A Web-based map application for the Risk Assessment of OOMW Disposal Areas

The geological, hydrological and land use features in the vicinity of all OOMW disposal sites of one of the three main areas of interest (prefecture of Rethymno, Crete, Greece) formed the spatial background information provided by the PROSODOL project to be used for evaluating the local risk imposed by the location of the particular facilities. In order to assess the appropriateness of the location of these facilities, two of the most used approaches to solve multicriteria problems, such as risk assessment analysis and suitability modelling, the Weighted Sum Model (WSM) and the Analytic Hierarchy Process (AHP) methods were applied in the wider area of the municipality of Nikiforos Fokas in Crete, covering actually the prefecture of Rethymno. GIS has been extensively used in applications related to environmental risk assessment. A web based map application tool was also implemented for evaluating the location suitability of the olive oil production facilities and further the waste disposal areas depending on several anthropogenic (residential areas, road network), environmental (slope, archaeological sites, lake and rivers area, Natura areas, landuse-Corine) and geological (hydrolithology, geology, faults) criteria-factors. Different scenarios were tested by weighting accordingly all these features giving evaluation suitability maps for the above risk assessment modelling techniques.

Customizing Data

Several studies have been focused on solving multicriteria problems that focus on risk assessment analysis and suitability modelling, such as the suitability assessment model for construction of Municipal Solid Waste (MSW) landfills by using multicriteria evaluation techniques such as the AHP method, enhanced with fuzzy factor standardization [1], or the risk assessment model for archaeological sites in Crete, by applying fuzzy logic and neural networks or by using multivariate statistical analysis by defining different weighting schemes [2, 3]. Another research based on the later one

is an earthquake vulnerability and seismic risk assessment model of urban areas that can become a significant tool for confronting crises resulting from future earthquake incidences [4].

In multi-criteria problems such as suitability or risk assessment modeling, one must define the problem, break the model into sub-models, and identify the appropriate input data. Since the input criteria data (which are actually in most cases raster 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 indicates the relative confidence that we have in the influence of a criterion compared to another [5]. The preference values are on a relative scale. That is, a value of 10 is twice as influential as a value of 5.

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

For example, in a simple risk assessment or suitability assessment model for OOMW disposal areas, you may have three input criteria: slope, residential area, and rivers. 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 the distance to residential areas, with the more favorable distance - in this case the one which is furthest from a residential area, being assigned the higher values. The same reclassification process is applied to the distance to rivers criterion. The locations further to the rivers are more favorable since the possibility of contamination from the olive oil mills wastes is less than locations near rivers. 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 the river layer.

On the other hand each of the criteria in risk assessment analysis may not be equal in importance. One may weigh the important criteria more than the rest. For instance, in the underlying suitability model, one might decide, that because geological factors like geological formations or faults may be less important than environmental factors associated with the slope

and distance to rivers criteria, to weight the environmental values as twice as important than the geological criteria. Depending on the technique used, like the Weighted Sum Model or the Analytic Hierarchy Process method, various weighting schemes are introduced and different suitability location areas are exposed in the final web map application.

Existing Tools

There are several tools and techniques in order to present the risk assessment or suitability maps via an understandable and easy to use interface. In our case the need was to present those maps (i.e. images actually) inside the website of **Prosodol**, so that the end a web based application implemented to be used and handled by the wider public. This fact pushed us to integrate the entire modeling process results into a Map API such as Google API, or Google Earth API, flash maps techniques (Flash Builder software), so that a user can view the risk assessment area images simultaneously above a topographic/satellite map provided by those APIs. After consideration of the Surface Interpolation Web based Map application functionality (which a user can view the chemical parameters diffusion in a subsurface over time), testing and using several of the above techniques, **Google Earth API** was decided as the most appropriate to use.

What about though of the risk assessment process and the data needed? We chose ArcGIS Desktop for creating the risk assessment maps using the **ArcGIS ModelBuilder**[1] Tool. ModelBuilder is an application in which one can create, edit, and manage models in general. In the next section we are going to cover the whole process for creating the risk assessment maps in order to provide them in the end as input, to the Google Earth API of the final web based application.

ArcGIS ModelBuilder

In order to create the risk assessment surfaces we have to study carefully the several steps, processes needed, from the beginning. The way to build a model is by building and connecting processes. A process is simply a tool plus its variables. A variable is either a data variable that references our data (layers, shape files of measurements information), or a value variable, which is anything else, such as numbers and text strings. Variables are connected to tool parameters. The ArcToolbox provides all the necessary

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[1] For more see "An overview of ModelBuilder"

tools that our model needs. The following figure shows how such a process works.

The **Input data** for the Model are stored as a shape or raster file and presented as a layer in the ArcMap application as in the following Figure 2. The particular layers in case that they are shape format they are also accompanied by a table of attributes which actually represents the different categories that exist in the particular variable.

Figure 2

The **Derived Data** are going to be the XML files that contain the risk assessment maps, in order to be given as input to the Google Earth web application. As previously said, the **Tool** of Figure 1, is a process, actually a group of several processes that have to take place in order to export out risk assessment maps to XML files. In the following, these tools are going to be described step by step.

Thirteen criteria were gathered and selected for the area of interest. Three of them compose the anthropocentric main factor, seven of them compose the environmental factor and the rest compose the geological main factor in the underlying model. So, there are three main groups of criteria, and thirteen extended sub-criteria to take into account (as mentioned each criterion must be reclassified into a common preference scale such as 1 to 10). Every one of them needs different customization as introduced in previous section and is going to be explained in detail how this is accomplished further below.

Anthropogenic Criteria

Residential area – Depending on the population for each residential place (village or city) in the area of interest, a buffer around the place was created in order to assign a suitability weight inside (a prohibitive value 0) and outside the buffer (max positive value of 10). Population data between the years of 1951-2001 created a tendency of increase factor a = 0.06 (by decades, see Table 1) for the following buffer distance equation:

$$distance = a \times population + 1000, \text{if } population > 0$$
$$distance = 3000, \text{if } population = 0$$

So, when no population data existed, a buffer distance with fixed radius of 3000 m was created, while a residential area, for example with a population of 1000 inhabitants, a buffer distance with a radius of 1060 m was created.

Residential Area Name	POP 1951	POP 1961	POP 1971	POP 1981	POP 1991	POP 2001
Platanos	547	532	530	520	503	504
Agia	272	0	215	222	216	308
Dafnedes	349	325	217	201	193	172
Damavolos	151	183	146	160	153	158
Agios Mamas	296	236	235	230	214	275
Kalyvos	442	399	456	399	393	408
Agios Ioannis	233	211	118	91	71	68
Garazo	887	931	752	676	629	712
Apladiana	219	209	219	253	295	337
Livadia	807	772	946	1215	1534	1536
Zoniana	926	958	1056	1071	1285	1578
Veni	265	295	303	389	331	350
Axos	699	689	676	701	710	727
Kryoneri	130	133	93	69	88	53
Theodora	212	167	150	123	129	56
Aloides	428	473	362	340	302	314
Sisses	297	465	469	486	528	525
Chonos	305	353	247	184	146	203
Aimonas	402	401	360	269	296	355
Anogia	2685	2548	2820	2509	2290	2507

Table 1. 20 / 200 illustrative residential areas with population data for 6 decades

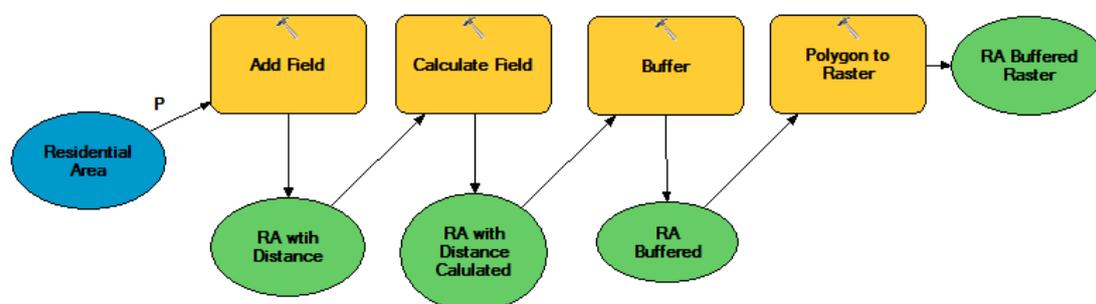The sub-model for this criterion is showed in Figure 3 below.

Figure 3

Road network – Two criteria take place in this sub-model, the main and secondary roads of the area of interest, in order to create a buffer around

the road network where a suitability weight according to the distance to the road line is created as following: For the Main road network a suitability value of 0 is assigned if the distance is 200m far from the road, a value of 5 if the distance is between 200-500m far from the road and a value of 10 if the distance is more than 500m from the road. The corresponding suitability values for the secondary road network are for 100, 300 and more than 300m far from the road line. The sub-model for this criterion is showed in Figure 4 below.
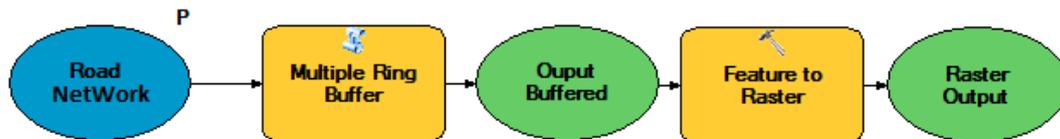

Figure 4

Environmental Criteria

Slope – Depending on slope degree a reclassification take place where a suitability weight value of 10 is assigned when the slope is until 7 degrees, a value of 8 if the slope is between 7-10 degrees, a value of 6 if it is between 10-15 degrees, a value of 3 if it is between 15-20 degrees and a weight value of 0 (prohibited) if slope is more than 20 degrees. The sub-model for this criterion is showed in Figure 5 below.
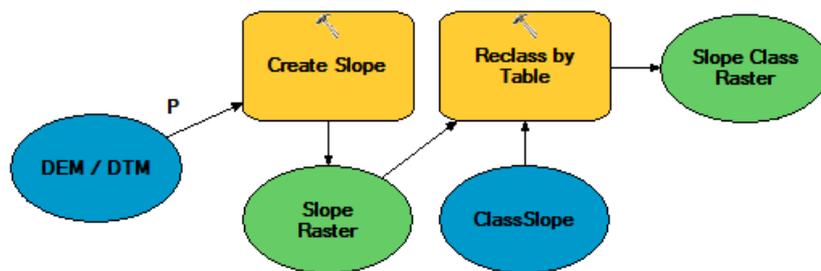

Figure 5

Archaeological sites area – Buffers of 500m, 1000m and more than 1000m where created for each archaeological site, in order to assign a suitability value of 0, 5 and 10 accordingly. The sub-model for this criterion is pretty the same as the Road Network sub-model.

Lakes, Rivers, Natura 2000 and Coastline area – For these four criteria, same as before, buffers of 500m, 1000m and more than 1000m where created for each corresponding feature (lake, river, etc.), in order to assign a suitability value of 0, 5 and 10 accordingly. The sub-model for this criterion is similar to the previous sub-model.

Land Use and Corine area – For this criterion depending on the feature description a reclassification take place where a suitability value of 10 is assigned for features like natural grasslands, pastures, moors and heathland or bare rocks, a value of 8 is assigned for features like olive groves, sparsely vegetated areas, or transitional woodland-shrub areas, a value of 5 for features like sclerophyllous vegetation, while a value of 2 is assigned for features like vineyards, non-irrigated arable land or complex cultivation patterns areas, and a prohibited value of 0 to the rest of them. The sub-model for this criterion is showed in Figure 6 below.
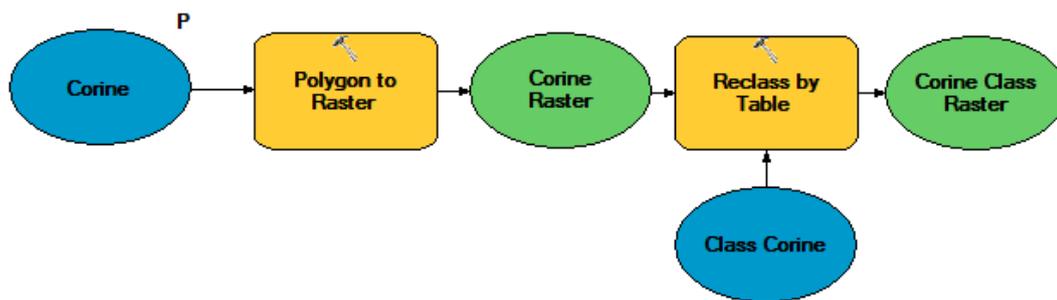

Figure 6

Geological Criteria

Hydrolithology – Depending on the hydro-lithological formations in the area of interest a reclassification takes place once again, in order to assign a suitability value of 7 (high enough) for features like practically impermeable formations of low to very low permeability or selective circulation formations of low to very low permeability. A suitability value of 7 was assigned for karstic formations of moderate to low permeability and granular non-alluvial deposits of low to very low permeability. A suitability value of 6 was assigned for plaster formations. A suitability weight of 3 was assigned for karstic formations of high to moderate permeability, while a suitability value of 2 for granular mainly alluvial deposits of varying permeability features. The sub-model for this criterion is showed Figure 7 below.
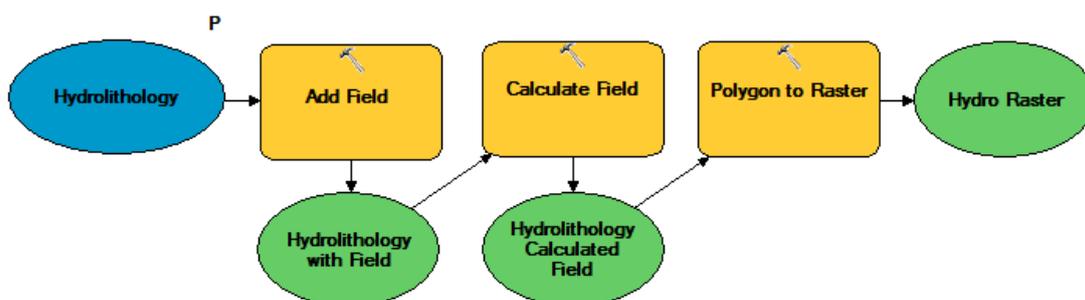

Figure 7

Geology – Depending on the geology of the area of interest a reclassification takes place once more. Suitability values are assigned with values, 10 for Marls, Ambelouzos formations and recent littoral deposits with sand, 9 for limestone formations, and a value of 8 for Gneiss and Flysch formations. The sub-model for this criterion is as same as the previous sub-model.

Faults – Buffers of 200m, 500m, 1000m and more than 1000m were created around each fault (taking into account the active faults), in order to assign a suitability value of 0, 2, 5 and 10 accordingly. The sub-model for this criterion is similar to the Road Network sub-model.

The final model that incorporates all the above sub-models, and takes into account all the thirteen sub-criteria is shown in Figure 8 below.
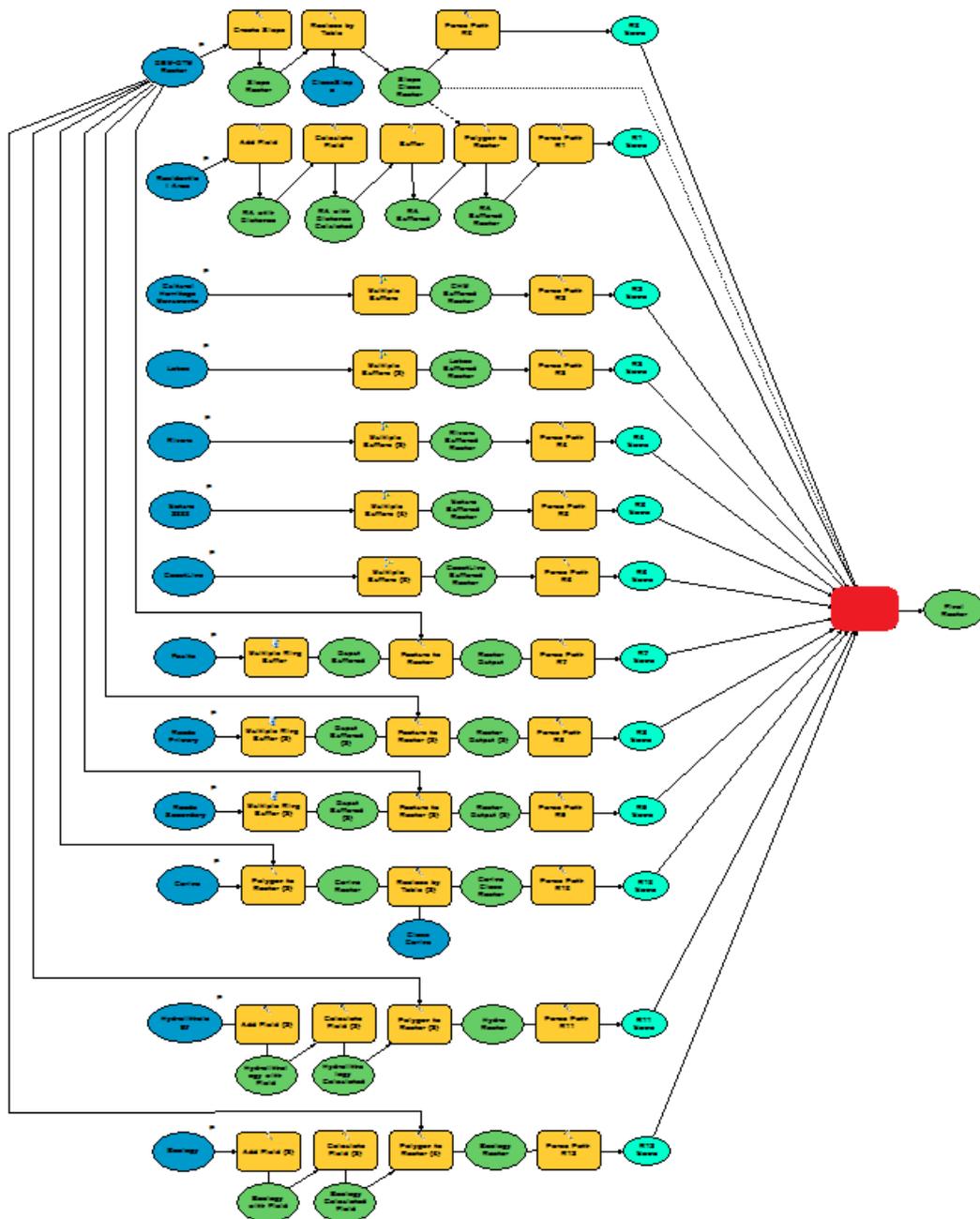
Figure 8

The final process that need to be done for estimating the risk of OOMW disposal areas in respect with the three main criteria, anthropogenic, environmental and geological (or thirteen sub-criteria), takes place in the tool (coded in Python), the red square shown at the figure above, where two different approaches for the multi-criteria analysis may take place, the Weighted Sum Model (WSM) or the Analytic Hierarchy Process (AHP) method. A user may define the desire percentage of importance for each factor or sub-criteria, while the above approaches give the user the ability to decide the analysis process. According to the method the user chooses, different

risk assessment result maps may be emerged. In the next section the description and usage of the two main approaches is explained in detail.

Multi-Criteria Problem Solving Approaches and Scenarios

The *Weighted Sum Model (WSM)* is a very well-known and simplest multi-criteria decision analysis (MCDA) / multi-criteria decision making method for evaluating a number of alternatives in terms of a number of decision criteria. As mentioned in the Customizing data section, it is applicable only when all the data are expressed in exactly the same unit, which is why reclassification process took for the variables involved [6].

In general, let us assume that a given MCDA problem is defined on *m* alternatives and *n* decision criteria. In the underlying case of this Risk Assessment Model, there are as many alternatives as the raster cells of the area of interest. So a given MCDA problem is defined on *m* alternatives and *n* decision criteria. Furthermore, all the criteria are benefit criteria, that is, the higher the values are, the better it is. W_j denotes the relative weight of importance of the criterion *j (j=1 to n)* and a_{ij} is the performance value of the only alternative A_i when it is evaluated in terms of criterion *j*. Then, the total (i.e., when all the criteria are considered simultaneously) importance of the alternative A_i, denoted as $A^{\text{WSM-score}}$, is defined as follows [7]:

$$A_i^{WSM-score} = \sum_{j=1}^{n} w_j a_{ij} \text{ , for } i = 1,2,3,...,m$$

The *Analytic Hierarchy Process (AHP)* is a structured technique for organizing and analyzing complex decisions. The Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales. It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgements that represents how much more one element dominates another with respect to a given attribute. The judgements may be inconsistent, and how to measure inconsistency and improve the judgements, when possible to obtain better consistency, is a concern of the AHP [8].

To make a decision in an organized way to generate priorities someone need to decompose the decision into the following steps.

1. Define the problem and determine the kind of knowledge sought.
2. Structure the decision hierarchy from the top with the goal of the decision, through the intermediate levels (criteria on which

subsequent elements depend) to the lowest level (which usually is a set of the alternatives).

3. Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.

4. Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.

There is no need to get deeper in explaining this method. It is also a very well-known decision making method. The next step is to define the scenarios needed for each of the above techniques.

Scenarios

Seven scenarios were created both for the WSM and AHP method in order to determine the risk assessment for the OOMW disposal areas in terms of the various components of the anthropogenic, environmental, and geological criteria and moreover to fill the bulk of the diversity of the importance of these various criteria.

Scenario 1 – For the WSM this scenario is based only on the anthropogenic aspect of the risk assessment analysis. The importance is given only on anthropogenic sub-criteria (100%) while the rest are not taken into account (0%). As for the AHP the anthropogenic criteria are more important (biggest priority) than the environmental and geological criteria, while the environmental criteria are also more important than the geological ones.

Scenario 2 – For the WSM only on the environmental aspect of the risk assessment analysis is taken into account. The importance is given only on environmental sub-criteria (100%) while the rest are not taken into account (0%). As for the AHP the anthropogenic criteria are more important (biggest priority) than the environmental and geological criteria, while the geological criteria are more important than the environmental ones.

Scenario 3 – For the WSM this scenario is based only on the geological aspect of the risk assessment analysis. The importance is given only on geological sub-criteria (100%) while the rest are not taken into account (0%). As for the AHP the environmental criteria are more important (biggest priority) than the anthropogenic and geological criteria, while the anthropogenic criteria are more important than the geological ones.

Scenario 4 – For the WSM the importance is given in all factors and sub-criteria (100%) which actually are normalized to have an equal weight of importance. As for the AHP the environmental criteria are more important (biggest priority) than the anthropogenic and geological criteria, while the anthropogenic criteria are less important than the geological ones this time.

Scenario 5 – For the WSM this scenario has given an advance in importance on the anthropogenic aspect of the risk assessment analysis (50%) while the rest are sharing the rest percentage (25% and 25%). As for the AHP the geological criteria are more important (biggest priority) than the anthropogenic and geological criteria, while the anthropogenic criteria are more important than the environmental ones.

Scenario 6 – For the WSM this scenario has given an advance in importance on the environmental aspect of the risk assessment analysis (50%) while the rest are sharing the rest percentage (25%/25%). As for the AHP the geological criteria are more important (biggest priority) than the anthropogenic and geological criteria, while the anthropogenic criteria are less important than the environmental ones this time.

Scenario 7 – For the WSM the importance is given in all three main factors (100%) which actually are normalized to have an equal weight of importance, but this time giving an importance in residential area criterion a 70%, and a 30% for the road network criteria. In the environmental aspect of the criteria, full importance is given to slope, aquifers and coastline, while medium importance on the rest environmental sub-criteria. For the geological aspect of the analysis only the hydrolithology sub-criterion was given an importance of 80% having the rest sub-criteria sharing the remainder percentage. As for the AHP the environmental criteria are more important (biggest priority) than the geological, the geological criteria are more important than the anthropogenic, while the anthropogenic criteria are more important than the environmental ones, giving in such a way a balanced importance to all main factors.

It has to be noted that for all the AHP scenarios the sub-criteria importance was assigned according to the AHP weighting scheme of the last scenario, which was considered the most suitable for realistic assumptions. Scenario result maps are illustrated for each scenario in Table 2 below. These maps illustrates regions (alternative locations derived from the two multi-criteria modeling techniques) of suitability values according to the legend showed in Figure 9 below. Evaluation results are explained in detail in the next section.
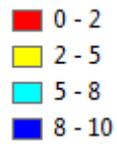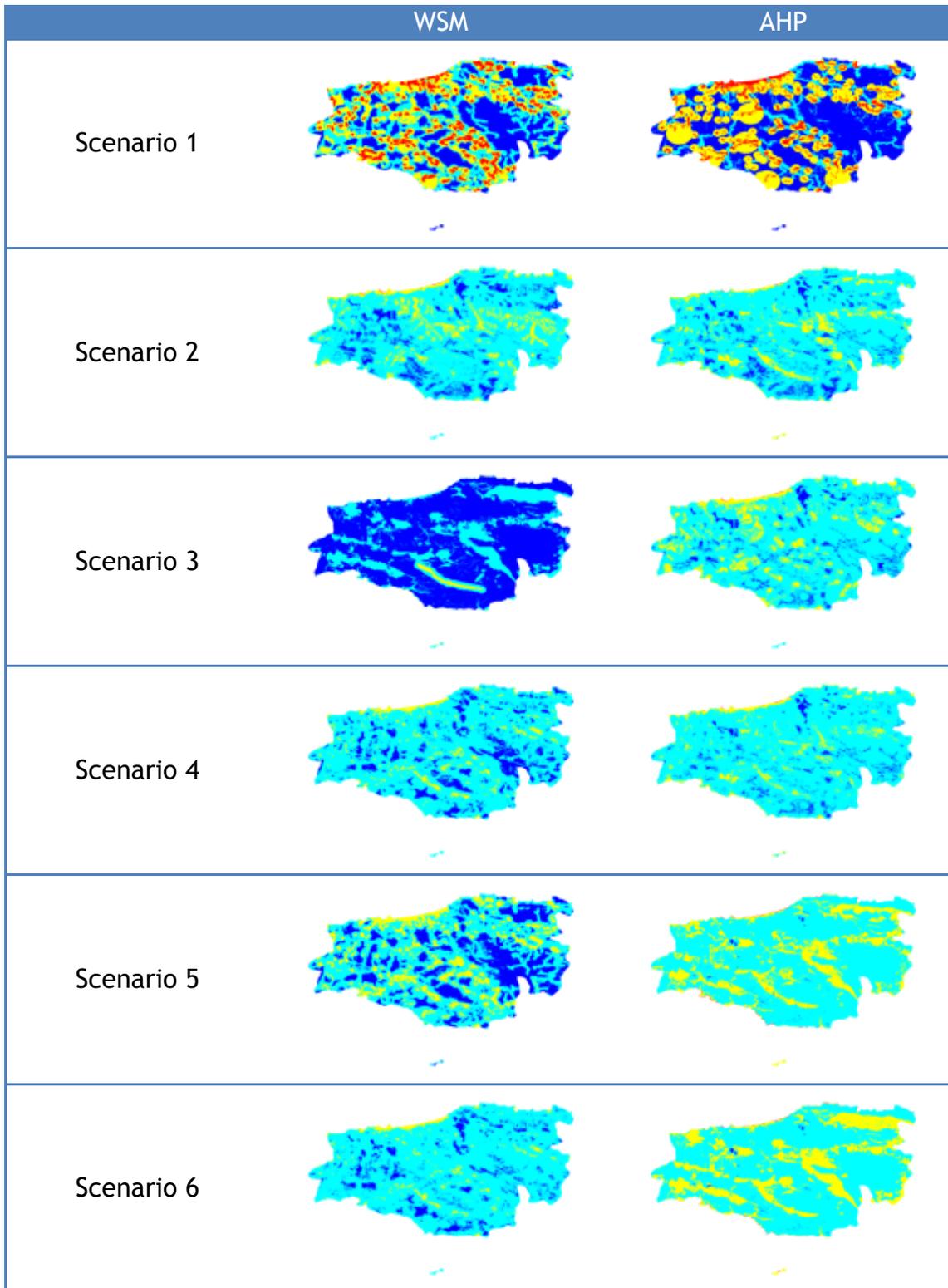
Figure 9. Suitability legend of OOMW disposal Areas for the Risk Assessment Model
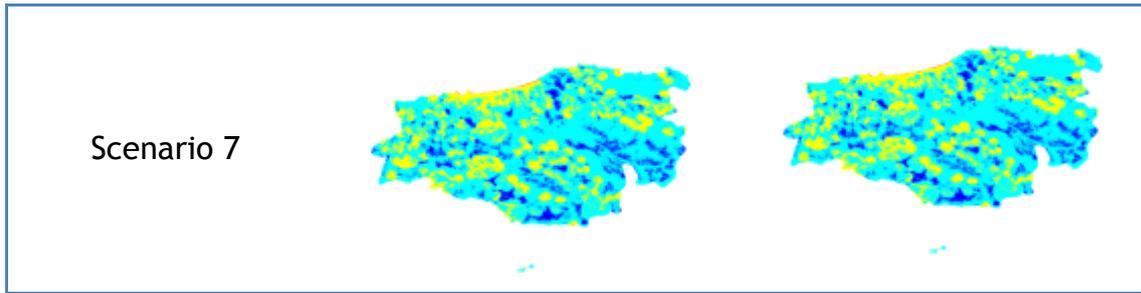
	WSM	AHP
Scenario 1		
Scenario 2		
Scenario 3		
Scenario 4		
Scenario 5		
Scenario 6		

Scenario 7		

Table 2

Evaluation

In Table 3 below the suitability of the known OOMW disposal areas locations (locations with suitability value < 5), according to the seven mentioned scenarios for each of the two decision making approaches, is shown.

	Scenario1	Scenario2	Scenario3	Scenario4	Scenario5	Scenario6	Scenario7
WSM	21%	100%	100%	92%	71%	98%	73%
AHP	22%	97%	95%	97%	85%	87%	73%

Table 3

In scenarios 2, 3, and 4, where the environmental criteria and further the geological criteria were taken into account rather than the anthropogenic factor it seems that the existing OOMW disposal area locations are very well suited. When the anthropogenic criteria and further the environmental criteria is given more importance there is a decline in suitability going from 98%, to 71% (scenario 5 and 6) and falling to 21% if only the anthropogenic parameters are taken into account (scenario 1). It becomes obvious that the anthropogenic factor was not taken into account when the existing OOMW disposal area locations where established.

Moreover, the more realistic scenario (scenario 7), the suitability of the existing OOMW disposal area locations falls to 73%. Need to say that these statistics are only for the scenario proposed, while different results and statistics may emerge from other scenarios.

Finally, as mentioned in the previous section, fourteen scenarios in total (seven for each technique) made a set of fourteen KML files which were constructed by the final Model. In the next section we are going to describe the Google Earth API application (web based) implementation and usage, for hosting and presenting the specific KML derived files.

Google Earth API Application

The Google Earth API it is a JavaScript API which let us embed Google Earth, a 3D digital globe, into Prosodol Web site. Using the API we can load KML files, allowing us to build a 3D map application. The implementation of the map application is quite straightforward, and it was handled with JavaScript

over PHP pages of the Prosodol web site. By selecting the user defined method (WSM or AHP), the modeling scenario, and submitting the information to the application, the corresponding risk assessment map is loaded.

In Figure 10 below, the interface of the map application is presented. Let's describe the several features that are shown, and which allow the user to find the information needed in order to view a specific risk assessment result.
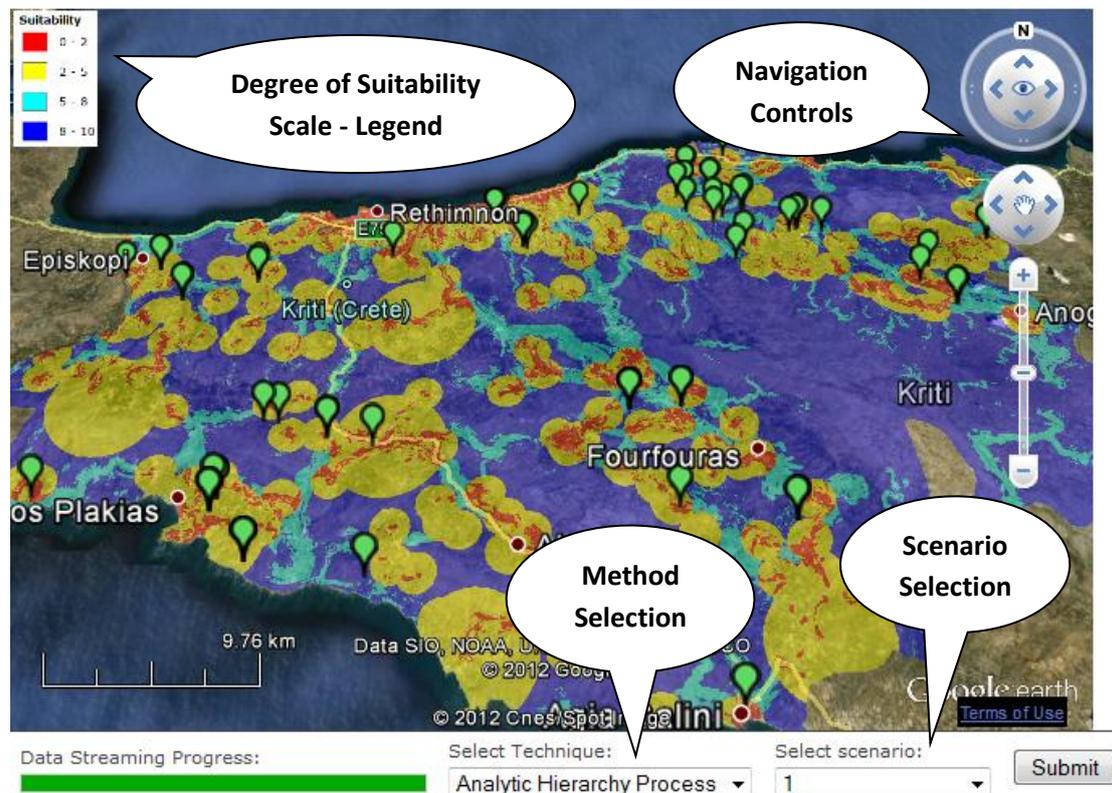

Figure 10

Method Selection – The user selects the needed solving technique in order to see the corresponding risk assessment map.

Scenario Selection – By selecting the method and the introducing scenario, a user can submit the information provided, and the map application starts to stream the data needed for the map application to present the corresponding risk assessment map.

Navigation Controls – The user may navigate inside the map through the navigation controls, in any direction, angle, pan and zoom, giving him the freedom of any view perspective.

Degree of Suitability Scale – Legend – When the risk assessment map is loaded the corresponding scale of the suitability degree of the selected method and scenario is shown (0 – prohibitive and 10 – most suitable).

The 3D map application was designed in such a way, that the end user can easily and effectively use, and retrieve the risk assessment information needed.

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