GEO-INFORMATIC WEB-BASED APPLICATIONS FOR OLIVE OIL MILLS' WASTES DISPOSAL AREAS MANAGEMENT

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Abstract: LIFE+ project "Strategies to improve and protect soil quality from the disposal of olive oil mills' wastes (OOMW) in the Mediterranean - PROSODOL", aims towards the development and application of technologies for the protection, improvement and remediation of soils which are polluted from the disposal of OOMW. In this effort, two major geospatial web-based application tools were developed and implemented aiming to the effective monitoring of soil quality and wastes disposal areas management.

Soil parameters were mapped with respect to the depth, date and temporal variations of their spatial distribution (spatial surfaces). Furthermore, the diffusion of these parameters in the subsurface was also studied. Interpolated surfaces based on the Inverse Distance Weighted method (IDW) were created and integrated within a geospatial web based map application tool. On the other hand, anthropogenic, environmental and geological features in the vicinity of all OOMW disposal sites of one of the main areas of interest (former municipality of Nikiforos Fokas and in extent the prefecture of Rethymno, Greece) were 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 a range of multicriteria problem solving techniques, such as the Weighted Sum Model (WSM) and the Analytic Hierarchy Process (AHP) methods, were applied in prefecture of Rethymno area for the risk assessment modeling of the OOMW disposal areas. A second web based map application tool was implemented for evaluating the location suitability of the OOMW disposal areas and further the olive oil production facilities depending on several anthropogenic, environmental and geological criteria. Different scenarios were tested by weighting accordingly all these features giving evaluation suitability maps for each of the underlying risk assessment modeling techniques.

1. Introduction

The project was based on the collection of more than 1000 soil samples throughout the course of the project which were chemically analyzed in order to indicate the most significant soil parameters that could most suitable describe soil degradation due to OOMW disposal. Based on these results, the soil parameters were mapped with respect to the depth, date and temporal variations of their spatial distribution (spatial surfaces). Furthermore, the diffusion of these parameters in the subsurface was also studied. Interpolated surfaces were created and integrated within a geospatial web based map application tool. Interpolated surface maps can be viewed simultaneously above topographic and satellite maps, providing a possible overview of the diffusion of the parameters in the subsurface and thus the risk-level in the vicinity of the waste disposal areas to the users.

The soil parameters and organic compounds content as well as other geological, hydrological and land use features in the vicinity of all OOMW disposal sites of the three main areas of interest (former municipality of Nikiforos Fokas (Greece), Albenga region and Loano comune-municipality

(Italy)) form 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. A range of multicriteria problem solving techniques, such as the Weighted Sum Model (WSM) and the Analytic Hierarchy Process (AHP) methods, were applied in the prefecture of Rethymno in Crete for the risk assessment modeling of the OOMW 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) factors, a web based map application tool was implemented for the risk assessment modeling of the OOMW disposal areas and further the suitability of location of the olive oil production facilities. Seven major scenarios were tested for each multicriteria problem solving technique (WSM and AHP) by weighting accordingly all these features giving evaluation suitability maps. Finally, evaluation results are presented and discussed.

The map applications were designed and implemented with the help of the ESRI ArcGIS Model Builder tool (and Python), Google Earth and Map API's (and Java/JavaScript) and are available to use and interact from the web site of the project (www.prosodol.gr).

2. Surface Analysis & Interpolation Methods

Soil samples were chemically analyzed to indicate the most significant chemical parameters that could most suitable describe soil degradation due to OOMW disposal. In order to address the monitoring of the dispersion of such chemical parameters in a wider area, which were measured from various soil cores (with different depth penetration), surface images that represent the possible diffusion of them and the degree of risk in the vicinity of the waste disposal areas needed to be created. The chemical parameters were mapped with respect to the depth and date of acquisition of the samples, allowing the study of the temporal variations of their spatial distribution and the diffusion of them in the subsurface.

The Inverse Distance Weighted (IDW) interpolation method [1] produced the most satisfying results among the interpolation algorithms that were tested. IDW calculates cell values by averaging the values of sampling points in the vicinity of each cell based on distance,

$$Z_j = \sum_{i=1}^{n} \frac{z_i}{{d_{ij}}^2}$$

where Z_j is the interpolated value at node j, d_{ij} is the distance between the grid node j and its neighboring node i and z_i are the neighboring points. In order to have valid interpolated surfaces, the creation of surfaces was allowed only when more than four known values were available for interpolation. In cases where the measured values were less than four it was not possible to interpolate surfaces and therefore no results were produced.

Surfaces were implemented in a web GIS based application at the PROSODOL web portal. In order to achieve such integration, Map APIs such as Google API or Google Earth API and flash maps techniques (Flash Builder software) were employed, so that a user can view the interpolated surface area images simultaneously above a topographic/satellite map provided by those APIs. After consideration of the time based functionality, which a user can view the chemical parameters diffusion in a subsurface over time, Google Earth API was chosen as the most appropriate to use, since it handles integration of time tagged images via XML, a language designed to transport and store information data. ESRI ArcGIS Desktop software was chosen to create the interpolated surface maps using the ArcGIS ModelBuilder [2].

The way to design 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. Variables are connected to tool parameters. The ArcToolbox of ArcGIS Desktop software provides all the necessary tools that our model needs. Several processes (tools) need to be performed in order to achieve the resulted interpolation surfaces. The first step for the whole interpolation process is to define the date and depth of a measurement for the interpolated output map file. In the following step the interpolation process takes place. At this point it has to be noted that the interpolation of a surface, in other words, the diffusion of a chemical parameter in an area, has no meaning above a radius or a distance from the measurement points. For this reason a "mask" polygon is necessary to limit the interpolated area boundaries. At this phase, the entire interpolated surface, with the corresponding mask areas, depending on the measurements (more than four) according to depth, date and chemical parameter selection is materialized. Finally, a symbology layer file is needed to provide the tag of the range of values, which denotes the degree of risk with a color scheme. For example the chemical parameter “Total phenols” has a range of value 0.1-700 mg/kg, while a value between 40-150 mg/kg is considered a medium risk range zone [3] and above 150 mg/kg a high risk zone [4]. Knowing the minimum and maximum variable limits, the red colors designate a high risk area of a certain chemical parameter, while the blue colors designate the low risk areas.

In every process step, ModelBuilder constructs the derived layers temporarily and only the final layer (the interpolated, masked, symbology accompanied layer) is stored, in order to provide it as an input to the Layer to KML process, which constructs our final KML file, namely an XML format file suitable for the Google Earth API application. Using the API, KML files can be loaded, allowing us to build a 3D map application. The particular API allows the time plug-in, where time information contained to the derived KML files (as a feature), can be introduced to the plug-in and can be attached as a map view.

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 measurement, measurement’s depth, and submitting the information to the application, the corresponding interpolated surface map is loaded. In Fig 1, the interface of the map application is presented.

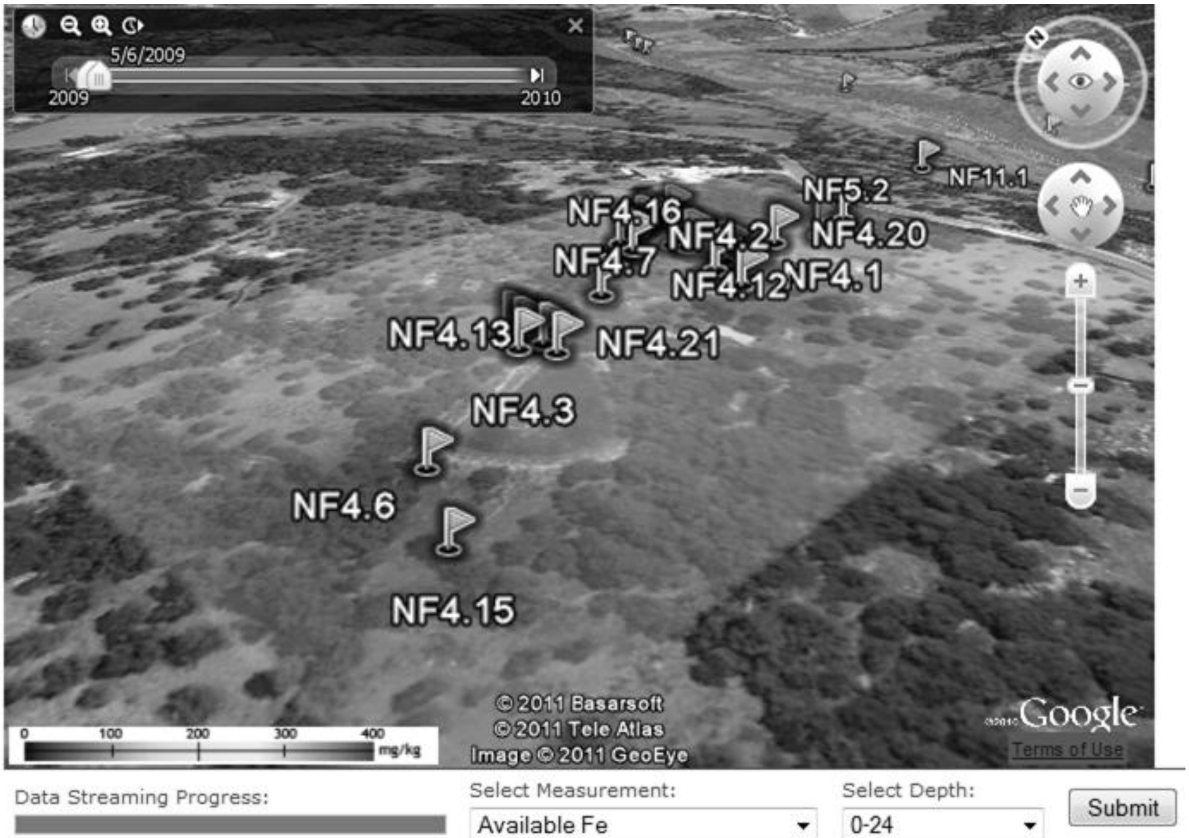


Fig 1. The User Interface of the 3D Google Map application indicating the surface distribution of the chemical parameters in terms of the date of sample acquisition and depth.

3. Risk Assessment of OOMW disposal areas

Several studies have been focused on solving multicriteria problems that focus on risk assessment analysis and suitability modeling, 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 [5], or the risk assessment model for archaeological sites in Crete, by applying fuzzy logic and neural networks [6] or by using multivariate statistical analysis by defining different weighting schemes [7]. 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 [8]. For the underlying risk assessment model ArcGIS Desktop was used once again for creating the risk assessment maps using the ArcGIS ModelBuilder Tool.

3.1 Data analysis and tools

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 [9]. The preference values are on a relative scale. That is, a value of 10 is twice as influential as a value of 5, and the preference or suitability value should also have the same meaning between other criteria.

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.

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 (each criterion must be reclassified into a common preference scale such as 1 to 10).

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) for the following buffer distance equation:

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

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

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: 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 ≥ 500m from the road. The corresponding suitability values for the secondary road network are for 100, 300 and ≥ 300m far from the road.

Environmental Criteria

Slope – Depending on slope degree a reclassification take place where a suitability weight value of 10 is assigned when the slope is up to 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.

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.

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.

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.

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.

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.

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 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) is process coded in Python, where two different approaches for the multi-criteria analysis may take place, the WSM or the 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 emerge.

3.2 Multi-Criteria Problem Solving Approaches

Weighted Sum Model (WSM)

The 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 it was mentioned, it is applicable only when all the data are expressed in exactly the same unit, which is why reclassification process took place for the variables involved [10].

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 $(j=1 \text{ to } n)$ 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 $A^{WSM\text{-}score}$, is defined as follows [11]:

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

Analytic Hierarchy Process (AHP)

AHP is a structured technique for organizing and analyzing complex decisions. The 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, is a concern of the AHP [12].

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.

The next step is to define the scenarios needed for each of the above techniques.

3.3 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.

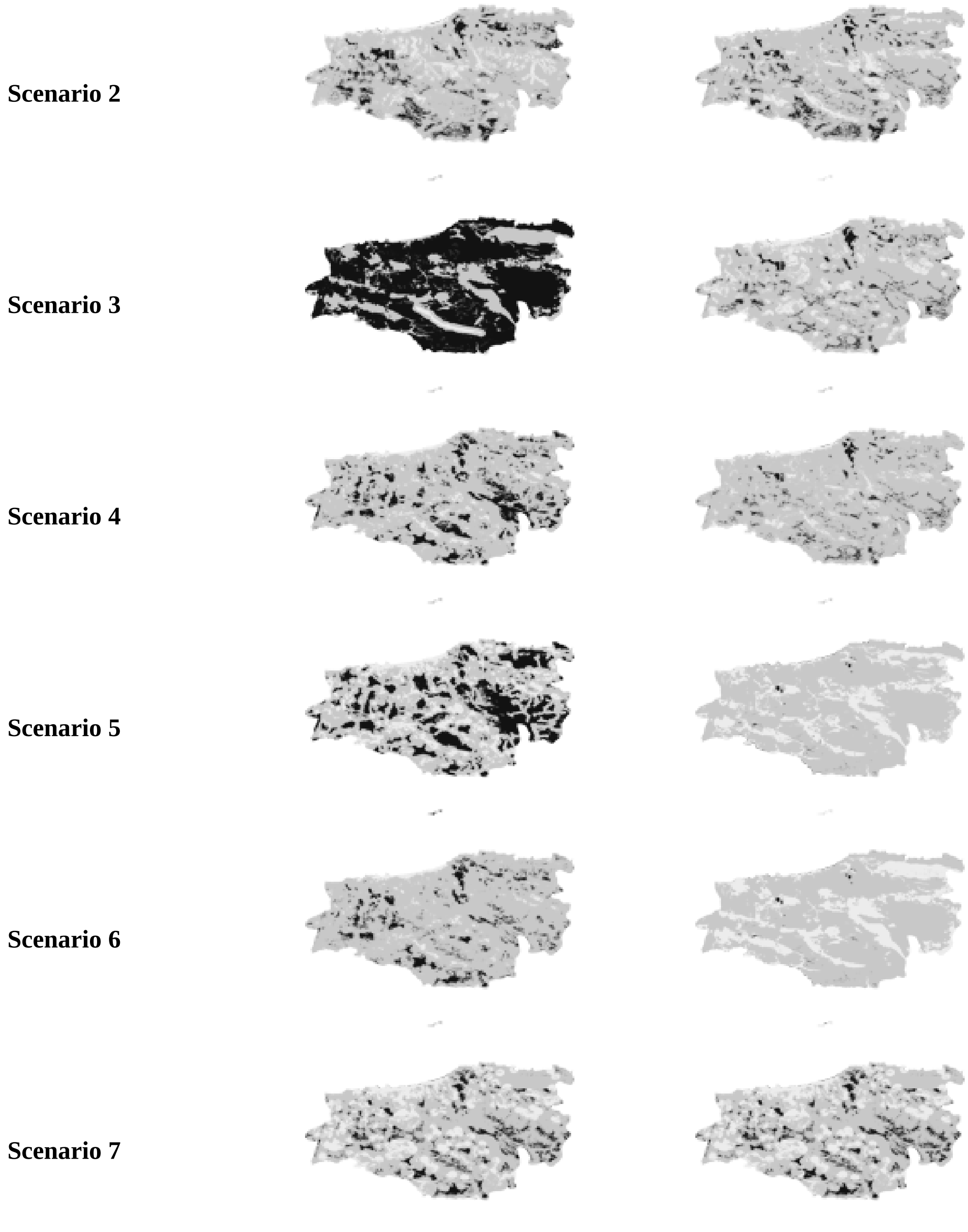
Scenario 6 – For the WSM this scenario has given an advance in importance on the environmental aspect of the risk assessment analysis (50%) while the rest are sharing the rest percentage (25%/25%). As for the AHP the geological criteria are more important (biggest priority) than the anthropogenic and 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 1 below.

Table 1. Risk Assessment Model scenario result maps

	WSM	AHP
Scenario 1		



These maps illustrates regions (alternative locations derived from the two multi-criteria modeling techniques) of suitability values according to the legend (Table 1). Evaluation results are explained in detail in the next section.

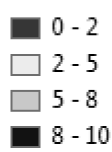


Fig 2. Suitability legend of OOMW disposal Areas for the Risk Assessment Model

3.4 Web-based GIS map application

Fourteen scenarios in total (seven for each technique) made a set of fourteen KML files which were constructed by the final Model. The Google Earth API was used for hosting and presenting the specific KML derived 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 (Table 2).

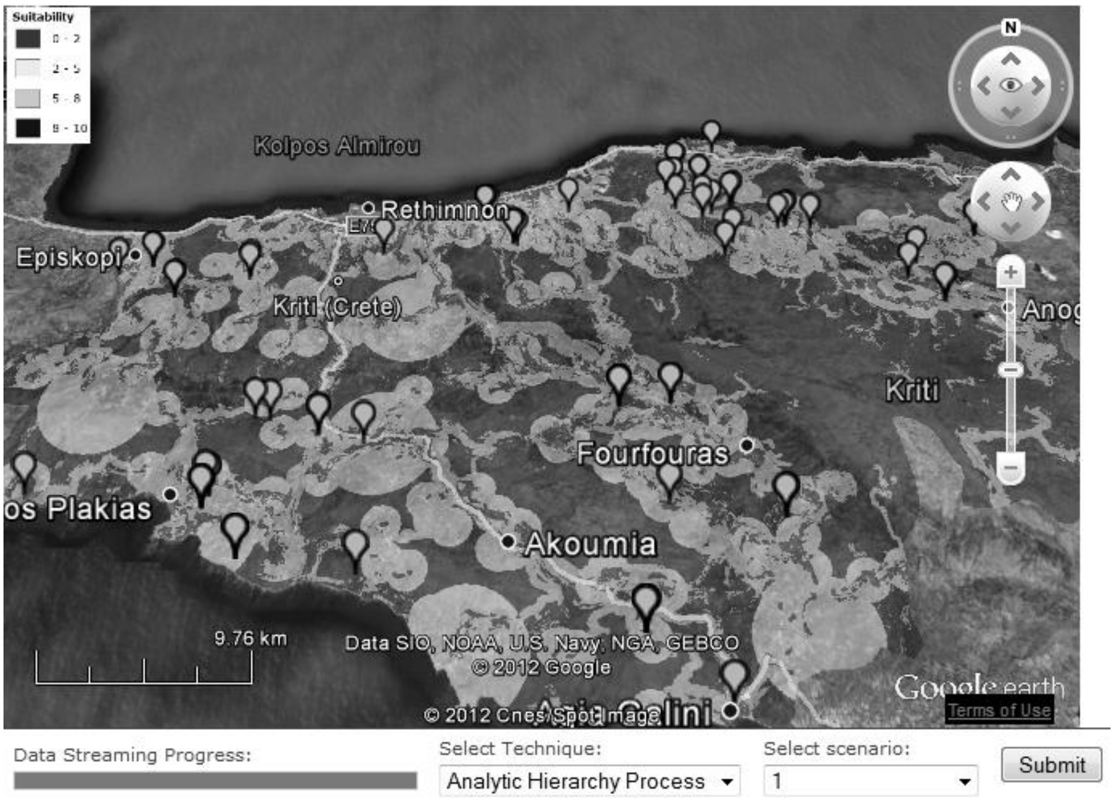


Fig 3. Risk Assessment Web Application Tool UI

4. Evaluation results

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 in Table 2 below.

Table 2. OOMW location suitability percentage

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

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 are 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 were established.

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

5. Conclusions

Two major geo-informatic web-based application tools have been presented for the olive oil mills' wastes (OOMW) disposal areas management, manifesting the potential of the particular technologies in an environmental issue which is of crucial importance in the Mediterranean area. Among the various techniques used the underlying web based map application tools have been developed for the monitoring of several chemical parameters which reflect the wastes’ disposal activity as well as for the risk assessment of the OOMW disposal areas in the wider area of the prefecture Rethymno.

The surface interpolation web based map application was made for the monitoring the distribution of different chemical parameters (in terms of depth and time) that represent the possible diffusion of them and the degree of risk in the vicinity of the waste disposal areas. The produced OOMW risk map of the risk assessment modeling of these areas can provide substantial information for the development of OOMW disposal areas and production facilities in a suitable location in respect with various anthropogenic, environmental and geological factors. Based on the information provided from the risk maps of Rethymno, such locations must take into account several of the presented criteria.

These modules have made use of the Google Earth API, so that the particular results can be projected on the available topographic and satellite images provided by Google Earth. Finally, the GIS based map applications of the project PROSODOL were made available to the public to use and interact through the web site of the project.

6. Acknowledgments

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