `Suit1` in the attribute table connected to the map.
- Create a map `Suse` in which you renumber the map `Landuse` with the values from the column `Suit1`.

Step 4: The waste disposal sites should be located within 2 km distance from the city centre of Chinchina, but further than 300 meters from any existing built-up area

Again we will treat the two criteria individually, using the maps `Landuse` (in which all built-up areas are indicated) and `City` (in which the city centre of Chinchina is indicated).

In section 18.2.4 you have already created the two distance maps: `Cdist` (distance from Chinchina town), and `Bdist` (distance from built-up areas). Both maps should be converted to class maps, before weights can be assigned.

We start with the map `Cdist`.



- Classify the map `Cdist` in zones of 500 meters. Thus, class 1 (0-500), class 2 (500-1000) etc. The result is called `Cdistc1`.
- Create a table connected to the map `Cdistc1` and assign weights in the range from 0 to 10 to each of the classes. Put them in the column `Suit1`.
- Create a map `Schin` in which you renumber the map `Cdistc1` with the values from the column `Suit1`.

The same procedure should be followed also for the map `Bdist`.



- Classify the map `Bdist` in zones of 100 meters, class 1 (0-100), class 2 (100-200) etc. The result is called `Bdistcl`.
- Create a table connected to the map `Bdistcl` and assign weights in the range from 0 to 10 to each of the classes. Put them in the column `Suit1`.
- Create a map `Sbuil` in which you renumber the map `Bdistcl` with the values from the column `Suit1`.

Step 5: The waste disposal site should be constructed on clay-rich soils (with more than 50 percent of clay), with a soil thickness of more than 5 meters and a permeability lower than 0.05 meters/day

The average percentage of clay, the average soil thickness and the average permeability were already calculated in exercise 18.2.5.

Here we will differentiate between these three criteria, by defining three separate columns indicating the weights for the different geological units for each of the three criteria.



- Classify the units in the map `Geol` according to the values in the column `Avgthick`. Also classify them according to the columns `Avgclay` and `Avgperm`.
- Create a new column `Suitthic` in the table `Geol` in which you enter the weights for the criteria "thickness should be more than 5 meters" for each geological unit. The weights should range from 0 to 10.
- Create also a column `Suitclay` in which you enter the weights for the criteria "clay content more than 50 percent".
- Create a column `Suitperm` in which you enter the weights for the criteria "permeability less than 0.05 m/day".

From these three columns index weight maps can be created by renumbering the map `Geol` with the weights contained in these columns.



- Create a map `Sthick` by renumbering the map `Geol` with the

column S_{itthic} from the table $Geol$.

- Create a map S_{clay} by renumbering the map $Geol$ with the column S_{itclay} from the table $Geol$.
- Create a map S_{per} by renumbering the map $Geol$ with the column S_{itperm} from the table $Geol$.

Step 6: Combining the suitability maps using Index-Overlay

After having completed the calculation of individual weight maps (i.e. the calculation of S_{ij}) the following maps, representing spatial distribution of weights that determine the suitability for a waste disposal site, are available:

S_{slide}	The waste disposal can not be built on landslides which are active or which may become active in the future.
S_{slope}	The waste disposal site should be located on a terrain with a slope less than 20 degrees.
S_{use}	The waste disposal site can only be constructed in areas which do not have an important economic or ecological value. The only suitable land use classes are: Shrubs and Bare.
S_{buil}	The waste disposal sites should be located further than 300 meters from any existing built-up area.
S_{chin}	The waste disposal sites should be located within 2 km distance from the city centre of Chinchina.
S_{thick}	The waste disposal site should be constructed on soils with a soil thickness of more than 5 meters.
S_{clay}	The waste disposal site should be constructed on clay-rich soils (with more than 50 percent of clay).
S_{per}	The waste disposal site should be constructed on soils with a permeability lower than 0.05 meters/day.

To complete the equation 18.2 you need to know the weights of the individual maps. In the exercise on Binary Evidence Maps you already decided on the weights for the first 5 maps. The criteria related to the geological units is now separated in three criteria. You have to define weights for each of these three.



- Assign a weight between 0 and 10 to the maps S_{thick} , S_{clay} and S_{per} . For the other maps you can use the weights previously assigned in section 18.3.2.
- Apply the formula 18.2 in **MapCalc** and create the suitability map

Suit4 by combining the 8 maps.

- Reclassify this map in three classes.
- Compare the map Suit4 with the maps Suit1, Suit2 and Suit3. What is the difference? Do you think that this method is better than the others? Why?

18.5 Fuzzy logic method

In classical set theory, the membership of a set is defined as true or false: 1 or 0. Membership of a *fuzzy set*, however, is expressed on a continuous scale from 1 (full membership) to 0 (full non-membership). Thus individual classes of maps can be evaluated regarding their membership of a set, based on subjective judgement. The membership always relates to a certain proposition. In our case the proposition is "favorable location for a landfill".

Fuzzy membership values must lie in the range (0,1), but there are no practical constraints on the choice of fuzzy membership values. In the previous exercise we have been working with weights in the range of 0 to 10. We could use in fact the similar weights now as fuzzy membership values, if we divide them by 10.

However an important difference compared to the index overlay method is that fuzzy membership values must reflect both the relative importance of each map, as well as the relative importance of each class of a single map. In contrast the weights used in the previous exercise were evaluated separately for the individual maps, and for the classes of every single map. For this reason the weights from the previous exercise cannot be simply divided by 10 to obtain fuzzy membership values.

In the forthcoming exercise you will have to evaluate for each class in every map, what will be the membership of that class in the fuzzy set supporting the proposition "suitable location for landfill".

If you examine the fuzzy membership values in table 9-5 from Bonham-Carter's book (1994) you can see that there are no 0 nor 1 values. Unsuitable classes are given a membership value of 0.1 and highly suitable classes a membership value of 0.9. This is because one can never be completely certain on the basis of 1 class of a map that the site is suitable for landfill. There may be other conditions that will make the site less suitable.

18.5.1 Assigning fuzzy membership values to map classes

The procedure for assigning membership values is practically the same as assigning weights in the index overlay method with multi-class maps, as described in sections 18.4.1 to 18.4.6. Write down fuzzy membership values for the map classes also considering the relative importance for suitability for a land fill site between maps.



- Create a column Fuzzy in the table related to the landslide map Slide and renumber this map with membership values to the map Fslide.
- Repeat the procedure for the maps Landuse, Slope, Cdistcl, Bdistcl, Sthick, Sclay and Sper and create the corresponding maps with fuzzy membership values Fluse, Fslope, Fchin, Fbuil, Fthick, Fclay and Fesper.

Each of the input class maps has now been renumbered with fuzzy membership values and can be combined with a number of operators analogous to Boolean operators.

18.5.2 Fuzzy AND

This is equivalent to a Boolean AND (logical intersection) on classical sets of (1,0) values. It is defined as:

$$\mu_{combination} = \text{MIN}(\mu_A, \mu_B, \mu_C, \dots) \quad [18.3]$$

where μ_A is the membership value for map A at a particular location, μ_B is the value for map B and so on. Using this operation the minimum value of one of the eight input maps determines the final value for a certain pixel. It will therefore result in rather conservative values.

This means that for each pixel you have to get the lowest value from the maps Fslide, Fslope, Fluse, Fbuil, Fchin, Fthick, Fclay and Fesper.



- Combine in MapCalc the 8 maps using the fuzzy AND combination, by taking for each pixel the minimum value of all 8 maps. Call the result Suit5. Use a nested Min combination of this type:
$$\text{Suit5} = \text{Min}(\text{Min}(1, 2, 3), \text{Min}(4, 5)) \downarrow$$
- Classify the map in five suitability classes.

18.5.3 Fuzzy OR

The fuzzy OR operator is the like of the Boolean OR (logical union) in that the output membership values are controlled by the maximum values of any of the input maps at a particular location. It is defined as:

$$\mu_{combination} = \text{MAX}(\mu_A, \mu_B, \mu_C, \dots) \quad [18.4]$$

Using this operation, the combined membership value at a location (=suitability for landfill) is limited only by the most suitable of the evidence maps, which is not a particularly desirable operator for the landfill case.



- Combine in MapCalc the 8 maps using the fuzzy OR combination, by taking for each pixel the maximum value of all 8 maps. Call the result *Suit6*.
- Classify the map in five classes.

18.5.4 Combination with fuzzy algebraic product

Here the combined membership function is defined as:

$$\mu_{combination} = \prod_{i=1}^n \mu_i \quad [18.5]$$

where μ_i is the fuzzy membership function for the i -th map, and $i=1,2,\dots,n$ maps are to be combined. The individual maps are multiplied, and this results in very small combined membership functions, due to the effect of multiplying several numbers less than 1. Note that if one of the maps has a fuzzy membership value of 0, the result will also be 0.



- Combine in MapCalc the 8 maps using the fuzzy algebraic product by multiplying the 8 maps. Call the result *Suit7*.
- Classify the map in five classes.

18.5.5 Combination with fuzzy algebraic sum

This operator is complementary to the algebraic product, being defined as:

$$\mu_{combination} = 1 - \prod_{i=1}^n (1 - \mu_i) \quad [18.6]$$

The result is always larger (or equal to) the largest contributing membership value. The effect is therefore "increasing". Two pieces of evidence that both favour a hypothesis reinforce one another and the combined evidence is more supportive than either piece of evidence individually.



- Combine in MapCalc the 8 maps using the fuzzy algebraic sum. Call the result `Suit8`.
- Classify the map in five classes.

18.5.6 Combination using the fuzzy Gamma Operation

This is defined in terms of the fuzzy algebraic product and the fuzzy algebraic sum by:

$$\mu_{combination} = (FAS)^\gamma * (FAP)^{1-\gamma} \quad [18.7]$$

where FAS is the fuzzy algebraic sum, calculated in exercise 18.5.5, and FAP is the fuzzy algebraic product, calculated in 18.5.4. γ is a parameter chosen in the range (0,1). When γ is 1 the result is the same as the fuzzy algebraic sum. When γ is 0 the result is equal to the fuzzy algebraic product. See the chapter from Bonham-Carter, pages 297-299, for more explanation.



- Select the gamma value 0.8.
- Use the results of the previous two exercises as FAS (fuzzy algebraic sum) and FAP (fuzzy algebraic product). Execute formula 18.7, and call the result `Suit9`.
- Classify the map in five classes.
- Discuss the results of using the different fuzzy operators for the land fill selection problem.
- Make some more tests with other gamma values.

References

- Bonham-Carter, G.F. (1994). Geographic Information Systems for Geoscientists. Modelling with GIS. *Computer Methods in the Geosciences*, 13: pp 267- 302. Pergamon.

