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## INTEGRATED MONITORING SYSTEM FOR DESERTIFICATION RISK ASSESSMENT

# MOONRISES

ΟΛΟΚΛΗΡΩΜΕΝΟ ΣΥΣΤΗΜΑ ΠΑΡΑΚΟΛΟΥΘΗΣΗΣ ΓΙΑ ΤΗΝ  
ΕΚΤΙΜΗΣΗ ΤΟΥ ΚΙΝΔΥΝΟΥ ΕΡΗΜΟΠΟΙΗΣΗΣ

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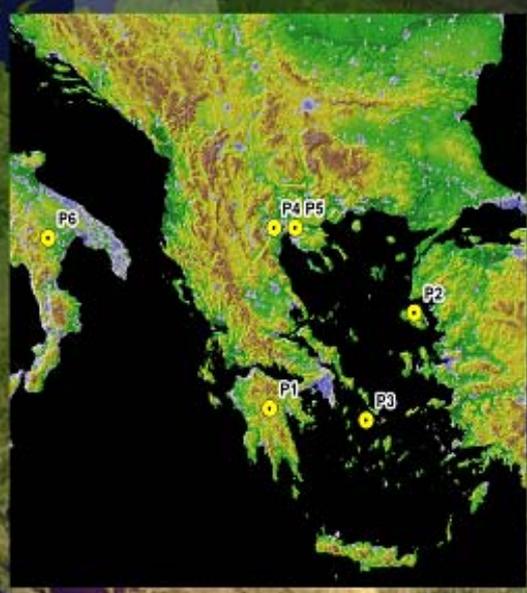
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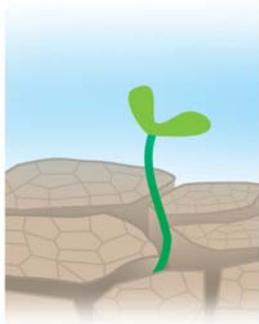
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# **MOONRISES**

**INTEGRATED MONITORING SYSTEM  
FOR DESERTIFICATION RISK ASSESSMENT**

## **SPATIAL MULTI-CRITERIA DECISION SUPPORT SYSTEM (DSS)**

|                           |   |
|---------------------------|---|
| <b>Program</b>            | <b>Interreg III B - Archimed</b>  |
| <b>Measure</b>            | <b>3.3 - Management, prevention and reduction of natural risks</b>      |
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# CHAPTER 1: IDENTIFICATION SHEET

## Identification Sheet

|                                |  |
|--------------------------------|--|
| <b>Package</b>                 | <b>WP. 7: Data collection, Data pre-processing and data processing</b>   |
| <b>Action</b>                  | <b>7.1. Development of software for the Decision Support System using the Spatial Multi-criteria Weighed General Prediction Model (GPM)</b>  |
| <b>Deliverable</b>             | <ul style="list-style-type: none"> <li>• Decision Support System</li> <li>• Documentation for             <ol style="list-style-type: none"> <li>1. Data input</li> <li>2. Data output</li> <li>3. Expected results</li> </ol> </li> </ul> |
| <b>Type</b>                    | RTD  |
| <b>Version</b>                 | FINAL  |
| <b>Responsible Partner</b>     | P1   |
| <b>Involved Partners</b>       | P5   |
| <b>Authors</b>                 | Format Σύμβουλοι Επιχειρήσεων ΑΕ-GEOINFO ΧΡΗΣΤΟΥ ΟΔΥΣΣΕΑΣ, FORMAT CONSULTANTS ΑΕ   |
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| <b>Distributed to Partners</b> | Lead partner, P5   |

|  |   |
|--|---|
| <b>Deliverable</b>   | <b>Technical report-model description</b> |
| <b>Abstract</b>  |   |
| <p>This action's objective is to develop the Desertification Risk Monitoring Model, that will provide guidelines and depict standardized procedures for desertification risk monitoring activities and methods.</p> <p>Given the outputs of the previous actions and the amounts of processed data, parameterized indicators and maps this model will provide guidance for:</p> <ul style="list-style-type: none"> <li>• Combining indicators and processed data along with previously obtained results in order to find patterns of desertification evolution</li> <li>• Extracting hidden knowledge from desertification data bases using statistical or other methods</li> <li>• Producing standardized procedures and rules for desertification monitoring and prediction</li> </ul> |   |
| <b>Keywords:</b>   |   |
| <b>DECISION SUPPORT SYSTEM</b>   |   |

# Spatial Multi-criteria Decision Support System

## CHAPTER 2: Decision Support Systems

Due to the diversity of decision-making approaches and the wide range of domains in which decisions are made, the concept of *Decision Support Systems* (DSS) is very broad. Loosely defined, a decision support system can be characterised as a computerised system that helps the decision makers in making decisions. Decision support systems support a decision by gathering information, generating alternatives and supporting the choice making process by estimating, evaluating and comparing alternatives.

Over the past few years there has been considerable interest in the use of Decision Support Systems in GIS. However the unique characteristics of spatial decision problems require new approaches and methodologies to be developed. Such characteristics include<sup>1</sup>:

- A large number of decision alternatives
- the outcomes or consequences of the decision alternatives are spatially variable,
- each alternative is evaluated on the basis of multiple criteria,
- some of the criteria may be qualitative while others may be quantitative,
- there are typically more than one decision makers (or interest groups) involved in the decision-making process,
- the decision makers have different preferences with respect to the relative importance of evaluation criteria and decision consequences,
- the decisions are often surrounded by uncertainty.

### Definitions<sup>2</sup>

#### *Decision*

A decision can be defined as a selection (choice) between alternatives. The alternatives may represent different courses of action, different hypotheses about the character of a feature, different classifications, etc. Each set of alternatives is called a *Decision Frame*. The decision frame for a zoning problem may be for example commercial, industrial and residential. The individuals to which the decision is applied is called the *candidate set*.

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<sup>1</sup> Malczewski, J. (1997) Spatial Decision Support Systems, *NCGIA Core Curriculum in GIScience*, <http://www.ncgia.ucsb.edu/giscc/units/u127/u127.html>, posted October 6, 1998

<sup>2</sup> Adapted from Eastman, J.R, 1993. Decision Theory and GIS, Proceedings, Africa GIS '93, UNITAR, Geneva.

### *Criterion*

A criterion is the basis for a decision that can be measured or evaluated. It is the fact on which the decision should be based on. There are two kinds of criteria: constraints and factors. A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration while a constraint serves to limit the alternatives under consideration.

### *Decision Rule*

A decision rule is the procedure by which criteria are selected and combined in order to arrive at a particular evaluation, and by which evaluations are compared and acted upon. Decision rules typically contain procedures for combining criteria into a single composite index and a statement of how alternatives are to be compared using this index.

### *Objectives*

Decision rules are structured in the context of a specific objective. The structure of a decision rule is guided by the nature of the objective. While many decisions are guided by a single objective, there are cases in which a decision should satisfy several objectives. A multi-objective problem is encountered whenever there are two candidate sets (i.e., sets of entities) that share members. These objectives may be complementary or conflicting in nature

### *Evaluation*

The actual process of applying the decision rule is called evaluation.

### *Multi-Criteria Evaluation*

In order to meet an objective, it is not uncommon that several criteria may need to be evaluated. A procedure that involves evaluation of several criteria is called multi-criteria evaluation. Multi-criteria evaluation is most commonly achieved by one of two procedures. The first involves Boolean overlay whereby all criteria are reduced to logic-at statements of suitability and then combined by means of one or more logical operators such as intersection and union. The second is known as Weighted Linear Combination wherein continuous criteria (factors) are standardised to a common numeric range, and then combined by means of a weighted average. The result is a continuous mapping of suitability that may then be masked by one or more Boolean constraints to accommodate qualitative criteria, and finally thresholded to yield a Final decision.

While these two procedures are well established in GIS, they frequently lead to different results, as they make very different statements about how criteria should be evaluated. In the case of Boolean evaluation, a very extreme form of decision making is used. If the criteria are combined with a logical AND (the intersection operator), a location must meet every criterion for it to be included in the decision set. If even a single criterion fails to be met, the location will be excluded. Such a procedure is essentially risk averse, and selects locations based on the most cautious strategy

possible-a location succeeds in being chosen only if its worst quality (and therefore all qualities) passes the test. On the other hand, if a logical OR (union) is used, the opposite applies-a location will be included in the decision set even if only a single criterion passes the test. This is thus a very gambling strategy, with (presumably) substantial risk involved.

Unlike Boolean evaluation techniques, with Weighted Linear Combination, criteria are permitted to tradeoff their qualities. A very poor quality can be compensated for by having a number of very favorable qualities. This operator represents neither an AND nor an OR -it lies somewhere in between these extremes. It is neither risk averse nor risk taking.

For reasons that have largely to do with the ease with which these approaches can be implemented, the Boolean strategy dominates vector approaches to Multi-criteria evaluation, while Weighted Linear Combination dominates solutions in raster systems.

## CHAPTER 3. The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision support method that was developed by Prof. Thomas Saaty. AHP uses paired comparisons in order to calculate the weights of multiple criteria. It has an advantage over other multi-criteria methods as it can also calculate the consistency ratio, which detects the possible inconsistencies in the comparison. The weights of the criteria are derived from the principal Eigen Vectors and the consistency ratio is derived from the principal Eigen value.

### Process Description

All criteria that take part in the analysis are compared pair-wise with the use of a comparison matrix allowing the user to express the relative preference of one factor against another by using numerical values. The numerical values that are used in the comparison are values emerging from the SAATY scale<sup>3</sup> (Table 1). Saaty proposed a scale of comparison consisting of values ranging from 1 to 9 which describe the importance of one factor against another.

| Value       | Importance                    |
|-------------|-------------------------------|
| 1           | Equal                         |
| 3           | Moderate                      |
| 5           | Strong                        |
| 7           | Very strong                   |
| 9           | Extreme                       |
| 2,4,6,8     | Intermediate values           |
| Reciprocals | Values for inverse comparison |

**Table 1: The SAATY Scale**

Table 2 shows an example of a comparison matrix that depicts the comparison of three criteria C1, C2 and C3. C1 is set to have strong importance (value 5) against C2 and moderate to strong importance (value 4) against C3. C2 is set to have equal to moderate importance against C3 (value 2). The inverse positions of the table automatically get a reciprocal value (0.2, 0.25 and 0.5)

| Criteria | C1   | C2  | C3 |
|----------|------|-----|----|
| C1       | 1    | 5   | 4  |
| C2       | 0.2  | 1   | 2  |
| C3       | 0.25 | 0.5 | 1  |

**Table 2: The Comparison Matrix**

The next step in the Analytic Hierarchy Process involves applying an algorithm that yields similar results to that of the principal component analysis. The algorithm consists of the following steps:

1. Sum each column of the comparison matrix
2. Divide each element of the matrix with the sum of its column in order to calculate the normalized relative weight

<sup>3</sup> Saaty, T.L., (1977). "A scaling method for priorities in hierarchical structures". Journal of Mathematical Psychology, 15, pp. 231-281

3. Calculate the average value of each row in order to get the principal Eigen value
4. Sum each row and divide by the number of criteria in order to calculate the criteria weights.

Considering the possible number of comparisons in the comparison matrix it is possible that inconsistencies may arise mostly due to human error. The AHP process offers a consistency ratio (CR) which is a numerical index that aims to detect such inconsistencies. CR is defined as the ratio of consistency index (CI) to an average consistency index (RI):

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

The values for RI are related to the order of the comparison matrix. Table 3 shows the RI values for a matrix of an order up to 8.

| n  | 2    | 3    | 4    | 5    | 6    | 7    | 8    |
|----|------|------|------|------|------|------|------|
| RI | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 |

**Table 3: Values for RI (n=order of matrix)**

The consistency index can be calculated from the comparison matrix using the following formula:

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

where

$\lambda_{\max}$ : greatest Eigenvalue of the preference matrix  
 $n$ : order of matrix

A revision of the preference matrix is recommended if the consistency ratio (CR) exceeds a value of 0.1.

## CHAPTER 4. The AHP Application

The AHP Application is written in Visual Basic for Applications and works as an extension to ArcGIS. The application currently works with raster shapefiles and provides a graphical user interface in order to perform the Analytic Hierarchy Process.

### Accessing the Application

In order to use the application the user will initially have to perform the following steps:

1. Launch ArcMap
2. Go to “Tools” menu and select “Customize”
3. Go to “Commands” and in the “Categories” list select “UIControls”
4. Drag the “Project.MultiCriteria” command and drop it on any toolbar on the ArcMap environment.

After following these steps the user can access the application by clicking on the “Multicriteria” button (Figure 1).



**Figure 1: The “Multicriteria” Button**

### Using the Application

#### *Main Screen*

By pressing the “Multicriteria” button the application main screen appears. The main screen displays two choices (figure 2):

1. Multicriteria DSS
2. Site Location Application

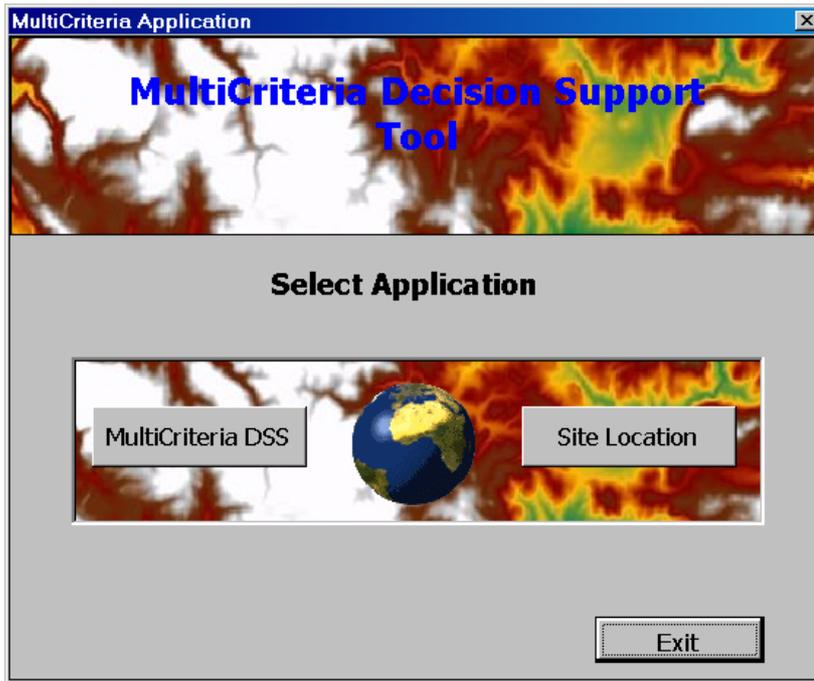


Figure 2: The application main screen

### Multicriteria Decision Support Tool

The AHP multicriteria application is initialized by pressing the “Multicriteria DSS” button. The first screen of the application consists of two steps (figure 3):

1. Step 1: Reclassify Layers
2. Step 2: Select Criteria and Calculate Weights.

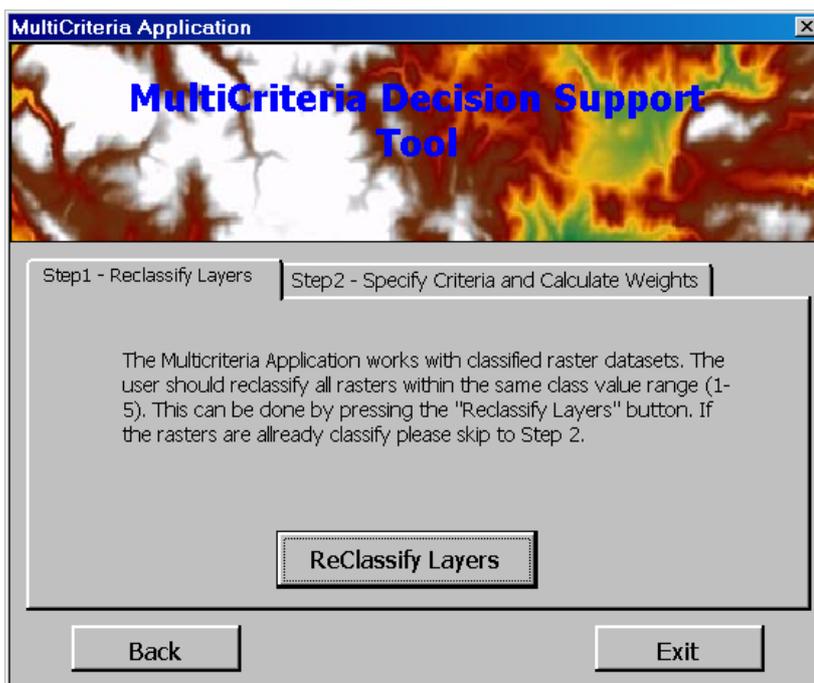
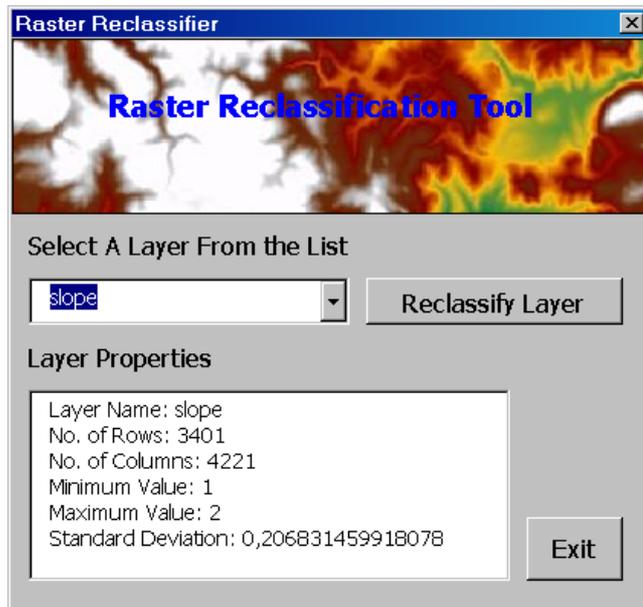


Figure 3: DSS application options

### Step 1: Reclassify Layers

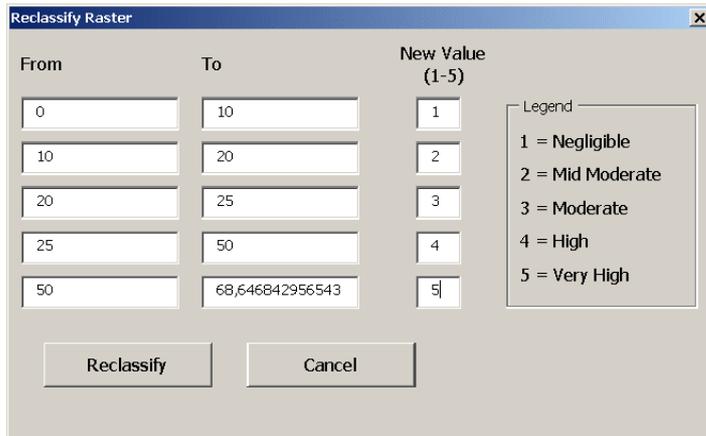
The Multicriteria application works with classified raster datasets. All rasters that will take part in the Analytic Hierarchy Process should be classified within the same class value range. The application offers a classification tool that can reclassify raster shapefiles to a proposed 5 classes. This step is optional as the user can alternatively use the “Raster Reclass” tool from the ArcGIS toolbox.

By pressing the “ReClassify Layers” button the application displays the available raster layers and the properties for each selected layer (Figure 4). The user chooses a layer from the list and presses the “ReClassify Layer” button.



**Figure 4: Reclassify Layers main screen**

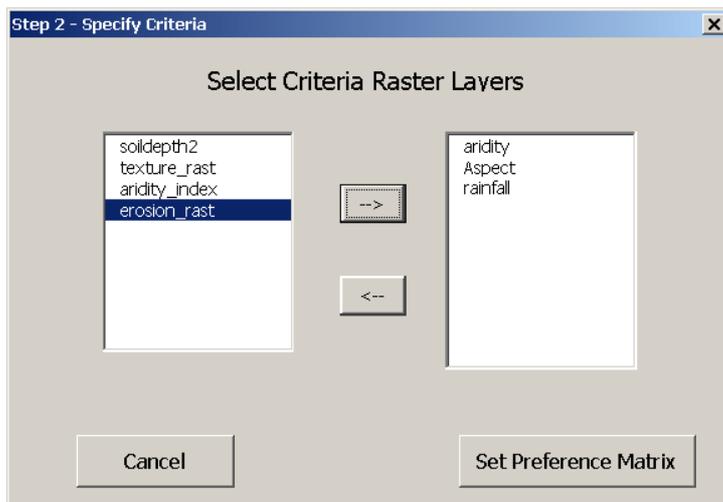
By pressing the “Reclassify Layer” button a new form appears and allows the user to set the lower and upper boundaries for each new class as well as the new value that will correspond to each class. A legend in the right part of the screen proposes a classification scheme for the new values. When the user completes the form (figure 5) a new raster is created and placed on ArcMap by pressing the “Reclassify” button.



**Figure 5: The Layer Reclassification screen**

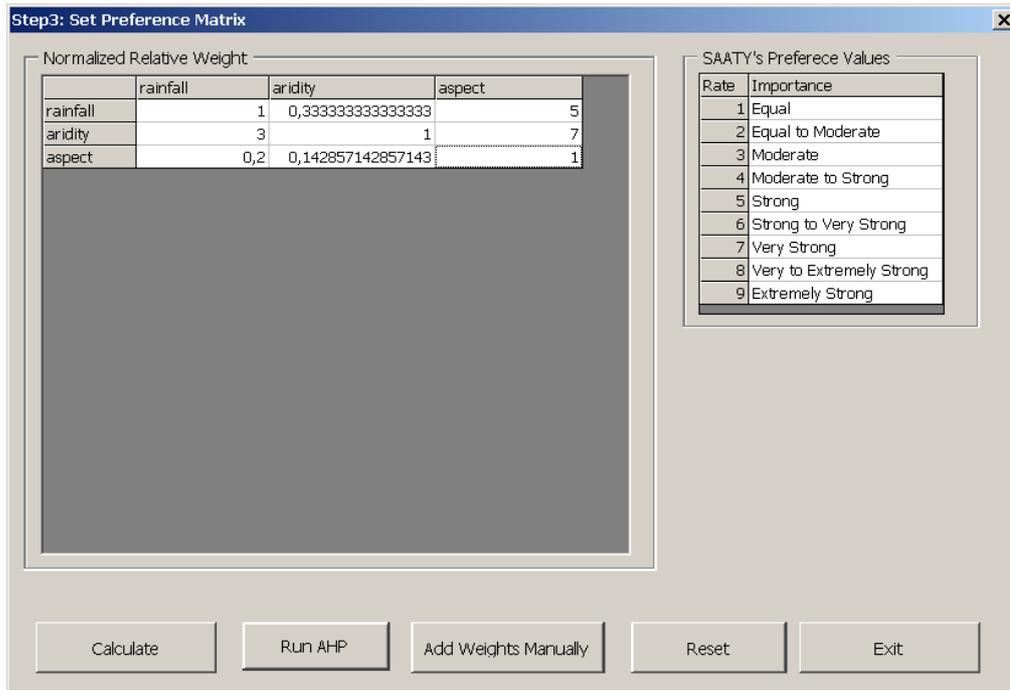
*Step 2: Select Criteria and Calculate Weights*

The second step of the application allows the user to complete the Analytic Hierarchy Process. The first screen displays a list of all the available raster layers and allows the user to choose the layers (criteria) that will take part in the process. The user selects the criteria by moving them to the list on the right (figure 6).



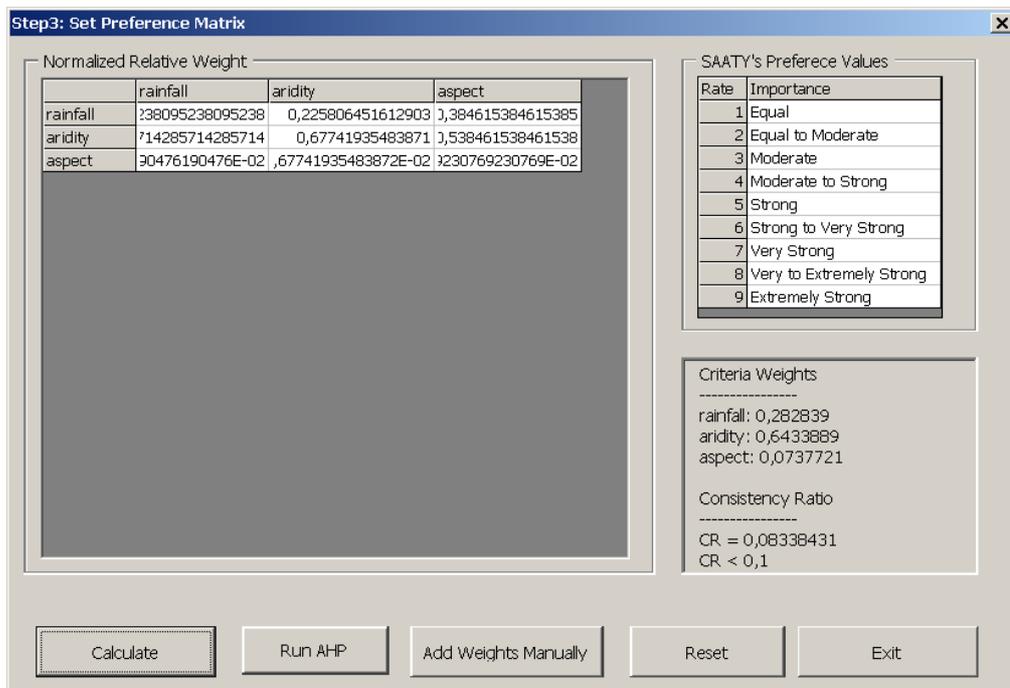
**Figure 6: Selecting the criteria from the list**

By pressing the “Set Preference Matrix” Button a matrix with the selected criteria appears. The user enters the preference values on the matrix by clicking on the corresponding matrix cell. When the user enters a value, the transpose position in the matrix is automatically filled with the inverse value (Figure 7). The values that the user enters should be values that correspond to the SAATY scale (e.g. 1 to 9).



**Figure 7: The preference Matrix**

When the user finishes entering values on the table, the criteria values can be calculated by pressing the “Calculate” button. The criteria weights appear on the right side of the screen (figure 8) along with the consistency ratio. By pressing the “Run AHP” button the application uses the criteria weights in order to calculate the weighted sum of the defined raster layers and create a new raster that will be added to the ArcMap current project. By pressing the “Reset” button the user can reset the table and begin a new calculation.

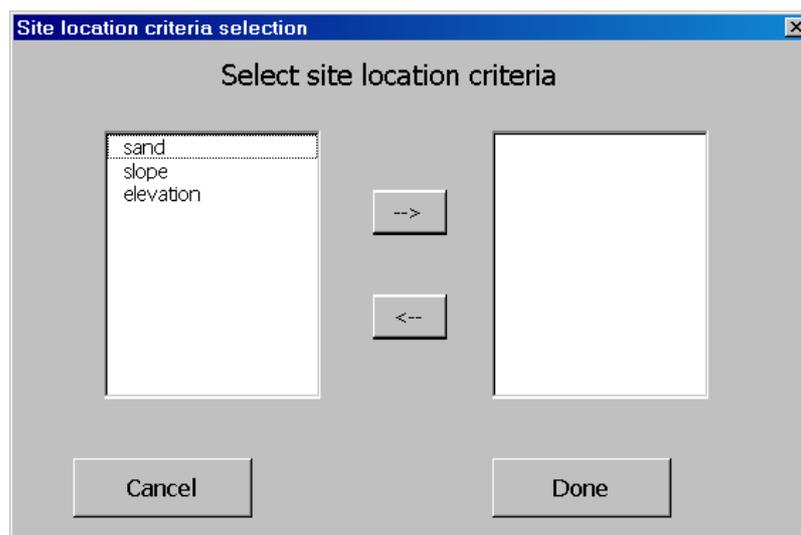


**Figure 8: The calculated weights**

## CHAPTER 5. Site Location Application

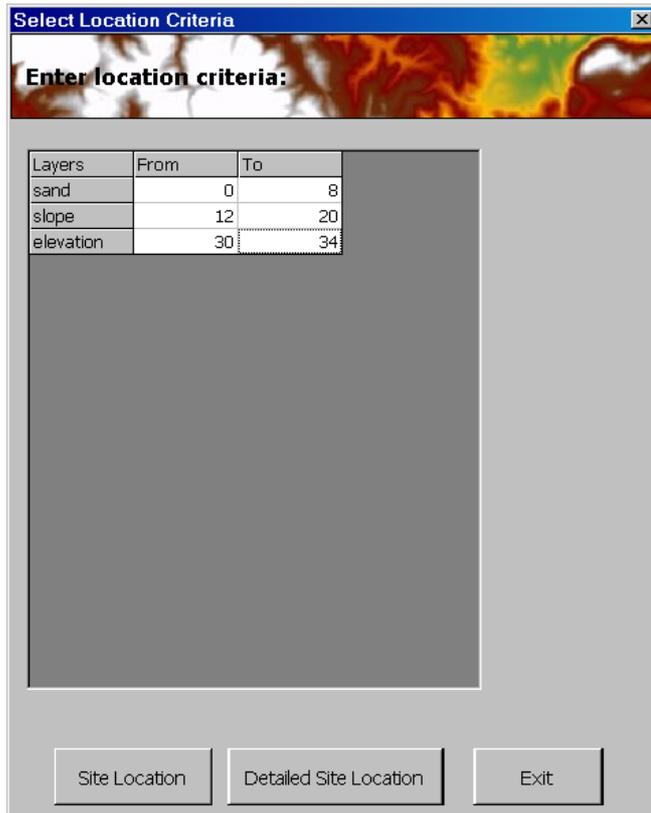
Site location is a common and important process in Geographical Information Systems. A common example is locating the optimum site location for a new facility. Such a process often requires a complex series of calculations as numerous criteria with different natures are normally taken into consideration. An example would be the selection of a location based on elevation, temperature, proximity to a certain area, humidity etc. GIS have a unique ability to integrate such diverse characteristics of geographical data providing thus an ideal tool for such applications. Aim of this application is to automate these steps and provide a user friendly interface guiding the user through each step of the site location process.

The site location application initializes by pressing the “Site Location” button on the main screen of the application (figure 2). The application allows the user to select a location based on a series of criteria. Each criterion is represented by a map (in raster format). The first screen that appears is the “Site location criteria selection” screen. Similarly to the AHP application, the user selects the layers (raster files) to be considered in the site location process by dragging them to the right box (figure 9).



**Figure 9: Site location criteria selection window**

When the user is finished selecting the layers that will take part in the process as location selection criteria, the criteria specification screen is initialized (figure 10). In the criteria specification screen the user enters the preferred range of values for each layer. In the figure 10 example the user tries to locate areas where sand has a value range between 0 and 8, slope 12 to 20 and elevation 30 to 34. After specifying the value ranges the user is presented with two options: 1) site location and 2) detailed site location.



**Figure 10: Site location criteria window**

### *Simple Site Location*

By pressing the “Site Location” button the areas on each raster map (criterion) that satisfy the criteria entered by the user are assigned a value of 1, while areas that don’t satisfy the criteria are assigned a value of 0. Figure 11 displays the individual criteria satisfaction maps according to the example of figure 10. Thus areas on the sand map that have a value between 0 and 8 are represented with 1 while the other areas are represent with 0. On the elevation map the areas that are represented with 1 are the areas with values between 30 and 34 while on the slope map areas with values between 12 and 20. These maps are not presented to the user. Instead they are added together on a new map. The new map is then automatically placed on the ArcMap table of contents (Figure 12).

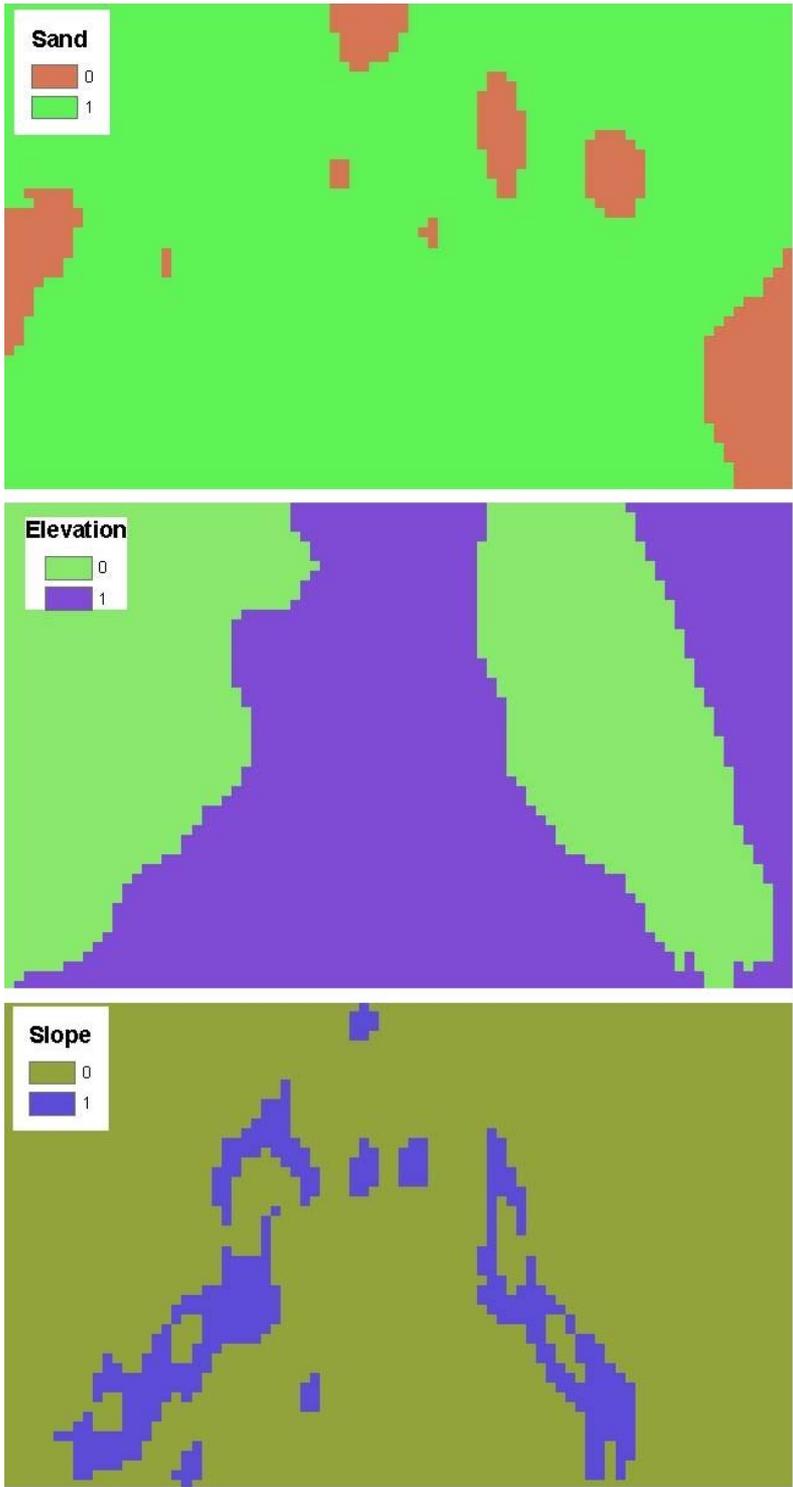
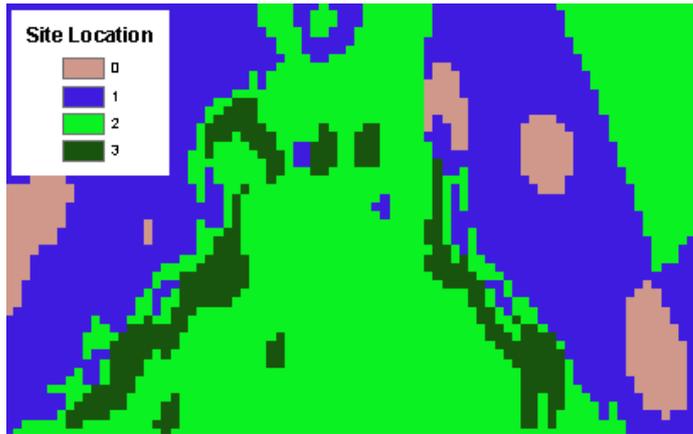


Figure 11: Individual site location maps



**Figure 12: Simple site location result map**

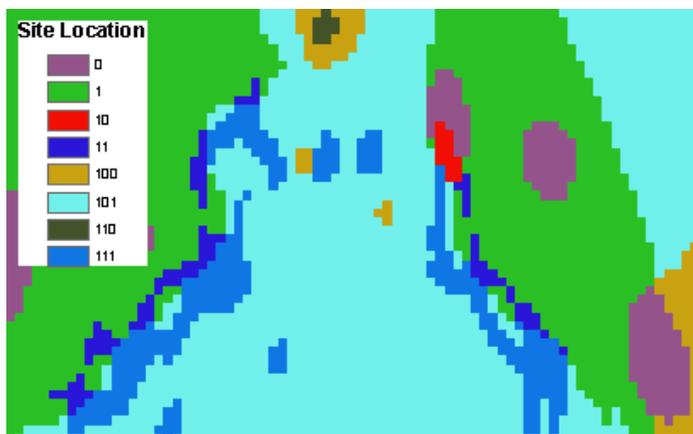
The new map is displaying the areas that satisfy the criteria the user has entered in the previous steps. Areas with value 0 represent areas that don not satisfy any of the criteria the user has entered. Areas with value 1 represent areas that satisfy only one of the criteria the user has specified, areas with value 2 represent areas that satisfy two of the criteria, while areas with value 3 satisfy all of the criteria. Table 4 displays a detailed description of the map legend.

| Value | Criteria Satisfied |
|-------|--------------------|
| 0     | None               |
| 1     | 1                  |
| 2     | 2                  |
| 3     | 3                  |

**Table 4: Simple site location legend description**

### *Detailed Site Location*

By pressing the “Detailed Site Location” button, similarly to the “site location” process, a new map is created and automatically placed on the ArcMap table of contents (Figure 13). The main different lays on the fact that the truth values (areas that satisfy the criteria entered by the user) for each criterion (raster map) are multiplied by 10. This process allows for a more detailed depiction of the results.



**Figure 13: Detailed site location result map**

In the case of the example depicted on figure 10, true values for sand get a value of 1, true values for slope get a value of 10 and true values for elevation get a value of 100. Table 5 provides a description of the map legend of the resulting map.

| <b>Value</b> | <b>Criteria Satisfied</b> | <b>Example</b>           |
|--------------|---------------------------|--------------------------|
| 0            | None                      | None                     |
| 1            | First                     | Sand                     |
| 10           | Second                    | Slope                    |
| 11           | First & Second            | Sand & slope             |
| 100          | Third                     | Elevation                |
| 101          | First & Third             | sand & elevation         |
| 110          | Second & Third            | slope & elevation        |
| 111          | All                       | sand & slope & elevation |

**Table 5: Detailed site location legend description**

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